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TECHNICAL REPORT

Cataract Blindness and Simulation-Based Training for Cataract Surgeons

An Assessment of the HelpMeSee Approach

James R. Broyles, Peter Glick, Jianhui Hu, Yee-Wei Lim

Sponsored by HelpMeSee, Inc.

RAND HEALTH

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Preface

An estimated 20 million people around the world are blind from cataracts, mostly in developing countries, where blindness and visual impairment can have enormous negative impacts on the quality of life, in addition to reducing life expectancy and economic productivity. The great majority of cataract cases can be cured by quick and inexpensive surgical procedures that have been shown to have very high success rates in developing country contexts. However, a shortage of trained cataract surgeons makes it unlikely that the need for such surgeries can be met under current practices.

To address this problem, HelpMeSee, Inc. (HMS) is developing an innovative approach to cataract surgery training and delivery. The HMS approach includes: use of high-fidelity simulator technology for high-volume training in cataract surgery; an HMS-supported system of independent private surgery practitioners (a contrast to traditional highly centralized, hospital-based systems); and the training of significant numbers of nondoctors in cataract surgery, with the expectation that such individuals will be willing to live and work in underserved areas.

HMS approached RAND to undertake an assessment of its approach, with the objective of learning whether it could significantly reduce the problem of cataract-caused blindness and low vision in the developing world, and whether it would be a cost-effective means of doing so. The analysis in this report develops a model to forecast the prevalence of cataract-caused visual impairment in Africa, Asia, and Latin America under the "status quo" as well as several HMS scenarios. The model estimates the potential effects of HMS on the prevalence of cataract-caused visual impairment, Disability Adjusted Life Years (DALYs), and economic losses from blindness and visual impairment. We also assess the potential cost-effectiveness of the HMS model. Finally, we consider a range of potential challenges to the success of the approach, and discuss how a pilot study can assess some of these factors.

This research should be of interest to researchers, practitioners, and policymakers involved in vision care and eye health in developing countries, as well as those with a more general interest in the use of technology for training health care workers and those interested in different approaches to health service delivery in developing countries.

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The research was conducted as part of the Global Health Initiative in RAND Health, a division of the RAND Corporation. A profile of RAND Health, abstracts of its publications, and ordering information can be found at www.rand.org/health.

Comments or questions on this report should be addressed to the project leader, Peter Glick. He can be reached by email at pglick@rand.org.

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Summary

Introduction

Cataract accounts for about half of all cases of blindness worldwide, with an estimated 20 million people suffering from bilateral cataracts (World Health Organization website, undated). The overwhelming majority of these cases are in developing countries, where blindness and visual impairment (VI) can have enormous negative impacts on the quality of life, along with reducing life expectancy and economic productivity. Yet the great majority of cases of cataract VI can be cured by quick and inexpensive surgical procedures, with very high success rates in developing country contexts. Manual Small Incision Cataract Surgery (MSICS) is a safe, low-cost, and very rapid surgical method for cataract removal that has been shown to have success rates equivalent to more complex and costly methods.

Significant strides have been made in certain regions or countries in providing high-volume, low-cost, and high-quality cataract surgery. However, an acute shortage of trained cataract surgeons makes it unlikely that the need for such surgeries—estimated to reach 32 million cases globally by 2020—can be met under current practices. Uptake of surgery has also been constrained by cost, lack of geographical access (due to both an inadequate number of surgeons and the fact that those who can perform the procedure tend to practice in large urban centers), and low quality of outcomes in many contexts, which inhibits demand.

To address this problem, HelpMeSee, Inc. (HMS) is developing an innovative approach to cataract surgery training and delivery. The HMS approach includes the following:

- The use of high-fidelity simulator technology and associated course curricula for high-volume training in MSICS. Simulators have the potential to dramatically speed up surgical training as they reduce the need for actual patients and eliminate the risks of training on real eyes. HMS plans to open an initial regional learning (training) center as early as 2013 and three to five more centers within several years after that. The centers will be set up in Asia, Africa, and Latin America, and each is expected to have the capacity to train up to 1,000 MSICS surgeon candidates per year from countries across these regions.
- The development of an HMS-supported system of independent private MSICS practitioners, a contrast to traditional highly centralized, hospital-based systems. Practitioners will be part of a supply provision and oversight network administered by HMS. HMS will reimburse surgeons on a fee-for-service basis; hence they will be incentivized to seek out treatable cataract cases in the areas they serve. The objective is to select trainees who, in addition to having appropriate backgrounds and potential, will be willing to live and

work in underserved areas. Monitoring of quality of outcomes as well as documentation for reimbursements will rely primarily on photographic and other electronic documentation transmitted via Internet (or other means as needed) to HMS.

- Because of limits on the supply of ophthalmologists and medical doctors willing or able to perform cataract surgeries, the HMS training in MSICS will not be limited to medical doctors, although they are still predicted to make up perhaps 60 percent of the trainees globally. It will extend to other medical professionals as well as individuals without medical training as is necessary to meet the needs of local populations for qualified cataract surgeons.

This study assesses the potential of the HMS approach to significantly reduce the problem of cataract-caused blindness and low vision in the developing world. Specifically, the analysis develops a model to forecast the prevalence of cataract-caused vision impairment in Africa, Asia, and Latin America under "status quo" and several "HMS" scenarios to estimate the potential effects on the prevalence of cataract-caused VI, Disability Adjusted Life Years (DALYs), and economic losses. We assess the potential cost-effectiveness of the HMS approach (dollar cost per DALY averted). We also consider a range of potential challenges to the success of the HMS model, and discuss how a pilot study can assess some of these factors.

Existing Successful Models of Cataract Surgery Training and Delivery

A review of the main characteristics of existing successful cataract surgery systems in developing countries helps to put the HMS approach in broader perspective. We considered Aravind in India, Tilganga in Nepal, and Project Vision and He Hospitals, both in China, as well as several examples from Africa. Successful systems are marked by high quality of surgical outcomes, highly effective management and quality control, and a very high degree of specialization and standardization of tasks that applies to cataract surgeons, nurses, and other staff, including managers. Specialization and the efficiencies it brings make it possible to carry out a high volume of surgeries, which helps to build up and maintain surgeons' skills. High volume and efficient management allow for very low unit costs per surgery. High *quality* builds up the credibility of the program and thus further encourages greater uptake.

In addition to building a reputation for high-quality outcomes, high uptake in these examples is achieved through aggressive outreach and screening, To avoid inconvenience and excess transportation burdens on poor rural clients, surgery typically follows very soon or immediately after screening, usually via transportation to base hospitals or in some cases (as in Nepal) using surgical camps in rural areas. This way, patients do not have to travel long distances for a cataract diagnosis that will tell them if they can be treated. Further, other eye conditions are also diagnosed and treated in most approaches, not just cataracts.

Main Findings of the Forecasting Modeling

The model predicts that under the "status quo"—meaning that the current share of those in need who receive cataract surgery is constant into the future—the numbers of visually impaired (blind or with low vision) individuals needing cataract surgery will grow to huge pro-

portions in the coming decades. This reflects population growth as well as population aging, since cataracts are highly age-related. For example, the number of cases of cataract-caused VI in the Southeast Asia region (SEAR), which includes India, will be more than 32 million by 2012 and will rise to a staggering 53 million cases by 2030. For cataract-caused blindness specifically (as opposed to all VI), this corresponds to 8 million cases in 2012 and 14 million cases by 2030.

In the Western Pacific region (WPR), which includes China, the percentage prevalence is lower than in SEAR, as well as in the Africa region (AFR). Still, in absolute numbers, WPR contributes an enormous number of cases of cataract-caused VI (26 million in 2012) and blindness (6 million in 2012). By 2030, under the status quo, these numbers climb to 40 million and 9 million cases, respectively. Africa has 19 million cases of cataract-caused VI in 2012 and 5 million cases of cataract-caused blindness. Due to relatively rapid population growth, these numbers climb sharply over time to 32 million VI and 8 million blindness cases by 2030, even though prevalence rates increase only modestly in the region. In contrast, both nominal and percentage prevalence is forecasted to remain relatively low in the America 2 region (AMR 2), which includes Latin America.

Modeling the Potential Impacts of HMS

We used HMS's assumptions about costs and training capacity, and it is important to note that the results reflect these assumptions. We assume in our main simulations that resources are available to train a planned 30,000 new surgeons. We explored the impacts under different assumptions about uptake of HMS surgeries: low (20 percent of cataract-caused VI individuals not operated on elsewhere are operated on by HMS); medium (50 percent operated on by HMS); and high (80 percent operated on by HMS). The model predicts the impacts on cataract-caused blindness and low vision as a function of prevalence, demand or uptake, and the growth of the supply of surgeons. Under these assumptions, we find that:

- The HMS program will have the ability to scale up cataract surgical capacity very rapidly, reflecting the speed with which the simulator training produces new surgeons. Once this large supply of surgeons has been built up, the effects on VI prevalence will be determined mainly by the level of demand or uptake. Under very optimistic assumptions (80 percent), HMS can largely close the backlog of surgical cases in the four major regions studied, resulting in 21 million cases of cataract-caused VI in 2030 (including 5 million cataract-caused blindness cases) compared with 134 million cases (including 26 million blind) under the status quo. With medium uptake (50 percent), HMS can substantially reduce prevalence, by 82 million cataract-caused VI cases (13 million blind) relative to the status quo in 2030. Under low uptake (20 percent), impacts on prevalence are correspondingly modest.
- By reducing cataract-caused VI, the program potentially will have significant impacts in the future on DALYs and economic output. The latter outcome reflects the large expected losses to national income of cataract-caused VI under the status quo. SEAR sees the most dramatic reductions in prevalence under HMS, leading to a large benefit to gross domestic product (GDP) under high-uptake scenarios: for the 80 percent uptake scenario, the difference from the status quo in 2030 is about 0.6 of a percent of GDP for that year, or

in U.S. dollars (US$), about US$18 billion. For WPR 2, the proportional gains to GDP are similar, reflecting high employment rates, but the absolute or dollar gains are much larger given the economic size of this region: GDP would be US$52 billion higher in 2030. For AFR, the percentage gains by 2030 are also more than half a percent of GDP (US$9 billion) for the 80 percent uptake scenario.

However, the model also suggests the potential for a significant oversupply of surgical capacity (and surgeons) once the cataract surgery backlog is eliminated or reduced as much as it can be given uptake rates. When this occurs depends on regional variation in prevalence as well as assumptions about uptake; it will happen later if uptake is high, since there will be more back cases to operate on. For 50 percent uptake, this point is reached in 2021 in AFR (i.e., after eight years), 2024 in SEAR, 2023 in WPR (excluding developed nations), and 2017 in AMR 2. After that point, practitioners must rely solely on new cases of cataract-caused VI, or increased demand from those with less advanced cataracts. With regard to the latter, in the United States and other rich countries, where populations are also well insured, there is a very robust demand for cataract surgery from individuals who are mostly well below the World Health Organization (WHO) threshold for low vision. In poorer countries, the subjective threshold for desiring (and being willing to pay for) surgery is currently significantly higher. This may change as cataract surgery becomes more common and incomes rise. However, the prospects for this are uncertain, so there remains a possibility that the rapid scale-up of MSICS surgical capacity will eventually lead to redundancies among MSICS specialists. This will pose a problem for practitioners who do not have broader ophthalmological training in other, non-surgical areas of vision care. However, in some contexts even these specialists may be able to successfully adapt by turning to the provision of care for minor eye conditions, performing more referral functions for larger care organizations, or providing optometry services. The possibilities for these adaptations will depend heavily on the local licensing environment with respect to these services.

Costs and Cost-Effectiveness

Reducing costs per surgery through efficient management and high surgical volume is a key objective for cataract surgery systems. Given fixed costs of the learning centers and individual practices, unit costs for HMS depend on the number of operations each surgeon performs per year, which in turn depends on prevalence, the total supply of surgeons, and uptake rates. The model estimates for costs per surgery vary by region and year. For the year 2017 and 50 percent uptake, they range in international dollars (I$)from I$69 in SEAR to I$138 in AMR 2 (international dollars adjust for price differences across countries). These estimates are generally higher than other unit cost estimates for MSICS in the literature, but they include all program costs as well as costs of surgical training, not just the practitioner costs. The SEAR costs are broadly comparable to, although lower than, those for Aravind's Coimbatore hospital in Tamil Nadu, India. However, for later years, once the backlog of cases is cleared, per-surgery costs in the HMS system rise sharply, because the number of operations per surgeon falls.

Cost-effectiveness measures the cost in dollars of gaining an additional year of healthy life from an intervention. This is equivalent to averting one DALY. Under the assumptions about HMS's expansion of surgical capacity, the program can have very large impacts on DALYs:

Over the ten-year period from 2014 to 2023, for uptake of 50 percent, about 15 million DALYs would be averted in AFR, 18 million in SEAR, 16 million in WPR (excluding developed countries), and 7 million in AMR 2. Cost-effectiveness ratios, or the cost per DALY averted, range from I$114 in SEAR to I$515 in AMR 2, again assuming 50 percent uptake and a ten-year period. This is well under the per capita GDP of these regions, and the same holds for the other two regions. By this benchmark, the HMS program could be very cost-effective. In later years, however, this conclusion may not hold as costs per surgery rise due to falls in demand as the surgery backlog is closed or reduced.

Potential Challenges

While the use of simulator training and other aspects of the HMS model have the potential to make a significant impact on the prevalence of cataract-caused blindness and low vision in developing countries, there are also potential challenges to achieving this goal. One, already noted, is the potential for oversupply of surgeons in later years. The report identifies several other possible obstacles, based on the literature and extensive discussions with experts.

- Several aspects of the service delivery approach may pose challenges to the HMS model. Ensuring that outreach and screening efforts are adequate to bring large numbers of patients to individual practitioners is a key issue. While HMS is planning to conduct education outreach campaigns, at present it appears that arranging for the screening of individuals for operable cataracts will be the responsibility of the practitioner. This and other aspects of managing the practice may impose a significant burden on practitioners who are expected to perform high-volume surgery at the same time. In most successful cataract systems, all management as well as screening functions are out of the hands of the surgeons.
- In a number of other cataract care systems, efforts are made to ensure that patients do not have to travel far just to learn if they are operable, since having to do so is a disincentive to uptake. Instead, they only must get to local screenings. Transportation to surgery is often provided at or after the screening for patients diagnosed with operable cataracts. Unless HMS practitioners can organize local screenings by qualified medical staff, individuals with poor vision may be reluctant to travel to the practitioner's office, since they do not know if there will be a benefit. This will be offset to the extent that the distribution of independent MSICS practitioners makes them more locally accessible to rural populations, which will encourage visits. However, even independent practitioners will generally need to be centrally located in towns.
- HMS practitioners will be trained only to perform MSICS. This has benefits from the point of view of the gains in proficiency from specialization, as shown by existing successful cataract surgery systems. However, unlike other systems, treatment will not be provided for other eye conditions, so all such cases will have to be referred. This may create a situation where a significant share of clients are disappointed, with negative reputational and demand impacts, even though the HMS practitioners are appropriately refraining from treating conditions beyond their training. Whether this is a problem in practice depends on who comes to the HMS practitioner. "Disappointment" may occur frequently if people travel to the practitioner for a broad variety of eye problems such as infections,

which the HMS practitioner cannot treat. Marketing strategies need to be designed to ensure, to the extent possible, the appropriate kind of demand, i.e., from visually impaired individuals. This will narrow the pool of patients to those who may potentially be helped by the HMS practitioner. Still, some visually impaired patients—for example, those with glaucoma whose vision loss could be halted with appropriate treatment—will be told they must travel to a medical doctor or other facility for care.

- Monitoring of performance is much harder under a system of geographically dispersed independent practitioners than in, say, a hospital context. An effective system of surgical outcomes monitoring is essential if practitioners are to be incentivized to maintain the quality as well as the quantity of surgeries. Apart from incentives, oversight is especially important for the many HMS surgeons who will not be trained doctors or even medical professionals. HMS fully recognizes the need for strong oversight and is developing a technology-driven approach to this issue, relying on sophisticated imaging and other forms of verification. Some of these approaches are in use in other medical contexts (e.g., with SmileTrain), but they have yet to be tested for remote monitoring of cataract surgeon performance. Also untested are the systems for supplying dispersed local practitioners with lenses and other essential surgical items.

Benefits of a Pilot Study

Given the innovative nature of many aspects of the HMS approach, piloting is very important. HMS recognizes this and is planning a pilot involving 100 trainees, about 80 percent of whom would be licensed ophthalmologists with little or no surgical experience, with the remainder being MSICS surgeons who would enhance their skills to increase the quality and volume of surgeries they can perform. The objective of the pilot will be to assess the effectiveness of the simulator and courseware training approach. This pedagogical assessment is clearly the first order of business of an evaluation of the HMS system. The pilot will not assess other aspects of the HMS model, such as the monitoring and quality control system, supplies procurement, payment systems, and outreach. Thus, the pilot as planned will play an essential but limited role. The other aspects of the approach just described also need to be carefully assessed, since many of these are new, including the sophisticated remote monitoring of outcomes and the reliance on independent MSICS practitioners. Careful, ongoing monitoring will be essential, with adjustments to the approach made as needed. Starting with one regional center and carefully monitoring outcomes over a period of several years, rather than creating four to six such centers at one time, is highly advisable.

Another limitation of the pilot as currently planned is the limitation of trainees for the assessment to those who are practicing ophthalmologists; a minority will even be MSICS surgeons. It is logical to first pilot on relatively skilled individuals and then shift the focus to nondoctors (and nonmedical professionals), who will be more challenging to train. It would be advisable to follow the initial pilot with a similar evaluation of the teaching approach on an equivalently sized cohort of nondoctors and nonmedical professionals. This would establish the effectiveness of the training model for this group, or point to areas for improvement. This should be done before considering going to scale in the training of nondoctors.

Finally, the simulator may have significant benefits as a training tool for other cataract systems which otherwise share relatively little in common with HMS; for example, the cen-

tralized systems of training and delivery such as Aravind and Tilganga. The simulator as a training tool is separable from the other key components of the HMS approach—that is, the private-practice model and use of individuals who are not ophthalmologists. If the HMS pilot study demonstrates the pedagogical effectiveness of the simulator, it would be worth exploring whether the simulator technology can increase training output and efficacy in more standard cataract surgery systems as well.

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Abbreviations

AFR	Africa Region
AMR	American Region
CEC	Charity Eye Centers
CSC	cataract surgical coverage
CSR	cataract surgical rate
DALY	Disability Adjusted Life Year
ECCE	extracapsular cataract extraction
EMR	Eastern Mediterranean Region
ER	employment rate
EUR	Europe Region
GDP	gross domestic product
HCP	Himalayan Cataract Project
HMS	HelpMeSee, Inc.
I$	international dollars
ICCE	intracapsular cataract extraction
ICD-10	International Statistical Classification of Diseases and Related Health Problems, 10th Edition
IOL	intraocular lens
KCCO	Kilimanjaro Centre for Community Ophthalmology
LFPR	labor force participation rate
MSICS	manual small-incision cataract surgery
PHACO	phacoemulsification
PPP	purchasing power parity
SEAR	Southeast Asia Region
SLIMCE	sutureless large-incision manual cataract extraction
US$	U.S. dollars
VA	visual acuity
VI	visual impairment
WPR	Western Pacific Region
WHO	World Health Organization
YLD	years lost due to disability
YLL	years of life loss

CHAPTER ONE

Introduction

Cataract accounts for about half of all cases of blindness worldwide, with an estimated 20 million people suffering from bilateral cataracts (World Health Organization website, undated). The overwhelming majority of these cases are in developing countries, where blindness and visual impairment (VI) can have enormous negative impacts on the quality of life, as well as reducing life expectancy. The vast majority of the blind in these countries are unable to work, leading to an association of blindness and poverty (Kuper et al., 2010).

The great majority of cataract-caused VI can be cured by inexpensive surgical procedures with very high success rates in developing country contexts. Manual Small Incision Cataract Surgery (MSICS) is a safe, low-cost, and very rapid surgical method for cataract removal that has been shown to have similar outcomes to the more expensive and time-consuming phacoemulsification and conventional extracapsular cataract extraction (ECCE) (Khanna et al., 2011). The availability of low-cost intraocular lenses (IOLs) has further contributed to the reduction in cost per surgery. Some estimates suggest the cost-effectiveness of MSICS in particular is very high, and high in relation to many other health interventions (Baltussen et al., 2004; Muralikrishnan et al., 2004; Gogate et al., 2007). However, cataract surgery, which is routine for people living in the United States and other developed nations, remains out of reach for most of the world's poor. There is a backlog of millions of curable cataract-caused blindness cases globally, including more than 3 million in Africa and 6.7 million in China alone.

Significant strides have been made in certain regions or countries in achieving high-volume, low-cost (and high-quality) cataract surgery. Aravind in India, Tilganga in Nepal, and Project Vision and He Hospitals in China are well-known examples of systems combining training of surgeons and large-scale surgical centers. Although there are differences in approaches, important common characteristics of these successful systems include: a high degree of task specialization from the cataract surgeon on down; highly efficient management systems; aggressive outreach and screening to ensure high uptake; and following from all of the above, very high-volume surgical units that rapidly generate experience, quality, and efficiency.

However, an acute shortage of trained cataract surgeons makes it unlikely that the need for cataract surgeries—estimated to be 32 million cases globally by 2020—can be met under current practices. In some countries there is a relatively large number of ophthalmologists, but only a fraction have the training and experience to perform cataract surgery. In India, for example, there are about 60,000 professional ophthalmologists but only half have any surgical experience. In China, almost none of the 22,000 or so government-licensed ophthalmologists have had training in surgery; the rate of cataract surgeries per population is on par with the much poorer countries of Africa (Lam et al., 2009). In many poorer countries, the problem is especially acute, as the number of ophthalmologists with any sort of training, let alone surgical

training, is very low. In most of Africa, there is only one ophthalmologist per million population (Yorston, 2005). The geographical distribution of trained surgeons, not just their number, is another significant problem: they tend to practice in urban centers, largely inaccessible to the visually impaired in rural areas for whom travel to cities involves monetary expenses and lost work time of oneself or a helper.

To address this problem, HelpMeSee, Inc. (HMS) is developing high-fidelity simulator technology and associated course curricula for high-volume training in MSICS. The approach is modeled on the flight simulator, which for decades has been used to train pilots for the aviation industry. Just as the flight simulator makes it possible to provide trainees with many hours of highly realistic flying "experience" without the cost and risk of actual flying, the HMS simulator promises to provide surgical trainees with many simulated "eyes" on which they can safely operate. This can dramatically speed up the surgical training as it reduces the need for actual patients, allows for multiple repetitions of basic tasks, and can potentially simulate surgical complications in far greater numbers than students would normally see when performing a smaller, representative selection of real operations. HMS plans to open an initial training center in 2013 and three to five more centers within several years after that. The centers will be in Asia, Africa, and Latin America, and are expected each to have the capacity to train up to 1,000 MSICS surgeon candidates per year from countries across these regions.

A second new and significant aspect of the HMS approach is the development of an HMS-supported system of independent private cataract surgery practitioners. "Surgeon entrepreneurs" will run their practices as small businesses on a fee-for-service (payment-per-surgery) basis that will be subsidized in whole or in part by HMS. This alternative to more centralized, hospital-based systems of delivery is designed to incentivize graduates to provide services in areas that are underserved; for example, by setting up shop in towns or smaller urban centers that are more accessible to rural populations. While the enterprise model is not logically linked to the simulator training innovation, like the simulator it is conceived as a means of addressing the shortage of cataract surgeons in underserved areas.

Finally, a third important aspect of the HMS approach is that training in cataract surgery will not be limited to medical doctors, but will extend to other medical professionals as well as individuals without medical training as is necessary to meet the needs of local populations for qualified surgeons. In particular, Africa, with a severe shortage of ophthalmologists and doctors in general, would be a region where HMS would train significant numbers of nondoctors, though subject to the same performance and testing requirements as for trainees with medical backgrounds. The relative simplicity and high standardization of the MSICS procedure make it possible, in principle, to train nondoctors with appropriate background and characteristics (education, manual dexterity) to perform the procedure with high levels of proficiency. While this strategy also is not logically linked to the simulator technology, it too is designed to significantly expand the delivery of cataract surgical treatment.

Objectives of the Study

The general objective of this report is to assess the ability of the HMS approach to significantly reduce the problem of cataract-caused blindness and low vision in the developing world. Specifically, the analysis addresses the following questions:

- What is the potential impact of HMS learning centers on cataract surgical rates and the future prevalence of blindness and low vision in Africa, Asia, and Latin America? What are the impacts on economic productivity and disease burden as measured by Disability Adjusted Life Years (DALYs)?
- What is the potential cost-effectiveness of the HMS training intervention, that is, the cost per DALY averted?
- How does the HMS approach compare to a leading "traditional" model of cataract care, Aravind Eye Care System of India, in terms of training capacity and cost per surgery?
- What are the potential challenges to success of the HMS approach in areas such as quality and monitoring, the individual private surgical practice model, outreach and uptake, and cataract-only specialties? How can a pilot study address these issues?

We address the first three questions by constructing a model to forecast blindness and VI prevalence though the year 2040 under a "status quo" scenario in which the cataract surgery coverage of the population needing surgery is assumed constant, and an "HMS" scenario in which four regional "learning centers" (training and support centers) are set up to serve Africa, Asia, and Latin America. We run the HMS scenario and compare it to the status quo under different assumptions about the degree of uptake of HMS surgical services. To project the costs of the HMS program for cost-effectiveness analysis, we rely on estimates of the expected costs of setting up and operating the learning centers and delivering surgery provided to us by HMS.

Optimally, the estimated impacts of implementing the HMS surgery training and delivery approach on future blindness and VI would be compared to the impacts of using the same level of resources to scale up alternative approaches, such as Aravind, Project Vision, or Tilganga. Unfortunately, the data requirements to undertake such an analysis are formidable, as they would have to include detailed and accurate information on the costs of expansion of alternatives as well as an understanding of constraints to their expansion such as limits on the supply of potential surgeons, which may be as important as a lack of resources. Instead, we undertake a more modest comparison focusing on the cost side, and compare the current costs per surgery for Aravind Eye Care Center with the equivalent costs under the HMS model using detailed cost information from each. Even here there are issues of comparability, as we stress.

With regard to the fourth question, on potential challenges to the success of HMS, many or most of these challenges are not amenable to explicit incorporation into the formal model. For example, we have very little basis for quantifying the effect of quality and reputation on uptake, which is considered to be a key factor determining whether high volume cataract surgery is possible. Instead, our consideration of these issues will be based largely on our analysis on the literature in this area as well as on interviews with leading experts in the field.

Outline of the Report

The study is organized as follows. Chapter Two presents some background on the global cataract problem and cataract surgery backlog, introduces basic information on cataract surgery, and discusses constraints to higher uptake of such surgery in developing countries. Chapter Three reviews existing approaches to cataract surgery training and surgery delivery in order to put our analysis of the HMS model in perspective. We focus on the models noted above and describe reasons for their success as well as noting their limitations. Chapter Four provides a

detailed outline of the HMS approach. We discuss the HMS simulator technology, pedagogical approach, training center organization, practitioner enterprise model, monitoring and quality control approach, and strategies for outreach.

In Chapter Five, we present the forecasting model used for the analysis. We then present estimates from the model for four continent regions (Africa, Latin America, Western Pacific Asia, and Southeast Asia) of the future prevalence (through 2040) of cataract-caused blindness and low vision in the absence of the HMS intervention (the "status quo" scenario). This chapter also presents estimates of the future burden of cataracts in terms of DALYs and economic productivity losses. The discussion of the forecasting model is nontechnical; Appendix A presents the forecasting model in technical detail for interested readers.

In Chapter Six, we turn to the potential impacts of HMS. We consider the evolution of the following outcomes: number of trained cataract surgeons; surgical capacity (total number of surgeries per year that can be performed in the HMS system); and actual surgeries performed and the impacts on cataract-caused VI, using different assumptions about uptake of cataract surgery. We discuss the implications of these results for sustainability of the HMS surgeon practitioners.

Chapter Seven considers the cost-effectiveness of the HMS model. We discuss the range of costs associated with the program and assumptions used in the effectiveness analysis. Our approach follows the widely used guidelines set forth by the World Health Organization (WHO), in particular using a ten-year horizon from 2014 to 2023. We also compare costs per cataract surgery in the projected HMS approach with that of Aravind. Chapter Eight considers key challenges to the success of the HMS approach, and Chapter Nine concludes with a summary of the main findings along with a discussion of the limits of the study and needs for additional research. We discuss what could be learned from a potential pilot study of the HMS model and what such a pilot should include.

It is important to point out several things that this evaluation does not do. While we provide a description of the simulator being developed by HMS, we do not assess the simulator from a technical engineering standpoint, that is, in terms of its ability to replicate the feel of actual surgery or to incorporate complications and contingencies of surgery. Similarly, we briefly outline but do not evaluate the curriculum and pedagogical approach to the surgical training planned by HMS. Both areas are well beyond the scope of this study, which instead is concerned with costs and impacts. Therefore, we by and large assume that the technology and curriculum will work as planned, although in our sensitivity analysis we do allow for different levels of uptake, which could be a function of quality of surgical outcomes, hence by extension, the quality of training. The analysis also takes as given HMS's own projections of its costs of setting up and operating the learning centers and the costs of setting up and running individual HMS surgical practices. The sensitivity analysis also considers different assumptions about trainee intake and surgeon practitioner attrition rates.

CHAPTER TWO

Global Cataract Problem and Cataract Surgery Backlog

Cataract Burden in the Developing World

Recent statistics (WHO, 2011) indicate that about 284 million people worldwide are visually impaired, among which 39 million are blind and 245 million have low vision (see box). Developing countries account for the overwhelming portion—about 90 percent—of this disease burden. Among the six WHO regions, Southeast Asia and the Western Pacific alone account for 73 percent of moderate to severe VI and 58 percent of blindness. In a recent study (Rao, 2011), the prevalence of blindness among study populations in developing countries reaches as high as 7.7 percent, well above the WHO threshold that states blindness should be considered a public health problem if prevalence exceeds 1 percent. Older adults are at high risk for low vision and blindness, particularly through cataracts, and therefore they represent the majority of the visually impaired and blind population: Among all the visually impaired and blind worldwide, 63 percent and 82 percent are over 50 years old, respectively (WHO, 2011).

The costs of blindness and severe VI are very large in economic, health, and psychosocial terms. Economic costs are both direct (e.g., medical and treatment expenses) and indirect. The latter include loss of productivity and earnings, as most blind people in developing countries are unable to work; there is evidence of an association of blindness and poverty (Kuper et al., 2010). Caregivers also must give up some productive activities. Costs to the public sector include welfare payments and lost taxation revenue, although both are relatively rare in developing country contexts. Blind or severely impaired individuals suffer reduced quality of life, exacerbated by the general lack of services for the blind in poorer countries. Blindness is also associated with earlier mortality in developing countries (Pion et al., 2002; Taylor et al., 1991).

The economic cost of VI including blindness is estimated to be 3.0 trillion in U.S. dollars (US$) per year worldwide (Access Economics, 2010). The impact is especially profound in the developing world, where blindness was found to exacerbate poverty by sharply reducing the

Defining Blindness, Low Vision, and Visual Impairment

The World Health Organization uses the following definitions of blindness and low vision, based on Visual Acuity (VA). VA is reported as a numerator and a denominator. To measure VA, a patient is placed 6 meters (or 20 feet) away from a Snellen chart. If, for example, the patient can read the chart's metric 18 line (20 line in feet), the patient is said to have a VA of 6/18 (i.e., 20/60 or approximately 0.33).
Blindness: Visual acuity is below 3/60 meters (20/400 in feet), with best possible correction.
Low Vision: Visual acuity is 3/60 meters (20/400 in feet) or above, but below 6/18 meters (20/60 in feet) with best possible correction.
Visual Impairment: A person is defined as visually impaired if he or she is classified as having low vision or as being blind.

SOURCE: World Health Organization.

opportunities for participation in income-generating activities (Kuper, 2010). In India alone, the economic burden of blindness in 1997 was estimated at approximately US$4.4 billion (Shamanna, 1998).

The striking fact about blindness in developing countries is that half or more of the cases are curable. Cataracts—which usually can be cured surgically—are the leading cause of blindness in the developing world, responsible for about 50 percent of the blindness (Lawani, 2007) (see box). Recent surveys in India and Bangladesh suggest this percentage could be substantially higher in these countries—about 80 percent in rural areas (Neena et al., 2008; Wadud et al., 2006), although this may partially reflect the rapid assessment techniques applied in these studies. As noted in the Introduction, rapid and inexpensive surgical procedures for removing cataracts and restoring sight (described in the next chapter) have very high success rates in developing country contexts.

In recent years significant efforts have been made to address the problem of global blindness and cataracts specifically, through the establishment of national prevention programs, improvement in eye care services, campaigns to raise awareness, and successful international partnerships with engagement of the private sector and civil society. Much of this effort has been organized within the framework of Vision 2020, a global initiative for the elimination of avoidable blindness launched in 1999 by WHO and the International Agency for the Prevention of Blindness (Foster and Resnikoff, 2005). Many countries have indeed made significant progress in preventing and curing VI. These efforts have included programs to expand the coverage and quality of cataract removal surgery (several successful models are described in Chapter Three). As a result of these policies, the prevalence rate of VI has been decreasing since the 1990s. This primarily reflects the sharp reduction over the last two decades in the number of people with VI due to infectious diseases (WHO, 2011). However, expansion of cataract surgery, particularly in India, also probably plays a role.

In spite of the reductions in prevalence—the share of the population with VI—the absolute numbers of people with age-related VI, including from cataracts, will continue to increase, reflecting both general population growth and population aging in both developed and developing countries. It is projected that by the year 2020, there will be 452 million people globally who are visually impaired due to all causes excluding uncorrected refractive error (Access Economics, 2010). The situation in developing countries is the focus of concern, due to a more dramatic growth in the number of old people in the coming decades (Kinsella, 2001) combined with what are currently very inadequate vision services. In China, for example, the proportion of adults ages 65 and older will increase from 8.9 percent of the total population in 2010 to 25.6 percent by 2050; in India, the numbers are 4.9 percent and 13.5 percent in 2010 and 2050, respectively (United Nations, 2011). These percentages translate to fast-growing absolute numbers of older people. As approximately 85 percent of all cataracts are age-related,

Cataracts

- A cataract is a clouding of the lens inside the eye that reduces vision;
- Most cataracts are related to aging; other risk factors include certain diseases such as diabetes, personal behavior such as smoking and alcohol use, and the environment such as prolonged exposure to sunlight;
- A cataract can occur in either or both eyes;
- Cataract can be detected through a comprehensive eye exam that includes visual acuity test, dilated eye exam, and tonometry.

SOURCE: National Eye Institute.

Cataract Surgery Techniques

- **Phacoemulsification (PHACO)**—A modern technique that relies on ultrasonic emulsification of the cataract to allow removal through a small incision typically 3 mm or less. This procedure requires the use of foldable intraocular lenses (IOLs) since rigid IOLs are too large to be inserted through the small opening. It is considered the standard for cataract surgery in the United States and other developed economies and is best suited for cataracts that have progressed only to the point of being moderately dense or less.
- **Manual Small Incision Cataract Surgery (MSICS)**—A modern technique suited for advanced cataracts that relies on creation of a sclera-corneal tunnel large enough to remove extremely dense cataracts in one piece. Any type of IOL can be used and the tunnel is made in such a way that it usually does not require suturing. It is possible to perform MSICS in low-tech environments. Foldable lenses are not required, contributing to lower costs relative to PHACO.
- **Extracapsular cataract extraction (ECCE)**— Manual removal of the lens through an incision in the cornea or sclera. This predecessor of modern techniques required a large corneal incision and suturing. This technique can generally produce good results but without the consistency of modern cataract techniques. The healing process is longer and suture management requires significant post-operative care. This technique is still widely used in developing nations.
- **Intracapsular cataract extraction (ICCE)**—No longer widely practiced, this technique requires removal of the cataract and its supporting capsule through a very large corneal incision. Complications are common and outcomes often poor. This technique is best used for dislocated cataracts (associated with trauma and a few genetic syndromes).

SOURCE: Adapted from HelpMeSee training materials.

this will have a great impact on the numbers of people with cataracts in developing countries. For India, Murthy (2008) projects that while the prevalence rate of cataract-caused blindness will fall, the actual number of cataract-caused blind will increase from 7.75 million in 2001 to 8.25 million in 2020 due to a substantial increase in the population ages 50 and over.

The majority of the cataract-caused blindness or VI cases in developing countries reside in rural areas. This raises numerous challenges to the expansion of cataract surgery: Health care manpower and medical equipment are often lacking in rural areas, access to eye care is limited, and awareness of cataract disease and cure is low. Most well-trained ophthalmologists who can do surgeries choose to live in cities for better working and living conditions, leaving it even harder for rural patients to access high-quality surgeries. These and other constraints to expanding cataract surgery coverage are discussed below.

Types of Cataract Surgery and Relative Costs/Benefits

Most cataract cases can be treated through surgical procedures to remove the clouded lens and implant an artificial lens. Techniques such as intracapsular cataract extraction (ICCE), extracapsular cataract extraction (ECCE), manual small-incision cataract surgery (MSICS), and phacoemulsification (PHACO) are used. Among the different types of surgery techniques, ICCE has essentially been replaced by ECCE due to the latter having better visual outcomes and fewer complications. In recent years, ECCE surgery techniques have evolved further to the modern PHACO and MSICS. All these techniques are dependent on the proper use of an intraocular lens for good results.

PHACO, a surgery technique in which the lens clouded by a cataract is broken up by ultrasound and then is irrigated and suctioned out, is the preferred surgical option in the developed world. However, it requires costly equipment and therefore is expensive for patients or insurers; in the United States, for example, the cost of PHACO surgery can be as high as US$3,000–5,000 per eye. This cost is well out of the reach of the large majority of citizens in

low- and even middle-income countries, although PHACO is often performed for those who can afford it. In addition, PHACO is a relatively complex procedure with a steep learning curve for surgeons, which also limits its expansion in developing countries. Another constraint is that the equipment used for PHACO is difficult to maintain.

MSICS is a rapid and substantially less expensive procedure than PHACO, in large part because it does not rely on complex surgical equipment. Despite being "lower tech," MSICS has been shown to have similar outcomes to PHACO as well as to conventional ECCE (Khanna et al., 2011). The availability of inexpensive intraocular lenses has also contributed significantly to the low cost per surgery for MSICS in developing countries.

Most leading cataract surgery centers in the developing world practice both PHACO and MSICS. The availability of middle-class and wealthy patients in countries such as India ensures a demand for PHACO, and the willingness of such individuals to pay substantial out-of-pocket costs makes PHACO more profitable than MSICS. As will be discussed below, revenues from PHACO are often used to support subsidized MSICS services for poorer patients.

With reasonable costs and high success rates, cataract surgery has been shown to be one of the most cost-effective health interventions (Lansingh, 2007; Lansingh, 2009; Baltussen et al., 2004). Cost-effectiveness measures the gains in health from an intervention relative to its cost. In the standard approach (Tan-Torres Edejer et al., 2003; Baltussen et al., 2004) health benefits are measured as DALYs averted; DALY is a measure of the overall disease burden, expressed as the number of years lost due to ill health or disability. The estimates of Baltussen et al. (2004) suggest that providing ECCE globally to 95 percent of cataract patients who need it (i.e., a 95 percent Cataract Surgical Coverage rate) would avert at least 3.5 million DALYs per year. Compared to the developed world where mortality rates are low and the cost of surgery is high, cataract surgery in the developing world is an extremely cost-effective intervention. A recent analysis (Baltussen, 2004) estimates that in international dollars (I$) it costs as little as I$57 per DALY averted in Southeast Asia,[1] while in developed regions such as the high-income WHO Western Pacific Region, the cost rises to approximately I$2,307 per DALY averted.

Cost-effectiveness has also been evaluated and compared across different surgery techniques in developing countries. Several studies in India compared ECCE, PHACO, and MSICS; some studies focused only on costs, but given the apparent similarity in clinical outcomes (effects) across techniques, cost-effectiveness differences among them will be largely determined by differences in costs. Among the three techniques, MSICS has been found to be the most cost-effective procedure, which is not surprising in view of the lower costs of MSICS (at least compared with PHACO). Gogate et al. (2003a) compared costs and surgery outcomes of MSICS with those of conventional ECCE and PHACO in a hospital setting in India (Gogate, 2003b, 2007). They found that average costs per operation of MSICS and ECCE were similar (US$15.68 vs. $15.82), but MSICS gave good surgery outcomes in a greater proportion of patients than ECCE. MSICS was almost as effective as PHACO, while much less expensive—the average cost of a PHACO surgery was almost three times that of an MSICS (US$42.10 vs. $15.34), largely due to the different prices of the intraocular lens used in the two procedures.

[1] The international dollar is a measure used to facilitate comparison of costs in different countries. See Chapter Seven for discussion.

Muralikrishnan (2004) estimated the direct and indirect costs of these three procedures using data from Aravind Eye Hospital.[2] Average unit (i.e., per surgery) provider direct costs were found highest for PHACO and lowest for ECCE, with the difference attributed to the cost of equipment and materials; the costs to patients (direct plus indirect) were found to be highest for ECCE and identical for PHACO and MSICS. Overall, ECCE had the highest total costs and MSICS the lowest. In Nepal, Ruit (2007) compared the efficacy and visual results of PHACO and MSICS and found that both surgical techniques achieved excellent surgical outcomes with low complication rates, but that surgical time for MSICS was much shorter than for PHACO (9 minutes vs. 15.5 minutes), and MSICS was less expensive and less dependent on technology.

In sum, cataract surgery is highly cost-effective relative to many other health interventions in developing countries. Yet there remains an enormous backlog of millions of cataract cases in need of surgery in these regions. The next two sections discuss the dimensions of this problem and the constraints to closing the surgery gap.

Cataract Surgery Shortfall

Two measures have been used to evaluate cataract surgery availability and use: cataract surgical rate (CSR) and cataract surgical coverage (CSC). WHO defines CSR as the total number of cataract operations performed annually per million population, and CSC as the proportion of people (or eyes) with "operable" cataracts who have already received surgery at a certain point in time. There is a vast disparity in CSRs between developed and developing nations. CSRs in the United States, Japan, and Australia are 6,500, 6,830, and 8,000 respectively;[3] CSRs are just 360 in Ethiopia, 575 in Kenya, 333 in Nigeria, 819 in Myanmar, and 380 in China (WHO website, undated). However, the CSR in India, reflecting an aggressive strategy aimed at cataract cases, was 4,500 per million in 2005 (Murthy et al., 2008)—exceptional for a developing country, if still below levels in the United States and similar industrialized nations.

Ideally the cataract surgical *coverage* rate should be 100 percent. The WHO target is for each country to reach the highest possible CSC, reaching at least 85 percent (WHO, 2007). The CSC varies in developing countries, but is especially low in Asia and Latin America, reflecting an acute shortage of qualified eye care practitioners, and in some cases, low productivities. China and India both have a large backlog of cataract patients. In contrast to dramatic gains in India, a lack of qualified surgeons has contributed to a persistently very low CSC in China—one estimate placed it at just 15 percent nationwide in 2004 (Yan, 2006). More than 75 percent of ophthalmologists in China cannot perform cataract surgery, and those who can are concentrated in urban areas (Tabin, 2008). Surveys in African countries suggest that barely a third of patients with cataract-caused blindness have had surgery (Cook et al., 1993; Lewallen and Courtright, 2001; Mathenge et al., 2007).

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[2] Direct costs are the monetary outlays associated with performing the surgery, incurred either by the provider or the patient (the patient's direct costs include, among other items, medicines and glasses). Indirect costs are other patient expenses related to accessing the surgery, including transportation costs and forgone earnings.

[3] Estimates for CSRs can vary even in data-rich countries, as the estimate requires information on the number of surgeries performed annually. A recent U.S. estimate is about 3 million surgeries per year (Ocular Surgery News, 2011), which would put the CSR at almost 10,000.

Low coverage translates into an enormous backlog of unoperated cataract cases in the developing world. In 2008, the cataract blindness backlog reached 6.7 million in China and 3 million in Africa, as noted in the Introduction. With low CSC, many or most of the estimated 1.3 million new cases each year in China will add to the backlog (Lam et al., 2009).

Constraints to Expanding Cataract Surgery Coverage

Despite the documented cost-effectiveness of cataract surgery, improving its delivery and coverage continues to be a problem in many developing countries (Rao, 2011), as the discussion in the previous section makes clear. A number of surveys carried out at the national or community level identify numerous barriers to surgery. In rural south India, survey respondents with cataracts who did not undergo surgery provided reasons such as cost, fear of surgery, lack of perceived need for the surgery, not having anyone to accompany them, and the service not being available (Chandrashekhar, 2007). In central Sri Lanka, the main barriers cited were "lack of desire" to improve vision, fear of surgery, lack of social support, and surgery cost (Athanasiov, 2009). Similar findings emerge from surveys in Pakistan (Jadoon, 2007) and Latin America (Limburg, 2009).

Access or availability clearly plays an important role for rural populations, which remain the majority in most developing countries. Lack of access translates into greater cost (for travel and accommodation, as overnight stays at or near an urban hospital are needed) or heightens the problem of not having a sighted person as an escort—two common barriers cited in the surveys. Health care resources (human and other), including those for vision care, are typically disproportionately allocated to urban centers. This disparity is stark in China and helps explain why cataract surgery coverage is so low in such a fast-growing and relatively affluent country (Tabin, 2008; Lam et al., 2009): Approximately 80 percent of potential cataract patients live in rural areas but some 70 percent of the human and infrastructure resources for cataract surgery are located in cities. In Africa, the urgent issue seems to be the extraordinarily low number of qualified personnel compared with the rest of the developing world. As noted in the Introduction, there is only about one ophthalmologist per million population in the region (Yorston 2005).

Poor quality is another vexing problem that has an important, if hard to quantify, negative effect on the demand for cataract surgery. Individuals will be reluctant to undergo surgery—a potentially costly and frightening procedure—if the outcomes experienced by others in the community are perceived to be poor. Cataract surgery quality is indeed low in many countries. WHO (2007) recommends a standard for high quality such that at least 85 percent of eyes should achieve visual acuity 6/18 or better postoperatively with best optical correction, and less than 5 percent should be worse than 6/60 (Lewallen and Thulasiraj, 2010). In rural China, studies have shown that as many as 50 percent of the cataract operations performed actually result in blindness (He, 1999; Zhao, 1998). For several African countries discussed in Lewallen and Thulasiraj (2010), between 23 percent and 58 percent of operated eyes had a final visual acuity less than 6/60 after cataract surgery, which is classified as severely visually impaired by WHO and considered blind in most developed countries.

Although country-specific barriers may be different, developing countries share many common constraints to expanding cataract surgery coverage, including availability, cost, awareness, and poor quality. Large-scale expansions of cataract coverage must therefore deal with a multiplicity of factors. Successful systems for cataract surgery take this approach. We describe several examples of such systems in the next chapter.

CHAPTER THREE

Existing Models of Cataract Surgery Training and Delivery

The HelpMeSee model is conceived as a response to concerns that existing approaches will not be able to close the global gap between the need for cataract surgery and the supply of surgical capacity. Still, in many respects, particularly the emphasis on specialization, high volume, and low surgical unit cost, HMS draws on existing models. To put the HMS approach in perspective, we outline the key characteristics of several of the most prominent models in cataract surgical training and delivery in the developing world: Aravind in India, Tilganga in Nepal, and Project Vision and He Hospitals, both in China.[1] We also discuss experiences in Africa and constraints to applying these models there. We discuss the approaches of each in several dimensions, including outreach and screening, management, volume and quality of surgeries, and financing. We conclude the chapter by highlighting common characteristics of successful approaches.

Aravind (India)

Aravind Eye Care System in India is probably the best-known training and eye care system in the developing world and is justly considered a leading model of successful eye care delivery. Starting from an 11-bed hospital in Madurai, India, in 1976, the Aravind Eye Care Center has grown to a comprehensive eye care system encompassing seven hospitals in five locations in the state of Tamil Nadu with more than 4,000 beds, an ophthalmic product manufacturing center, an international research foundation, and a resource and training center. Aravind operates outside the government health care system.

Efficiency is the key to Aravind's operation. Industrial process improvement techniques are applied to every aspect of the operation, from system management and cost control to surgery details such as minimizing unnecessary motion in the operating room. As this implies, tasks are both highly specialized and highly standardized. Eye surgeons only do surgery (both MSICS and PHACO) and in the same way, many times over, in the process gaining a high degree of expertise in these tasks. Preparation work, such as instrument and patient preparation, is done by other, equally specialized staff. Specialization extends to other categories of staff as well, including nurses, technicians, clinical assistants, outreach coordinators, and health care managers, and the Aravind training system pays as much attention to the specialized training of these staff as it does to surgeons and other ophthalmologists. In addition to

[1] Because they are prominent—and successful—these highly organized systems are particularly well documented. This chapter does not cover the full range of cataract surgery services throughout the developing world.

cataract surgery, Aravind provides specialty eye care services to patients with other eye diseases, as well as pediatric ophthalmology services and vision rehabilitation.

With less than 1 percent of India's total ophthalmic manpower, Aravind hospitals perform 5 percent of all ophthalmic surgeries nationwide. From April 2009 to March 2010, it performed more than 300,000 surgeries, 75 percent of which were provided for free or with substantially reduced fees. For each surgeon, the number of surgeries performed each year averages 2,000, while the average for surgeons in India overall is only 250. High volume reduces per-unit surgery cost and helps build up the expertise of surgeons and other staff, contributing to high quality of outcomes. Visual acuity after cataract surgery at Aravind is excellent, with low complication rates: Corrected visual acuity (with spectacles) better than 6/18 (considered "normal" by WHO definitions) is achieved in more than 90 percent of patients and visual acuity worse than 6/60 (considered severe VI by WHO and blind by most industrialized country definitions) occurs in less than 1 percent. Uncorrected visual acuity (without spectacles) is better than 6/18 in more than 60 percent of patients (R.D. Thulasiraj, personal communication). The high quality of cataract surgeries helps to build up Aravind's reputation among potential patients through word of mouth, and increases the demand for surgeries, helping to ensure high volume.

Avarind uses a "hub and spoke" model of care to provide surgery to rural patients: Screening camps are held periodically in different locations and operable patients are immediately transported to urban-based Aravind hospitals for surgery and an overnight stay, permitting checkup the following day. To find enough patients to ensure a high volume of surgeries, Aravind has used aggressive community outreach activities, carried out in partnership with community organizations, local industries, and educational and religious institutions, and coordinated with screening camps. Aravind outreach teams, typically composed of doctors, patient counselors, opticians, and technicians, make regular trips to these camps in rural areas to carry out screening and to bring patients back to the base hospital for surgery.

The Aravind experience also demonstrates that financial sustainability can be achieved through high volume and low unit costs combined with multi-tiered pricing. Patients in effect choose the price to pay based on their ability and willingness to pay for amenities—for example, patients with more resources who are willing to pay for additional services such as private rooms or special meals are charged more. These patients cross-subsidize surgeries for the poor. About 40 percent of patients pay a full, unsubsidized fee (average cost of US$200), 30 percent are highly subsidized (paying US$17.50 on average), while the rest (30 percent) are treated for free.

Given Aravind's success at providing high-volume and low-cost—but high-quality—cataract surgery, the question arises whether the model could be scaled up to close the cataract surgery gap throughout India (and potentially elsewhere). First, it should be noted that the gap in India is extremely large relative even to Aravind's sizable contribution (which is concentrated largely in Tamil Nadu). While Aravind performs about 300,000 surgeries annually, it has been estimated that 6 million are needed nationally just to keep up with new cases, let alone to clear the backlog. (Of course, many other programs provide surgery elsewhere in India, if less efficiently than Aravind.)

There are several potential constraints to a large-scale expansion of Aravind. These are not primarily financial but instead reflect constraints on the training of larger numbers of cataract

surgeons (about 50–100 such surgeons are currently produced annually in Aravind).[2] One is the limited supply of ophthalmologists, who make up the potential candidates for surgical training. Another is the limited number of potential trainers, who must be experienced ophthalmologic surgeons. Also, trainees must have extensive supervised surgical experience during the program, but this is constrained by the availability of patients and supervisor time. Management capacity may also be strained by a larger system. Finally, financial self-sufficiency may be more difficult with expansion if it means that the share of nonpaying poor in the patient pool increases, as might happen if the maximum possible share of wealthier individuals are already using the system. (That is, if people who can afford to pay are not putting off the procedure, so a matching influx of paying patients cannot be expected, making it hard to offset the cost of nonpaying patients). As described in Chapter Four, the HMS approach attempts to address several of these constraints, particularly with respect to limits on the production of new surgeons.

Tilganga (Nepal)

Tilganga Eye Center is a private, nonprofit initiative to prevent and control blindness in Nepal that operates in partnership with other nongovernment organizations such as the Himalayan Cataract Project (HCP) and the Fred Hollows Foundation. Tilganga provides treatment, research, outreach, and training through a clinical facility, an education and training department, an outreach unit, an eye bank, a manufacturing facility producing low-cost IOLs for cataract surgeries, and a research unit. Training is provided for surgeons and for other medical personnel and managers. The Himalayan Cataract Project also has a major presence in the broader Himalayan region and increasingly in Africa as well, for both cataract surgery and training.

Like Aravind, the Tilganga system features high surgical volume and efficient specialization of tasks. Quality of outcomes is very high (Ruit et al., 2007). The clinical facility, the Surgicentre, provides comprehensive eye services, including cataract surgeries and treatment of other eye conditions such as glaucoma, trachoma, and childhood blindness. Operating costs are covered completely though through patient fees. The pricing system at Tilganga is similar to that at Aravind in that revenues from those who can afford to pay are used to subsidize procedures for those who cannot. Approximately 53 percent of the services at the Surgicentre are paid for in full at an average price of US$120, 43 percent are provided for free, and the rest are substantially subsidized (Tilganga Institute of Ophthalmology, 2010). In contrast to Aravind, prices are based on a simple means testing procedure that gauges ability to pay, rather than allowing patients to pay more for amenities. In recent years the share of PHACO surgeries relative to MSICS has been increasing as the number of mature cataracts has declined in the country while demand for surgery by paying middle-class patients with moderate VI has increased; as noted, such cases are more suitable for PHACO.

Outreach and screening are also aggressive, with screening camps held in rural areas in partnership with local organizations. In some areas, surgeries are performed at base hospitals as in the Aravind approach, with transportation provided from the screening camps. However,

[2] For discussions on this point we are indebted to R.D. Thulasiraj and Deepa Krishnan, Executive Director and Senior Manager for Operations, respectively, of Aravind.

given the low population density in much of rural Nepal as compared with India, this model is not always efficient. For these areas, surgeries are performed by teams at camps or community eye centers. To date, more than 136,000 eye surgeries have been performed (most of them for cataracts) and more than 1,995,000 Nepalese have been screened (HCP, 2011). Although the focus of Tilganga is cataracts, care for other eye problems is also provided and has been growing. Increasing revenues from PHACO patients is subsidizing the expansion of subspecialty vision services such as pediatrics, retinal care, and corneal transplants.

Project Vision (China)

Established in 2004 by Dr. Dennis Lam, Project Vision is a Hong Kong–based program working at the local level in China to eradicate cataracts. It was developed to respond to several features of cataracts in China: very low cataract surgical rates despite large numbers of ophthalmologists and relatively high per capita incomes; large rural-urban disparities in access to vision care including cataract surgery; and very low quality of cataract surgery in rural areas (Lam et al., 2009).

A key feature of Project Vision is the training of local (county level) doctors and other medical personnel to develop teams that can provide high-quality surgeries using MSICS (though called sutureless large-incision, manual cataract extraction, or SLIMCE). As in the previous two models, the system trains both surgeons and other medical staff. Currently these teams operate in 19 rural Charity Eye Centers (CECs) in county hospitals in five districts of China, usually as part of the hospital's ophthalmologic division; Project Vision aims to have 100 such centers running by 2020. In contrast to Aravind and Tilganga, Project Vision operates within the government system, in government hospitals. However, as in the other models, unit costs are kept low through efficient management techniques, standardization, and high surgical volumes. Although Project Vision does not produce its own instruments and supplies, bulk purchasing enables the program to obtain these items for much lower than market prices, further reducing unit surgery cost. Almost 65,000 cataract surgeries had been performed to date, and more than 50 cataract surgeons have been trained, among whom more than 30 are qualified to train other local doctors. Data released by Project Vision indicates that its activities have essentially eliminated the cataract surgery backlog in Hainan province (Project Vision websites, undated). As in Aravind and Tilganga, the quality of cataract surgeries performed by Project Vision is high. A recent study of 176 postoperative patients operated on by rural surgeons in Project Vision shows that 96 percent had good vision (6/18 or better) after surgery (Lam et al., 2007).

The startup costs of each CEC are covered through donations and, increasingly, also through central and local government matching funds. Once in operation, however, CECs are expected to be financially viable based on low unit costs and revenue from patient fees. The typical charge per operation (for the half or so who pay) is about US$100 (Lam et al., 2009)—high by South Asian and African standards but more easily within reach of most Chinese. It is estimated that a CEC can break even at 1,500 surgeries per year (Congden, 2007); the typical plan is for a center to perform 500–1,000 cataract surgeries in the first year, 1,000–1,500 in the second, and 2,000 annually thereafter.

He Eye Care System (China)

The He Eye Care system in Liaoning province, China, was begun in 1995 by Dr. He Wei and was patterned after the Aravind system. The He Eye Hospital in Shenyang was the first private eye hospital in China. Originally focusing on cataracts, He Eye Hospital has become a comprehensive eye care system, including clinical service, education and training, research, public eye care, and manufacture of eye products. It currently includes four private hospitals and two managed eye departments operating in government hospitals. The screening system for cataracts and other eye problems is extensive. It encompasses locally organized monthly screening services in rural areas as well as screening camps in more remote areas and an urban network of 39 vision centers offering free screening and referrals.

Currently the He system is organized along the same lines as Aravind, with local screening and referral to large hospitals for cataract surgery. However, there are plans to develop service delivery in a more decentralized direction as well as to place significant reliance on financial (profit) incentives for providers to serve local populations—two characteristics that are also central to the HMS approach as discussed in the next chapter. Under this plan, delivery of eye care (including cataract surgery) would be decentralized from the tertiary level to small county "eye hospitals," each serving a catchment area of about half a million people. These hospitals (actually, care centers) will have a staff of five, including one cataract surgeon, one general ophthalmologist, and support staff. These units will receive financial support initially but eventually would be expected to grow into independent, financially self-sustaining enterprises. The teams, or a team leader, would have responsibility for (and be given training in) management of the centers. This strategy is informed by the notion that financial incentives are necessary and effective as a means to get medical professionals to serve poorer rural populations. The county eye hospitals will not do their own outreach—at least, not all of it—rather, they will connect into the primary health care infrastructure, relying on village doctors for diagnosis and referral of cataracts and other eye conditions. The hospital has started training village doctors in these methods.

Experiences in Africa

Despite the successful examples from Asia demonstrating that high-volume cataract surgery can be delivered at low cost and with excellent outcomes, similar systems have not been fully established in Africa. Even when affordable services of high quality are available (which is not the norm), the uptake of surgery remains low (Eloff et al., 2000; Chibuga, 2008). Further, those most likely to accept cataract surgeries may not be those who are blind or severely visually impaired, and the most elderly may be the least likely to accept surgery (Chibuga, 2008). The situation in Africa differs in important ways from that in Asia, as Lewallen and Thulasiraj (2010) note. Existing successful models such as Aravind and Tilganga rely on specialization and efficient and capable management.

However, management capacity is scarcer in Africa than South Asia—as are ophthalmologists themselves, as noted earlier. Low population density and low cataract prevalence relative to Asia also complicate the ability to achieve high-patient volumes and to deliver services with low unit costs. As Lewallen and Thulasiraj note, low population density makes surgical camps inefficient in most African contexts. Quality would be another concern with such camps.

Instead, screening camps with transportation to base hospitals for surgery are more appropriate. However, it still costs many times more than in India to transport each patient given longer distances, poor roads, and lower population density.

Despite these barriers, cataract service delivery systems designed along the lines of Asian systems have met with some success.[3] Two East African programs, in Kwale District of Kenya and Kilimanjaro Region in northern Tanzania, were patterned after Aravind, with community-based screening camps and immediate transportation provided to and from urban hospitals for surgery for operable cataract patients (Lewallen et al., 2005). Both achieved high volumes, although a substantial share of eligible patients (30 percent) in the Kenya site would not accept free surgery even with transportation provided. A study of cataract surgery in a high-volume eye hospital in Loresho, Kenya, found that outcomes were of high quality: 81.8 percent of the patients undergoing surgeries achieved postoperative uncorrected visual acuity of 6/18 and better by the fourth week (Trivedy, 2011).

Given the shortage of ophthalmologists in the region, nonphysician cataract surgeons are relatively common in Africa. A number of centers have been set up in the last two decades for the training of medical paraprofessionals such as medical officers, clinical officers, or ophthalmic assistants in cataract surgery (Courtright et al., 2007). Another motivation for training nonphysician surgeons is the expectation that they are more likely to work where they are needed most, in rural areas. However, productivity of these surgeons (measured by operations performed annually) appears to be very low—about 250 surgeries on average, an order of magnitude less than in high-volume centers such as Aravind. The main reason appears to be lack of post-training support for these surgeons in terms of providing the necessary equipment and helping with outreach to bring in patients (Lewallen and Courtright, 2010; Courtright et al., 2007). There is no direct evidence on the quality of outcomes of these nondoctor surgeons and how this compares to physician surgeons. Such evidence would be of significant interest for the present study in view of HMS's plans to train large numbers of nonphysician surgeons. It should be noted, however, that even if such studies existed they would be difficult to interpret, since both the training and subsequent support of surgeon practitioners in the HMS system will be different than in existing models.

Summary: Common Characteristics of Approaches

There are several common characteristics of the successful models discussed above. Quality of surgical outcomes is very high, a reflection of effective management and quality control (Lewallen and Thulasiraj, 2010). All feature a strong degree of specialization that applies to cataract surgeons, nurses, and other staff, including managers. All procedures, including but not limited to surgery, are highly standardized. This specialization and the efficiencies it brings make it possible to carry out a very high volume of surgeries. Specialization and volume build up the surgeon's skill to the point where he or she can complete a surgery successfully in a matter of minutes (for MSICS) with no sacrifice of quality, moving rapidly on to the next patient, who has been prepped by support staff and is ready to be operated on. Improvements in productivity, in turn, allow further increases in volume and make possible very low unit

[3] In Ghana, HCP is introducing the Tilganga approach through the construction of a new eye center and training facility in Kumasi.

costs per surgery. High *quality* builds up the credibility of the program and encourages greater uptake, overcoming legacies of poor quality outcomes, further increasing volume and reducing unit costs via scale economies.

High uptake is achieved not just by building up a reputation for quality but through strong outreach efforts—a common element to each of the programs considered above. Outreach variously involves partnering with local organizations and community groups (as in Aravind) or working through existing public health infrastructure where it is well developed (such as in the He Hospital system in China), but in all cases it is well organized and aggressive. The systems also generally provide mass screening for cataracts, which is usually tightly coordinated with outreach activities in terms of location and timing. The organization of both outreach and screening—and of surgical provision itself—varies by context, reflecting variation in population density, poverty, culture, and existing health infrastructure. In India, where population density is high and transportation networks are well developed, it is practical for Aravind to hold rural screening camps and bus surgery patients to urban hospitals. In Nepal, where many areas are more remote and hard to reach, hospital-based surgery is supplemented by mobile surgery camps. In the East African setting of the Kilimanjaro Centre for Community Ophthalmology (KCCO), rural populations are highly dispersed so it would be impractical to set up surgical camps in rural areas (the catchment areas would need to be very large, negating the purpose of camps, which is to make the service highly accessible). Instead, it is more practical—but still expensive—to transport patients from screening camps to surgery in hospitals.

Two important commonalities among these approaches to service delivery for rural populations—whether they bring surgery to patients or patients to surgery—are that (1) *screening and referral* are done locally (or as locally as practical) and (2) that once patients are screened and deemed eligible for cataract surgery, procedures are designed to make it convenient for them to get to the surgery. For surgical camps, convenient access to surgery is generally assured by design as this is the point of the camps; for cases where surgery is at a hospital not close to the screening, transportation to a hospital is typically provided after screening. Local screening and referral are important to avoid unnecessary travel to distant hospitals or lengthy referral systems for individuals who may in the end not be eligible for surgery. Otherwise, uptake among poor, visually impaired, rural residents would undoubtedly be much lower than is the case with these systems. It should also be noted that in all cases considered, even though the focus of screening may be cataracts, other eye conditions are also diagnosed and treated. The possibility of care for a range of eye problems also presumably contributes to the willingness of people to attend screenings, since they can expect that they will receive some treatment for whatever condition they might have, if treatment is medically possible.

Financial self-sufficiency is another feature of several of the programs considered, although in such cases self-sufficiency refers to covering operating costs, as donors contribute heavily to investments in equipment and expansion. Under multi-tiered pricing, fees paid by wealthier cataract patients subsidize surgeries on the poor so there is no reliance on external financing, although this is ultimately made possible by the very low unit costs of surgery—a result of efficient management and high surgical volume. At Aravind, patients essentially "choose" to pay more by opting for additional services such as private rooms and other amenities (paying above the cost of providing these things), while at Tilganga, the more challenging approach of means testing is used to determine the price to charge each patient. Not every program is self-sustaining, nor should this be expected. For systems in Africa, it is unlikely there would be

enough middle-class and wealthy cataract patients to cross-subsidize free surgery for the poor, so long-term donor support would be necessary.

Interestingly, the systems above achieve high surgical volume and excellent quality without the use of financial incentives or profit motive. Surgeons and other staff are paid, of course (and presumably adequately so), but as employees. As far as we know, with the exception of the plans for small eye hospitals of the He system, staff are not directly incentivized to increase the quantity (or quality) of surgeries performed. They may be highly motivated by a sense of professionalism or mission to serve the community; such intrinsic motivation has been cited in the success of most of the models above (Ruit et al., 2006; Lam et al., 2009; Bhandari et al., 2008). On the other hand, it may be noted that if a significant expansion of CSC required surgeons to live in more remote areas, specific incentives might be necessary.

A more general observation is that the examples considered (with the exception of the plans for the He system) are not networks of individual providers but rather highly organized and centralized systems of training and service delivery, often but not always integrated into the existing health care system. As elaborated in the next chapter, the HMS model features a network of individual, private practitioners operating within the HMS support system who are incentivized to seek out and treat cataract patients. Thus it represents a significant departure in terms of the service delivery mechanism for cataract care as well as systems of management and oversight.

CHAPTER FOUR

The HelpMeSee Approach

The HelpMeSee (HMS) initiative is an innovative system for cataract surgery training and delivery.[1] It aims at eliminating cataract-related blindness in developing countries by (1) providing intensive MSICS instruction to a large number of surgeon trainees in a comparatively short period of time, and (2) helping them to set up their own private practices in areas where cataract surgeries are most needed and to deliver high-quality cataract surgeries in sufficient volumes in these areas. With this initiative, HMS's goal is to train about 30,000 new MSICS cataract surgeons worldwide over a period of 12 to 15 years starting in 2014, who will perform some 60 million cataract surgeries by 2025.

As noted in the Introduction, several features distinguish the HMS model from the existing training and surgical care models in the developing world: the use of high-fidelity simulators coupled with standardized curriculum and courseware for training; the training of significant numbers of nondoctors, not just ophthalmologists, in cataract surgery; and a system of independent surgery practitioners who will operate on their own with HMS assistance, technical support, and oversight. An important implication of the last feature is that the practitioners, or many of them, are expected to set up practices in smaller urban areas or towns rather than large urban centers. Hence HMS hopes to make cataract surgery more accessible to underserved rural populations than standard models of urban hospital-based services do.

Simulator Training

The centerpiece of the HMS training program is a computer-driven cataract surgery simulation, which allows trainees to practice a large number of "operations" in a safe and controlled environment. Existing cataract surgery training programs are constrained in their ability to provide trainees with live surgery opportunities by the number of available eyes (cataract patients) and the need for trainees to be closely supervised by experienced surgeons, given the potentially severe consequences of surgical error. One solution that has been adopted is the use of wet labs, where surgical students practice on animal eyes, but animal eyes have significant surgical differences from human eyes. The use of simulators has the potential to significantly speed up the surgical training. It reduces the need for actual patients, makes it possible to repeat basic tasks until proficiency is gained, and potentially enables the simulation of complex

[1] We thank HMS for providing us with many of the details presented in this section, through both documents and conversations.

cases and complications in far greater numbers than students would normally experience when doing a small number of real operations.

The HMS simulation training system comprises a linked surgical simulator and surgical tutoring system, which are described in turn.

The Surgical Simulator: The surgical simulator is being developed by HMS to be consistent in terms of realism to the aviation industry's highest flight simulator standard, known as level D. This standard is recognized for its fidelity to real flying conditions and problems, and with accompanying courseware, trains pilots to very high levels of proficiency and safety. The simulator will have two major components, a hardware module and a software module. The hardware will interface with the software to generate high-quality "eyes" that trainees will learn and operate on. It will provide realistic visual and tactile feedback based on data obtained from actual MSICS surgeries. Hardware includes all electrical and mechanical equipment such as computers, visual hardware (e.g., microscopes, visual image generators), haptics devices (*haptics* refers to the science of touch in real and virtual environments), surgical equipment, and operator/mentor stations. The software module will include the following models to create realistic simulated surgeries:

- A physics-based computer model, which utilizes the best existing data along with HMS test data to produce high-fidelity simulation of eye geometry, tissue properties, instrument/tissue collision detection, cutting, tissue deformation, and fluids. HMS will choose the model from among possibilities such as Finite Element and Mass-Spring models.
- A visualization model, which will use data, including high-definition video of cataract surgeries, to create high-resolution, dimensionally accurate, photorealistic, and real-time visual images of eyes, eye tissue, fluids, and instruments.
- A haptics model, which will simulate the feel experienced by the surgeon during actual surgeries to deliver a realistic force feedback response.

The surgical mentoring and performance assessment system: According to HMS, the surgical instructional system will be designed to adapt to individual trainees' specific medical background (or lack of it), abilities, and performance. Training will follow a building-block approach with measurable objective performance standards. During the entire training program, the HMS tutor (in some situations an individual, in others the software program) will assess and record each trainee's progress and performance on surgical exercises. Based on this assessment, the "tutor" will select instructional goals, challenge levels, and tasks and skills to focus on. The tutoring system thus will make it possible for the training to be customized to individual trainees' need, abilities, and pace of learning. Drawing from experience in pilot training, the HMS training model consists of three basic training principles: need to know, learning by doing, and training to proficiency.[2]

The surgical training will be exclusively in the MSICS technique. Approximately 60 percent of all coursework will involve proficiency training in the procedure. In addition to the MSICS training, trainees will be taught to diagnose operable cataracts, perform preopera-

[2] "Need to know" means essentially that training is focused exclusively on the concepts and tasks needed for MSICS competence and proficiency, as opposed to general underlying theory and biology; "learning by doing" refers to emphasis on simulated surgeries in the training; and "training to proficiency" refers to repetition of tasks until proficiency is achieved, based on individual progress rather than having a fixed time for learning each task.

tive, operative, and postoperative care, and to treat intraoperative and postoperative complications. They will also be trained to do tonometry, dilated eye exams, A-Scan Biometry, and Keratometry. It is important to note that HMS will train individuals only to do MSICS; they will not be trained to treat other eye conditions, although they will be trained to identify these conditions and refer cases to appropriate institutions or specialists.

Advanced components of the curriculum cover pediatric cataract surgery to address the acute shortage of surgeons skilled to do such surgeries, as well as more complicated adult cataracts due to trauma. This training will require additional classroom hours, MSICS simulator hours, and practice surgeries.

Teaching staff in the learning centers will be composed of experienced MSICS practitioners. It is expected that eventually many of these will be drawn from the ranks of the best performing HMS graduates. For senior surgical faculty, HMS intends to recruit skilled MSICS surgeons as permanent instructors, supplemented by rotating senior international faculty willing to work in a minimum of 90 days and up to one-year engagements as volunteer faculty. Such faculty will be provided a modest stipend and housing within the campus and would be expected to interact with the trainees personally and professionally. Use of these expert volunteers will keep costs down.[3]

Since the goal of the HMS initiative is for many or most trainees to set up their own practices (described below), the curriculum will also include comprehensive training in building and managing practices, including instruction in maintaining medical and financial records, personnel training and management, and community outreach. The other major components of the business courseware will include: (1) refraction, optometry, and nursing support; (2) surgical practice facilities and maintenance of equipment; (3) surgical practice management, including marketing, record keeping, finance, supply chain management, and screening programs organization; and (4) patient services management, ethics, and legal compliance.

HelpMeSee Learning Centers

The learning centers will be free-standing, in-residence facilities. Rather than set up smaller centers to serve individual countries, the approach is to develop large regional centers to which trainees will be brought from countries around the region. A key aspect of the setup will be partnerships with host country governments as well as international organizations. HMS expects that countries or partners will competitively bid to host a regional learning center. "Local partners" could be a host national government or local government, a hospital, a medical school, or other institution. The local partners are expected to provide land, construction of special-purpose buildings according to HMS specifications, and electric power with backup generators. Host governments will be requested to provide student visas for all selected trainees, as well as exemption from taxes and import duties on equipment, and exemption from income taxes on medical services performed at or in association with the learning center.

The learning centers will be owned and operated by the local partner institutions, while HMS will provide technical, operating, and managerial expertise. The centers will be physically and organizationally free-standing institutions, independent of existing hospitals or med-

[3] The personnel cost information used later in this study reflects these assumptions.

ical schools (even if the partner is a hospital), although affiliations with local hospitals will be made.

A fully operating HMS training center will comprise approximately 240 staff, at least two-thirds of whom will be instructional and technical staff (the faculty), grouped into surgical instructors, basic science instructors, and management instructors. The rest of the staff will work in business management, administration, marketing, and facility management. The center will also hire short-term consultants and contractors.

To test the concept and feasibility of the model and facilitate the development of the simulator, HMS is planning to conduct a pilot program in a country yet to be determined. Six full simulators and the associated courseware will be used in this pilot with at least 100 trainees enrolled. The location of the pilot may ultimately be the site of one of the learning centers, but need not be. The trainees in the pilot will consist largely of trained ophthalmologists with little or no MSICS experience, including surgeons (hence corresponding to trainee categories 1 and 2 below). At the conclusion, each trainee's surgical skills and competence will be objectively evaluated by a team of third-party experts. The main objective of the pilot, which is expected to last six months, is to assess the effectiveness of the simulator and courseware training approach. The pilot itself will not assess other aspects of the HMS model, such as the monitoring and quality control system, payment systems, and outreach. However, HMS will follow and support this "graduated" cohort and will continuously monitor and evaluate these practices, even as the training centers are being set up. We discuss the structure of the pilot study in Chapter Nine.

Twelve to 15 months following the pilot (and incorporating lessons learned), country locations for the regional centers will be identified. The goal is to set up a total of four to six regional learning centers in Asia, Africa, and Latin America by 2016.

Composition of Surgical Trainees

Together with local partners, HMS plans to perform rigorous screening to recruit trainees from local communities to which they will return upon graduation. According to HMS, applicants will have to pass a personal interview and will need strong references, in addition to meeting a range of requirements related to general skills, health, and education—including academic background, good life skills, good hand-eye coordination, normal stereopsis (visual perception of dimensions), and normal color vision and hearing. Further, to increase the probability that the trainees will serve areas of greatest need for cataract surgery, the recruitment process will also consider whether the candidates are from areas that have strong needs that are not being met, and whether they have verifiable strong personal ties to their communities.

Given the stringency of the training, HMS estimates that only about 60 percent of entrants will complete the program.

HMS defines four groups of training courses to correspond to different types of trainees:

- The first group of trainees (a relatively small share of the total) will be knowledgeable, skilled ophthalmic surgeons who want to add another surgical skill (MSICS). Most of these trainees will be well established in larger urban hospitals and will not be expected to set up HMS practices. However, some are expected to become HMS instructors. Training can be done in two weeks or less for this group, requiring 24 classroom hours,

30 simulator hours, and 14 live surgery hours (the live surgeries will be carried out at affiliated hospitals).

- The next group comprises knowledgeable, ophthalmic-trained surgeons with poor surgical skills. In most developing countries, this characterizes the typical ophthalmic surgeon. It is expected that this group would be more willing to practice exclusive high-volume cataract surgery in rural or smaller urban areas. Training can be done in six to eight weeks for this group, requiring 120 classroom hours, 100 simulator hours, and 100 live surgery hours.
- While the first two groups of trainees are ophthalmologists, the third group will include many who do not have significant previous ophthalmic experience or knowledge. These can be general surgeons or other doctors who want to change specialties, or other medical professionals such as nurses with ophthalmic experience. They may also be individuals with no medical background at all but with adequate education (university) and other skills. In African settings, for example, this last category may be important given the existing limits on skilled human resources in health care. HMS argues that a reasonably skilled, educated person can be trained to be a proficient MSICS surgeon, and this group will play an important role in a strategy to create the surgical capacity to address global blindness. This group will require the full *ab initio* ("from the beginning") HMS curriculum: basic courses in anatomy, physiology, and pharmacology of the eye and eye diseases. Training for these individuals will take six months, requiring 430 classroom hours, 400 simulator hours, and 240 live surgery hours. The live surgery hours represent observation in the operating theater, assisting a qualified lead surgeon in performing the surgery, and performing 30 surgeries as the lead surgeon. These 30 surgeries will be reviewed and qualifying grades will be required for successful completion of the training.
- The fourth group is a refresher group returning for biannual evaluation, curriculum updates, and additional training. Training can be done in less than a week for this group, requiring 16 classroom hours, ten simulator hours, and ten live surgery hours.

As noted, for the initial pilot, the first cohort of 100 trainees will be composed largely or completely of ophthalmologists. Subsequently, each of the four to six learning centers will train up to 1,000 candidates per year, of which 60 percent are expected to be ophthalmologists—although not surgeons, for the most part.

Service Delivery Model

The HMS approach to service delivery is patterned in a number of respects after the successful SmileTrain approach to surgical correction of cleft palate and cleft lip in children. SmileTrain recruits local surgeons and hospital partners by providing them financial incentives to perform the surgeries. The surgery is provided for free to patients, while the surgeons (through payments to the hospitals) are guaranteed a fee for each operation performed, paid by SmileTrain. Sophisticated imaging software is used to document their work (with before and after photos) and ensure against fraudulent claims as well as to demonstrate quality of outcomes. Specifics of HMS's related approach follow.

Private Practices

It is intended that most HMS cataract surgeons will become small-business owners as well as surgeons, operating in relatively underserved areas, and typically locating in towns or small urban areas. A standard HMS practice will consist of the surgeon practitioner, two nurses (to handle patient preparation, screening, and other tasks), a front office manager, and a supplies manager. HMS estimates that this five-person team can do 1,000 to 2,000 surgeries per year. Larger teams—group practices containing multiple surgeons—are also possible and will be supported by HMS. A team of ten, including two cataract surgeons, will be able to handle 2,000 to 4,000 cases annually. The viability of joint practices as opposed to single-surgeon practices will clearly be a function of local population density, cataract prevalence, and acceptance of surgery, as these factors will determine the potential uptake in a catchment area.

HMS trained surgeons and their practices will use standardized instruments and tools for surgeries. Supplies such as surgical instruments, lenses, microscopes, anesthesia, drops, blades, and fluid will be purchased through the HMS system. HMS will provide the supply chain management to support the practices.

Ultimately, these practitioners/entrepreneurs will be successful only to the extent that they can locate an adequate supply of patients for their services. They, or someone on their staff, will be expected to work with community groups and others to mobilize the local population and get patients. Resources for this are supposed to come out of the revenues of the practice, but HMS will provide an initial amount of about US$1,000 to each practitioner for these activities. HMS also plans to financially support mass media campaigns organized at the national level during the first ten years of the program.

Financing System

HMS will assist the trainees to start up small private practices in needed areas, financially and technically, including a fully amortizable startup loan of around US$15,000 with a ten-year repayment term. The loan will be administered in partnership with local microcredit organizations or banks. In addition to the startup loan, a fee-for-service payment system is developed under which HMS will compensate the surgeons on a per-surgery basis, at a rate of up to US$35–50, depending on the country or region. In this respect the HMS approach is patterned after the SmileTrain approach, although payments do not go through hospitals but directly to the practitioners. To be viable, the surgeon/practitioner must get enough patients to cover costs. Therefore, he or she is incentivized to perform outreach and recruit cataract patients to ensure high volume and revenue.

Quality Assurance and Monitoring

HMS is well aware of the potential concerns related to quality and oversight in a decentralized system of cataract surgery providers. Existing systems such as Aravind or Tilganga are highly centralized and hospital-based, with strong systems of management and quality control. These tasks are clearly more challenging with a network of many geographically dispersed practitioners. A further challenge for oversight and quality is that, in many cases, the practitioners will not be medical doctors, and these individuals will be practicing without the direct supervision of a doctor.

HMS plans to use two approaches to ensure high-quality outcomes while also protecting against fraud: (1) remote monitoring by transmission of electronic data and photographic images of patients to the training centers, and (2) periodic on-site audits. With regard to monitoring, practitioners will be required to prepare and maintain electronic, transmittable documentation of all patients treated. A single digital patient record will serve both medical oversight and reimbursement purposes. The technologies for monitoring will include iris scans taken before and after surgery to be included in the transmitted patient reports. Cameras will be equipped with GPS and therefore will be able to capture time data and location stamps on all images. These data will be uploadable by cell phone or Internet. Transmitted photography will be processed with specialized software that will grade visual acuity and postoperative corneal clarity among other outcomes. Staff at the centers would only become actively involved (i.e., review and discuss cases with practitioners) when results are suboptimal or there are complications. It is planned for international staff to be on call to assist remotely with complications. Videos of surgery, especially useful for continued supervision, will also be possible. In case of inadequate connectivity, surgery data will be saved to CDs and electronically or physically transmitted to an institutional partner within the country to be uploaded to the HMS server.

HMS will also conduct on-site audits to ensure that the required standards have been met. Preoperative documentation will be reviewed to ensure that eye conditions other than cataracts are appropriately referred for advanced treatment. HMS plans to have such referrals compensated on a sliding scale depending on treatability.

CHAPTER FIVE

Forecasting the Burden of Cataract

Introduction

This chapter describes our modeling approach for predicting future prevalence of blindness and low vision caused by cataracts, and presents estimates of current and future cataract prevalence by region. In addition to prevalence, we also present projections of future costs in terms of DALYs and economic (productivity) losses associated with cataracts—two standard approaches to measuring the burden of disease or disability. We project each of these outcomes to the year 2040.

Our projections are of interest in terms of understanding the scope of the cataract problem, but they also lay the groundwork for analysis of the potential impacts of HelpMeSee in Chapter Six. The estimates in this chapter indicate what the future burden of cataracts will be in the absence of HMS, or the "status quo" scenario. As discussed below, the status quo incorporates assumptions about the expansion of cataract surgery over time. For the analysis of HMS impacts, we will restrict attention to the four regions where the learning centers are expected to be located: Africa, Latin America, Southeast Asia (including India), and Western Pacific Region (Including China). We discuss these regions below.

Regional Breakdown for the Analysis

For creating the global population forecasts and to capture regional differences, we divide the global population into regions based on the WHO Mortality Stratum Region. These divisions are useful because this is the level at which estimates of current VI prevalence are available in the literature, which are the basis for our projections. We aggregate the 14 WHO regions into eight "continent regions" as shown in Table 5.1. This is done to make the presentation more concise but also because the HMS learning centers will be designed to serve these continent regions rather than single WHO subregions. For example, it is expected that a single HMS training center would serve the overall Africa (AFR) region, including both WHO subregions AFR D and AFR E. The continent regions are identical to WHO's region—e.g., Europe (EUR), Eastern Mediterranean (EMR), and Southeast Asia (SEAR)—with the exception of the American Region (AMR) and the Western Pacific Region (WPR). We maintain the separation of Latin America (including Mexico) from North America (AMR 1, which does include Cuba as well as Canada and the United States). We also maintain separation of the Western Pacific Region into WPR 1, containing wealthy countries such as Australia and Japan, and WPR 2, containing China and other developing nations.

Table 5.1
List of Countries, WHO Mortality Stratum Regions, and Continent Regions

Continent Region Name	Continent Region Abbreviation	WHO Subregion	Countries
Africa	AFR	AFR D	Algeria, Angola, Benin, Burkina Faso, Cameroon, Cape Verde, Chad, Comoros, Equatorial Guinea, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Madagascar, Mali, Mauritania, Mauritius, Niger, Nigeria, Sao Tome and Principe, Senegal, Seychelles, Sierra Leone, Togo
		AFR E	Botswana, Burundi, Central African Republic, Congo (Brazzaville), Congo (Kinshasa), Cote d'Ivoire, Democratic Republic of the Congo, Eritrea, Ethiopia, Kenya, Lesotho, Malawi, Mozambique, Namibia, Rwanda, South Africa, Swaziland, Tanzania, Uganda, United Republic of Tanzania, Zambia, Zimbabwe
America 1	AMR 1	AMR A	Canada, Cuba, United States
America 2	AMR 2	AMR B	Antigua and Barbuda, Argentina, Bahamas, Barbados, Belize, Brazil, Chile, Colombia, Costa Rica, Dominica, Dominican Republic, El Salvador, Grenada, Guyana, Honduras, Jamaica, Mexico, Panama, Paraguay, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Suriname, Trinidad and Tobago, Uruguay, Venezuela
		AMR D	Bolivia, Ecuador, Guatemala, Haiti, Nicaragua, Peru
Eastern Mediterranean	EMR	EMR B	Bahrain, Cyprus, Iran, Jordan, Kuwait, Lebanon, Libyan Arab Jamahiriya, Oman, Qatar, Saudi Arabia, Syria, Tunisia, United Arab Emirates
		EMR D	Afghanistan, Djibouti, Egypt, Iraq, Morocco, Pakistan, Somalia, Sudan, Yemen
Europe	EUR	EUR A	Andorra, Austria, Belgium, Croatia, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Israel, Italy, Luxembourg, Malta, Monaco, Netherlands, Norway, Portugal, San Marino, Slovenia, Spain, Sweden, Switzerland, United Kingdom
		EUR B	Albania, Armenia, Azerbaijan, Bosnia and Herzegovina, Bulgaria, Georgia, Kyrgyzstan, Macedonia, Poland, Romania, Serbia, Slovakia, Tajikistan, the former Yugoslav Republic of Macedonia, Turkey, Turkmenistan, Uzbekistan
		EUR C	Belarus, Estonia, Hungary, Kazakhstan, Latvia, Lithuania, Moldova, Republic of Moldova, Russia, Ukraine
Southeast Asia	SEAR	SEAR B	Indonesia, Sri Lanka, Thailand, Timor-Leste
		SEAR D	Bangladesh, Bhutan, Democratic Peoples Republic of Korea, India, Maldives, Myanmar, Nepal
Western Pacific 1	WPR 1	WPR A	Australia, Brunei, Japan, New Zealand, Singapore
Western Pacific 2	WPR 2	WPR B	Cambodia, China, Cook Islands, Federated States of Micronesia, Fiji, Kiribati, Lao People's Democratic Republic, Malaysia, Marshall Islands, Mongolia, Nauru, Niue, Palau, Papua New Guinea, Philippines, Republic of Korea, Samoa, Solomon Islands, Tonga, Tuvalu, Vanuatu, Vietnam

Forecasts of Prevalence of Cataract-Caused Visual Impairment

Methodological Approach

The model forecasts cataract-caused VI by continent region. The starting point is a forecast of the population, including changes in composition by age group. Using these population forecasts and the assumption that prevalence rates of cataract-caused VI by age category remains constant in the future, the model then forecasts the overall cataract prevalence rate in the population, as well as the numbers with cataract-caused VI by age category.

We base our approach on established models of VI prevalence estimation and forecasting, such as Resnikoff et al. (2004), and Access Economics (2010). Resnikoff et al. use population estimates and prevalence estimates by WHO subregion to estimate regional and global prevalence of VI in 2002. Their prevalence estimates are by age group and are estimated from previously published vision surveys and region extrapolation. Access Economics forecasts VI prevalence at years 2010, 2015, and 2020 using population forecasts and information on prevalence by age group in Resnikoff et al. (2004).

Our model uses the international population forecasts provided by the U.S. Census Bureau's 2010 International Database. This database is a very detailed source of population forecasts by five-year age groups for most countries of the world. The Census Bureau considers age group–specific mortality, fertility, immigration, and emigration rates. Population forecasts are extended to 2050 but, in our modeling, we only consider forecasts to year 2040 as noted.

The definitions of low vision and blindness assumed in the forecasting are those in the standard International Statistical Classification of Diseases and Related Health Problems, 10th Edition (ICD-10). These definitions are widely used in the surveys that are the basis of prevalence estimates. A person is defined as visually impaired if he or she is classified as having low vision or as blind. Table 5.2 displays the ICD-10 standards for low vision and blindness classifications. To measure VA, which is reported as a fraction, a patient is placed 6 meters (i.e., 20 feet) away from a Snellen chart. If the patient can read the metric 18 line (20 line in feet) on the Snellen chart, the patient has a VA of 6/18 (i.e., 20/60 or approximately 0.33).

To forecast prevalence, we multiplied the U.S. Census Bureau population forecasts through 2040 for different age groups by Resnikoff et al.'s estimates for the current age-specific prevalence of VI. Estimates of blindness by age group are available in Resnikoff et al., but unfortunately, estimates of regional low vision by age group are not; only estimates of total regional low vision are available. Resnikoff et al. present the ratios by region for cataract-caused low vision to blindness (not by age group) and we will use these to estimate regional low-vision prevalence by age group as described below. Appendix A, Table A.1, displays Resnikoff et al.'s estimates of blindness prevalence by age group and low vision ratios.

To estimate future VI from cataracts we first estimate future blindness by multiplying the U.S. Census Bureau's age-group specific population forecasts by Resnikoff et al.'s age-grouped

Table 5.2
ICD-10:H54 Visual Acuity Definition of Low Vision and Blindness

Visual Acuity Definitions ICD-10:H54	Feet	Meters
Adequate vision	>20/60	>6/18
Low vision	≤20/60 and ≥20/400	≤6/18 and ≥6/120
Blind	<20/400	<6/120

blindness prevalence by region. As indicated in Appendix A, Table A.1, Resnikoff et al. provide prevalence information for the three broad age categories of less than 15 years, 15–49 years, and greater than 49 years of age. Therefore, we group the U.S. Census Bureau's population forecast into these three age groups.

From the estimates of blindness for each year and continent region through 2040, we calculate low vision using the regional ratios of low vision to blindness given in Resnikoff et al. The forecast of VI is then the sum of blindness and low-vision prevalence. This forecasting approach is very similar to that of Access Economics (2010). Finally, to estimate the prevalence of *cataract-caused* VI, we multiply total VI prevalence by the regional estimates of the fraction of VI caused by cataracts, also shown in Appendix A, Table A.1.

It should be emphasized that the model accounts for both overall population growth and the change in population composition by age (essentially the aging of populations) over time. The former implies a growing number of cataract-caused VI cases simply because the population is larger. The latter implies an increasing prevalence *rate* in most regions, because the population is on average getting older.

Our approach makes several assumptions that are also made by both Resnikoff et al. and Access Economics, and are necessary due to lack of data or of estimates in the literature. The following is a list of assumptions made when forecasting the status quo, i.e., cataract-caused VI in the absence of HMS:

- The VI prevalence percentages by age group shown in Table A.1 are assumed to remain constant into the future. However, as noted, the model does take into account changes in the age distribution of the population as forecasted by the U.S. Census Bureau—in particular, the overall aging of the population, which has important effects on cataract prevalence as cataracts are strongly age associated.
- The ratios of low vision to blindness prevalence in Table A.1 are also assumed to remain constant in the future.
- The share of VI caused by cataracts in Table A.1 is assumed to remain constant in the future. The literature provides no clear indication of how these values might change in the future. Note that the values in the last column of Table A.1 were actually specified for blindness; we assume that these values are accurate for low vision as well.
- The share of individuals needing cataract surgery who get this surgery remains constant into the future. As discussed in Chapter Two, this ratio is the CSC and we assume for the status quo that CSC remains constant over time. We found no published forecasts of CSC to incorporate in the model. In fact, forecasts of blindness prevalence generally make the constant CSC assumption although this is typically not made explicit.[1]

The last assumption is of particular note for our analysis. It indicates, first, that the "status quo" does not mean there is *no* expansion of cataract surgery in different regions of the world. Rather, the number of surgeries increases in proportion to the increase in the number of people

[1] Forecasts are based on estimates of current VI prevalence in a given region, and these prevalence estimates naturally exclude those who had cataract-caused VI that has been corrected. (Hence the rate is extremely low in the United States and western Europe, where the vast majority of cataract cases are operated on before severe vision impairment occurs.) Applying these prevalence ratios to predicted population by age in future years implicitly assumes that the same share of those in need will be treated into the future (that is, constant CSC assumption).

with cataracts (which comes from both population growth and population aging). At the same time, assuming a constant coverage rate is probably rather conservative, given the increasing attention to the need for vision-related services in the developing world, and the many initiatives organized around the principles of Vision 2020. The successful training and service-delivery systems described in Chapter Three have substantially reduced cataract prevalence in the areas they serve and will likely expand their reach (or export the models). However, it is impossible to make anything other than highly arbitrary assumptions about these potential impacts for the modeling.[2] It should be emphasized that assuming that the number of surgeries performed grows in proportion to the number of cataract cases does not mean the supply of surgeries matches the need, only that the current (usually low) share of those needing surgery who get it is maintained in the face of population growth and aging.

Finally, when accounting for the impacts of productivity loss due to cataracts, the model accounts for growth in incomes in different regions (which increases the loss of economic output associated with a visually impaired person working less than a nondisabled person). However, the model does not capture the effect of income growth on cataract surgical coverage. Even in the absence of specific programs, increasing income would be expected to increase the demand for cataract surgeries. Therefore it should be kept in mind that the estimates of prevalence in the status quo forecast may underestimate improvements in CSC (and thus overestimate prevalence).

Forecasts of Prevalence by Region

Figure 5.1 shows the prevalence forecasts for cataract-caused VI by continent region in units of millions of people and as a percentage of the population. SEAR has by far the largest numbers of cataract-caused visually impaired people currently and into the future, and among the highest shares of individuals with cataract-caused VI. This reflects, in part, the fact that India, with very high prevalence, contributes two thirds of SEAR's population (1.26 billion people, about 66 percent of SEAR's total population). The region also experiences the fastest growth of cataract-caused VI in terms of absolute numbers. The number of cataract-related VI cases in this region is 32 million in 2012 and rises to a staggering 53 million cases in 2030. Note that for blindness caused by cataracts (as opposed to all VI) this corresponds to 8 million cases in 2012 and 13 million cases in 2030.

These increases in absolute numbers of cataract-caused VI and blindness reflect both overall population growth (more people in all age groups) and the aging of the population (proportionately more older, hence cataract-prone, people). The latter explains why the prevalence *rate* in Figure 5.1b climbs so sharply. The same pattern applies to most of the other regions.

The WPR 2, which includes China, has the second largest nominal prevalence over most of the time frame. In 2009, China's population was approximately 1.32 billion, accounting for about 81 percent of WPR 2's total population. Despite the large nominal prevalence of WPR 2, the percentage prevalence is forecasted to remain smaller than that of SEAR, EMR, and AFR. Still, in absolute numbers, this region contributes an enormous number of cataract-caused VI cases (26 million in 2012) and blindness (6 million in 2012). By 2030 under the status quo, these numbers climb to 40 million and 9 million cases, respectively.

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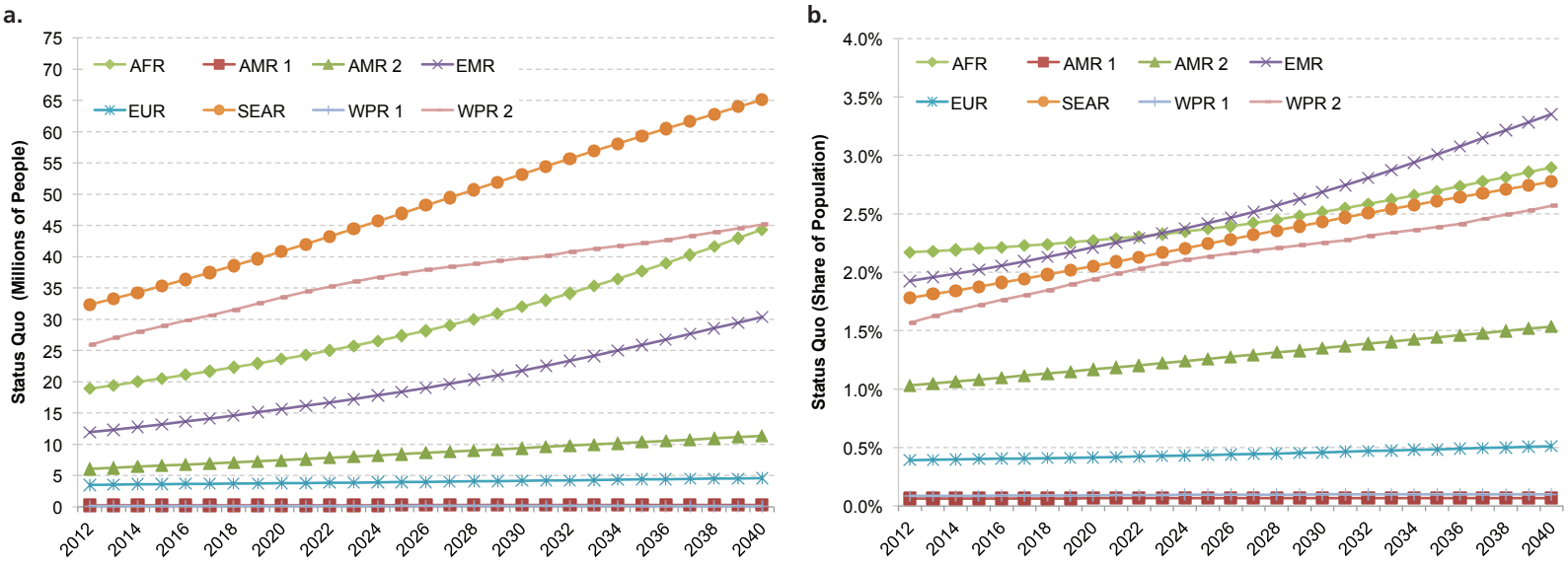
[2] The literature contains almost no systematic discussion, let alone estimates, of possible increases in CSC in the future. We also considered extrapolating recent trends in CSC, but data needed for this was also lacking.

Figure 5.1
Forecasts of Cataract-Caused Visual Impairment Prevalence



Africa contributes 19 million cases of cases of cataract-caused VI in 2012 and 5 million cases of cataract blindness. Due to relatively rapid projected population growth, the numbers climb sharply over time to 32 million VI and 8 million blindness cases by 2030, even while prevalence rates increase only modestly. In contrast, both nominal and percentage prevalence is forecasted to remain relatively low in AMR 2, which includes Latin America.

Finally, the exceptionally low current (2012) numbers as well as projections for AMR 1, EUR, and WPR 1 are noteworthy. With such high rates of cataract surgery in these industrialized, largely wealthy economies, prevalence is very low and will stay that way into the future.

Disease Burden—Disability Adjusted Life Years

The impacts of VI and blindness are felt through reduced quality of life and early mortality. These aspects of the burden of cataracts (as for other diseases or disabilities) are captured in the standard measure known as DALYs, first introduced by the World Development Report (World Bank, 1993) and the Disease Control Priorities Review (Jamison et al., 1996). One DALY represents the loss of the equivalent of one year of healthy life. This loss can occur through premature mortality due to the disease, or through living the same years but in poor health (and reduced quality of life), or a combination of the two. DALYs thus are defined as the sum of Years of Life Loss (YLLs) from the disease due to premature mortality and Years Lost Due to Disability (YLDs) due to reduced quality of life while living with the disability (see WHO, 2011). The YLLs are purely a function of the decreased life span of disabled people, while YLDs involve assumptions about the quality of life reduction due to disabilities. The most common means of estimating DALYs is an "incidence-based" approach. Incidence refers to new cases of a disease, while prevalence counts both new and existing cases. The incidence approach requires information on the likelihood of acquiring the disease by age and sex (e.g., women at age 50) in a population, and the expected reduced years of life as a result of the disease. We also would need to know the progression of the disease over the remaining lifetime, e.g., from low vision to blindness, as this will affect the weight for quality of life used.

We lack this systematic information on incidence of cataract-caused VI. Recall that we estimate prevalence by multiplying the VI prevalence in Appendix A, Table A.1, using the population forecast for three broad age groups: under 15, 15–49, and 50 or older. Therefore, we only have estimates of total *prevalence* by each age group, and these age groups are very broad. Although it is possible to derive age specific incidence from prevalence data by methods of smoothing from wide age bands (see Hollinghurst et al., 2000), these methods are likely to be very sensitive to assumptions about incidence within very wide bands as in our case.

Therefore we use a simpler, prevalence-based approached to calculate DALYs, originally discussed by Murray (1994). In this approach, to estimate YLDs we multiply a given year's prevalence of VI by the corresponding disability rates (shown in Appendix A, Table A.3, for VI). This product is, in essence, the YLDs only for the given year. Individuals who have cataract-caused VI for multiple years will contribute to each year's YLD estimate in which they are alive and have cataract-caused VI.

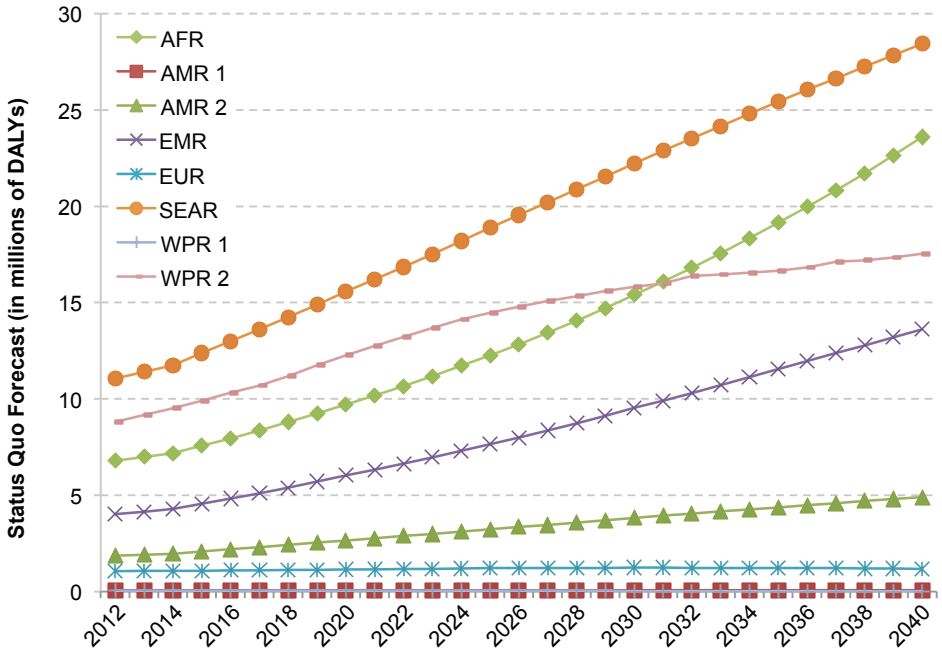
For impacts on YLL, we use an approach based on estimates in the literature of the effects of blindness or low vision on mortality probabilities. These estimates allow us to model what the population in our age groups would be with and without cataract-caused VI through the year 2040. By estimating YLL as the difference between the two population forecasts, the YLL

estimate is, in essence, the number of person-years lost due to cataract VI–associated early mortality in a given year. The YLL estimate for a given year does not include future or past person-years lost. Therefore like the prevalence-based YLD just described this YLL measure is a yearly measure. The sum of these YLD and YLL measures gives the disease burden for that year. Appendix A provides the details of the population forecasting and DALY calculations used for these estimates.

Figure 5.2 displays the status quo cataract DALY estimates for all continent regions.

Note that the DALY estimates are a function of the cataract-caused VI prevalence (seen in Figure 5.1a), disability rates, and mortality rates. AFR has high DALY estimates because this region has relatively high prevalence forecasts, a high disability rate, and high mortality from VI. WPR 2 also has high DALY estimates despite relatively moderate prevalence forecasts (Figure 5.1b) and moderate disability rates, because it has lower mortality rates. The relatively low mortality rates increase WPR 2's DALY estimates because the WPR population lives longer and incurs more years with lower quality of life (more YLDs). In Chapter Six, we use this method of estimating DALYs to forecast the DALYs averted by the HMS program under different assumptions about uptake of surgery.

Figure 5.2
Forecasts of Status Quo Cataract DALYs by Continent Region



Forecasts of Productivity Loss Due to Cataracts

Methodology[3]

To calculate economic productivity losses from cataract-caused VI, we follow the methodology of Smith et al. (2009). Economic productivity losses arise from individuals not being able to work, or work fully, due to a VI disability—their own or that of someone they must spend time caring for. First, we calculate an initial productivity loss estimate by applying productivity loss weights (or disability rates) for blind and low-vision individuals to their expected income, which is based on the region's expected GDP per capita. We use disability weights for cataract-caused blindness and low vision estimated by WHO (Mathers et al., 2003); these are shown in Appendix A, Table A.3. For Africa, for example, a blind person is assumed to produce about 40 spercent of the income of a person without VI.

The estimate for the productivity loss for a region is based on these weights and the regional prevalence forecasts discussed in the previous chapter. Specifically, if a person has cataract-caused low vision or blindness, their economic productivity loss is the product of regional GDP per capita and the appropriate disability rate, and these losses are summed over all people with VI in the region in that year to get the productivity loss for that year. We use the 2009 GDP per capita estimates from the United Nation's National Accounts Main Aggregates Database (United Nations, 2010). Appendix A, Table A.4, displays the GDP estimates used for the calculations.

We also want to account for loss of income of caregivers, as noted. We assume that each blind or low-vision individual has a caregiver whose own productivity loss is 0.10 for a blind person or 0.05 for a low-vision person; that is, this share of caregiver work time (and income) is given up to care for an individual with VI. The use of disability rates and caretaker disability rates follows the approach in Smith et al. (2009).

Next, we have to account for the fact that the probability an able-bodied individual would actually be working is less than 100 percent, since not all working-age people are in the labor force—and some in the labor force are unemployed. Therefore we use Labor Force Participation Rates (LFPRs) and Employment Rates (ERs) (the latter being the share of labor force participants who are working) to derive an adjusted economic productivity loss for each blind or visually impaired person and their caretaker. All of the above factors differ over region. Differences in productivity loss across regions thus will depend on the following: (1) prevalence of VI, (2) per capita income, and (3) the probability of being employed if able bodied. In addition, it will depend on the growth of productivity or per capita GDP in the economy. All things equal, regions with small LFPRs and small ERs will have less productivity loss per visually impaired person than regions with large LFPRs and large ERs, as a smaller share of the population would normally be employed in the former.

The productivity loss is calculated for the population ages 15 years or older. Smith et al. (2009) assume similarly that economic productivity loss is negligible for those under the age of 16 years and that all people ages 16 or greater have the same productivity. For our analysis, we make the same assumption using age 15, as this matches the age groups in Resnikoff et al. on which our prevalence forecasts are based. Since the vast majority of cataract-caused VI is in older adults, the assumption of zero productivity of children (whether under 15 or 16) is not an important assumption. For the other two age groups in our model, 15–49 and 50 and over, we

[3] Details on the methodology and assumptions used are provided in Appendix A.

use separate estimates of labor force participation rates, derived from data presented in Kapsos (2007). This is important since participation among older adults, who have much higher rates of cataract-caused VI, is lower than participation of those age 15–49. For a complete description of the procedure and the data sources for LFPR and ER, see Appendix A.

We note, further, that when forecasting economic productivity losses we assume that disability rates (Table A.3) and the LFPRs and ERs (in Table A.6) remain constant through the forecasted future. Finally, we model the expected growth of GDP per capita by assuming the estimated GDP per capita growth rates specified in Mathers and Loncar (2006) and listed in Appendix A, Table A.5.

Results

Figure 5.3 displays the forecasted productivity loss due to cataract-caused VI using this approach. The WPR 2 (including China) is the region with the largest productivity losses due to cataract-caused VI: starting with about US$27 billion in 2012 and rising to about US$75 billion in 2030. The enormous total cost for this region reflects its very large population and relatively high per capita income, as well as the fact that the LFPR and ER are largest for this region. In addition, the WPR 2 has the largest estimated GDP growth among all the regions. Our forecast of WPR 2 as the highest economic productivity loss due to cataract-caused VI is consistent with Smith et al.'s (2009) productivity loss findings. Losses are much smaller in dollar terms for other regions, either because they are much poorer (AFR) or because prevalence is very low (AMR 1 and EUR).

Although the calculations of productivity losses in Figure 5.3 give an impression of the scale of these losses, they do not accurately portray the relative impacts on different regions, because of the sheer differences in income across regions. Therefore, in Figure 5.4 we present

Figure 5.3
The Status Quo Economic Productivity Loss Forecast

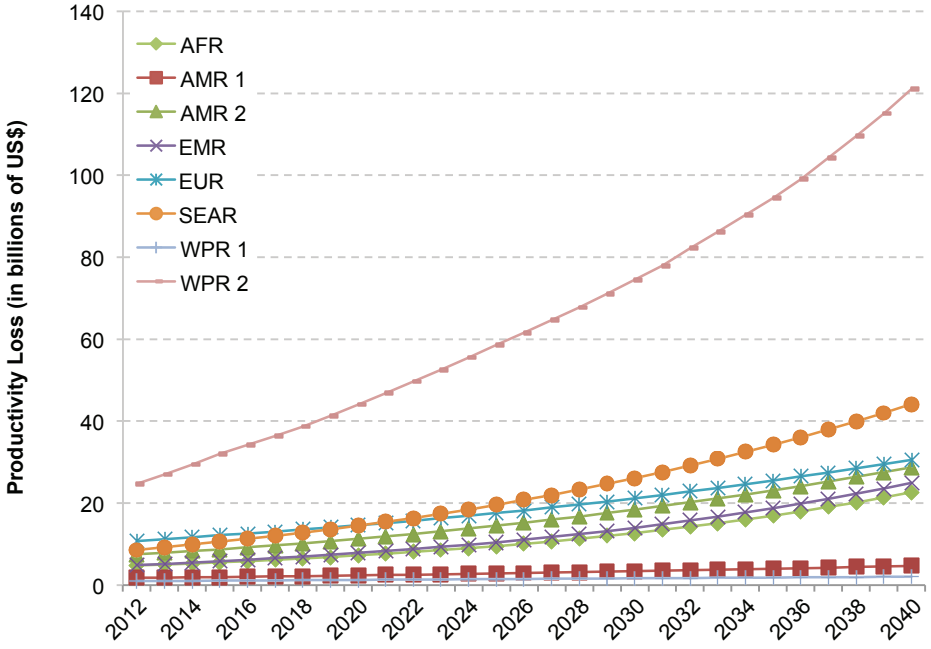
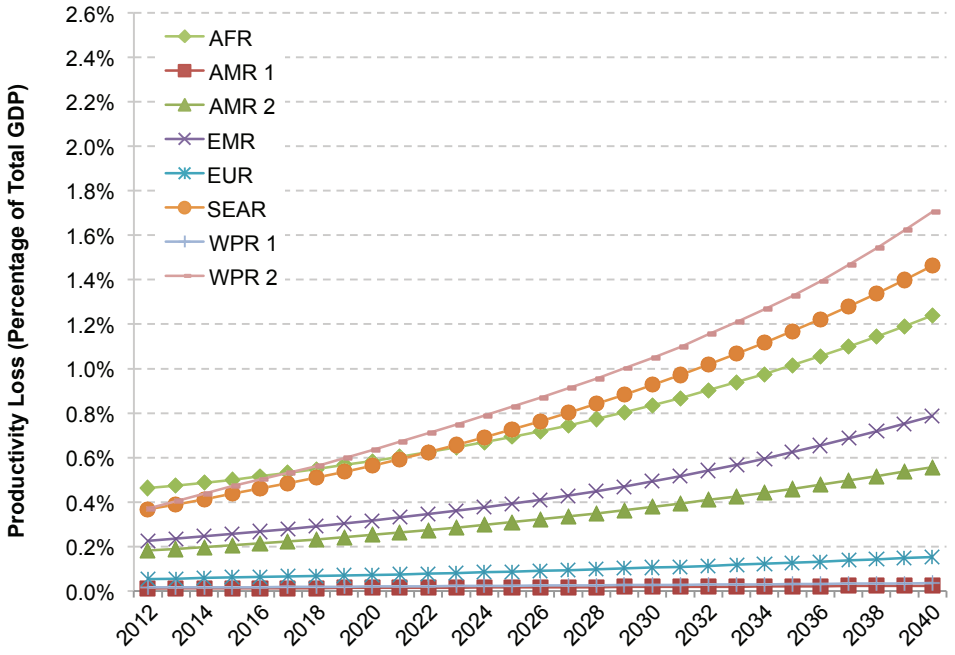


Figure 5.4
Status Quo Economic Productivity Loss as a Percentage of GDP



the economic productivity loss in each region as a percentage of the total GDP for the region. Here again, the WPR 2 has the largest losses, but the differences with other regions are much less pronounced. Both SEAR and AFR are also forecasted to have large proportional economic productivity losses. For example, the productivity loss for SEAR due to cataracts will reach 0.8 percent of GDP by 2027, up from less than 0.4 percent currently.

These projections are highly dependent on the assumptions and approach used. They suggest very large economic losses compared with estimates for many other disabilities in the literature. For example, Abegunde et al. (2007) estimated the economic losses caused by premature deaths from chronic diseases (primarily coronary heart disease, stroke, and diabetes) in low- and middle-income countries. The losses in China and India over a ten-year period (not annually) were US$14 billion and $10 billion, respectively, in their analysis. On the other hand, our results are generally similar to those of Smith et al. who specifically considered losses due to uncorrected refractive error.

Summary

This chapter presented our modeling approach for predicting future prevalence of blindness and low vision caused by cataracts, and presented estimates of current and future cataract prevalence by region. In addition to prevalence, we also presented projections of future costs in terms of DALYs and economic (productivity) losses associated with cataracts—two standard approaches to measuring the burden of disease or disability. The model predicts that under the "status quo"—meaning that the current share of those in need who receive cataract sur-

gery is constant into the future—the numbers of visually impaired (blind or low-vision) individuals needing cataract surgery will grow to huge proportions in the coming decades. This reflects population growth as well as population aging, as cataracts are highly age-related. The number of cases of VI from cataracts in the SEAR region, which includes India, will be over 32 million in 2012 and will rise to a staggering 53 million cases in 2030. For cataract-caused blindness specifically (as opposed to all VI) this corresponds to 8 million cases in 2012 and 14 million cases in 2030. Productivity losses due to cataracts are projected to be extremely significant. These will be largest by far in the WPR 2 region, where they are estimated to be about US$27 billion in 2012 and would rise to US$75 billion by 2030 in the absence of improvements in cataract surgical coverage. As a percentage of GDP, losses are still greatest in WPR 2, but are more similar are across regions than absolute losses.

CHAPTER SIX

Modeling the Impacts of HelpMeSee

In this chapter we examine the potential impacts of the HelpMeSee approach. We consider the following outcomes: number of trained MSICS specialists; surgical capacity, or the total number of surgeries per year that can be performed in the HMS system; and actual surgeries performed and the impacts on cataract-caused VI. The last of these, of course, is the key variable of interest—the ability of the HMS approach to substantially close the cataract surgery gap over time relative to the status quo scenario presented in the previous section. We consider the same 2012-2040 time frame as in the previous section, and model impacts on prevalence of cataract-caused VI under different assumptions about uptake of the HMS surgery.

We begin by discussing the assumptions underlying the modeling of HMS impacts. These include parameters regarding the planned initiation of MSICS learning centers, as well as assumptions about training capacity per center, potential surgeries per year per surgeon, attrition, and other factors. Many of these assumptions are based on information provided by HMS. We also discuss assumptions about uptake or demand. In doing so we clearly lay out the limitations of the modeling, which derive largely from data limitations. We then present the forecasts for the number of surgeons, surgical capacity, and impacts on prevalence. We also present forecasts for the actual number of surgeries performed per HMS–trained practitioner and discuss the implications of this for the viability of the surgical practices.

Assumptions of the Model

As noted in Chapter Four, HMS plans to establish its first training center in Asia, Africa or Latin America in 2013, corresponding to our continent regions SEAR and WPR 2 (combined Asia), AFR, and AMR 2. Subsequently, three to five additional learning centers will be established in these regions. Therefore we model here the impacts of their plans for these four regions, henceforth ignoring AMR 1, EUR, and WPR 1.

The key assumptions of the model are listed below. They reflect both HMS expert input and findings in the literature.

- 60 percent of trainees will successfully complete the program (estimated by HMS). This reflects the quality and testing standards HMS plans to incorporate into the training program.

- HMS centers will operate four learning centers (with no more than one in each continent region).[1] The first training center will open in 2013, so we assume that the first practitioners will not start performing surgeries until 2014. Each year, each center will admit 1,000 surgical trainees, of which 600 are expected to graduate in that year (the rest leave the program). Overall, HMS plans to graduate about 30,000 practitioners in all of its learning centers. Therefore, we assume that each learning center aims to graduate 7,500 surgeons (one quarter of the total). After this point, each center will reduce the number of trainees so as to maintain a constant level of practitioners in the face of attrition. This assumes that the necessary supply of incoming trainees will be forthcoming—that is, that the startup and reimbursement incentives offered by HMS (discussed below) will be adequate. We relax this assumption in the sensitivity analysis.
- Surgeon practitioners have a 5 percent chance of quitting their practices each year. Lewallen and Courtright (2010), in a study of nonphysician cataract surgeons in sub-Saharan Africa, found that about 10 percent leave each year. Lewallen and Courtright's attrition estimate was for nonphysician surgeons, who generally have low surgery volume and poor support infrastructure. HMS plans a system of support that will assist their practitioners in significant ways. Therefore a 10 percent rate may not be appropriate for HMS practitioners, and we assume, somewhat arbitrarily, 5 percent attrition (sensitivity analysis that explores the impacts of different assumptions is discussed below).[2] Still, sustainability will depend on each practitioner's ability to secure adequate demand for his or her services, and to do so in part by carrying out high-quality surgeries and gaining reputations for doing so. Later we discuss viability more explicitly, by assessing potential demand for surgery facing each practitioner.
- All people with cataract-caused VI are assumed to have bilateral cataracts. As previously stated, VI as defined in Resnikoff et al. and in this report refers to best corrected vision in the better eye. If VI is defined as on the better eye, we assume that the worse eye also needs cataract surgery. On one hand, this assumption may inflate the surgical demand because it counts people who have worse vision in one eye not due to cataracts as in need of two cataract surgeries. On the other hand, this assumption may underestimate demand because it excludes people who do not have cataracts and VI in one eye but desire to have surgery on the cataract in the other eye. Given these uncertainties and the lack of regional estimates of unilateral and bilateral cataracts in the literature, we assumed that all people with VI as defined in this report have bilateral cataracts.
- The HMS trained practitioners have a four-year "learning curve" post-training, at the end of which they can perform 2,000 surgeries per year provided there is sufficient demand. The 2,000 estimate is from HMS and is also close to the average for Aravind of about 2,200 per year (although some experienced surgeons, including at Aravind, are capable of many more than this). Given that Aravind is renowned as one of the highest throughput systems for cataract surgery, 2,000 seems a reasonable maximum for HMS surgeons. In the modeling, this means that even if demand for surgeries per practitioner exceeds 2,000 per year, the maximum each performs will be 2,000. The learning curve assumptions

[1] Ultimately there may be more than one per region.

[2] There are very few other estimates of attrition in the literature—especially for independent practices of the sort HMS plans to set up (as opposed to, for example, doctors practicing as employees in hospitals).

(rate of progression to 2,000 capability) are adapted from Courtright et al. (2007) and calibrated to the HMS maximum.[3]

- HMS practitioners are assumed to perform cataract surgeries on blind and low-vision cases in proportion to the shares of these two groups in the given region as given by Appendix A, Table A.1. It is HMS's primary objective to reduce blindness. However, evidence suggests that, in practice, those coming for screening and surgery will include blind and low-vision patients, sometimes more of the latter.[4] It would be impractical to require independent MSICS practitioners to prioritize the blindness cases (unless additional incentives to do so are provided). Therefore the simple proportionality assumption is reasonable.
- The visual acuity outcomes of MSICS surgeries performed by HMS practitioners will be 96.16 percent adequate vision, 3.04 percent low vision, and 0.80 percent blind. These estimates were created by statistically interpolating and extrapolating estimates of MSICS outcomes in the literature, which as noted indicate very high quality of outcomes for leading cataract surgery systems. Unsuccessful surgery cases (resulting in low vision or blindness) continue to contribute to VI prevalence in the model for the years after the surgery, until death. The details of the visual acuity outcomes estimation process are discussed in Appendix A.

Uptake

The above assumptions allow us to model the supply of surgeons and maximum surgical capacity over time in each of the four continent regions (or equivalently, the areas served by an HMS learning center). Also needed are assumptions about the demand for the services of these practitioners. It is clearly inappropriate to assume that these new surgeons will operate at full capacity simply because there are adequate numbers of individuals in need of surgery. The literature reviewed in Chapter Two made clear that there are numerous barriers preventing individuals from accessing existing cataract surgical services, including geographical inaccessibility, cost, expectations of poor quality outcomes, and inconvenience. The HMS system is designed to address several of these barriers, most notably by being able to place surgeons closer to poorly served potential patients in rural areas. However, there is a paucity of firm evidence from the literature that would allow us to, say, parameterize the effects of closer proximity on uptake, or to predict the effect of quality (share of surgeries with good outcomes) on demand.

Instead of making highly arbitrary assumptions about what these effects may be, we conduct a sensitivity analysis in which we model impacts on prevalence under different rates of uptake. Specifically, we carry out the forecasts assuming potential uptake of HMS surgery services of 20 percent, 50 percent, and 80 percent of the cataract-caused visually impaired. We use the term "potential" in the sense of willing and able to receive surgery;[5] the surgical capacity of

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[3] The estimates of Courtright et al. (2007) pertain to a surgeon with three or more support staff. We recalibrate this learning curve for HMS practitioners where 2,000 is the maximum number of surgeries that they can perform. Under these assumptions, practitioners can perform a maximum of 693 surgeries per year after one year, 1,284 surgeries per year after two years, 1,433 after three years, and 2,000 after four years.

[4] We thank Susan Lewallan for discussion on this point.

[5] "Willing" and "able" in the sense that they both want the surgery and have the means and family or other help to enable them to attend a screening and get to the surgical site if needed. In what follows we just use the term "willing" to refer to both factors being present.

HMS to meet this demand may or may not be present, depending on the year and other factors in the model. We note that assuming a constant rate of uptake over the forecast period is a simplification, in that uptake rates are likely to change over time depending upon the change in accessibility, the perceived quality of the HMS practitioners and outreach efforts by HMS. Generally we might expect an increase if accessibility increases or high quality of care becomes known. On the other hand, beyond some point it is often hard to improve uptake of health services as the remaining untreated population is particularly remote or otherwise hard to serve.

This assumed level of uptake, it should be made clear, is not total uptake of surgery but HMS-specific uptake over and above the status quo level. As discussed in the previous chapter, the status quo assumes that the number of cataract surgeries increases in proportion to the rising number of cataract-caused VI cases. It should also be noted that the 80 percent scenario is a very optimistic one. There is little hard evidence in the literature of the coverage in a population that aggressive cataract surgery programs can attain. However, an appreciation of the barriers to surgical access and acceptance suggests that 80 percent—which, together with existing services implies close to complete coverage—should be regarded as an upper limit.

What then does the model show us? It might seem that if we are simply assuming a given level of uptake of HMS, our forecasting is a somewhat tautological exercise. This is not the case. Our modeling will show the following:

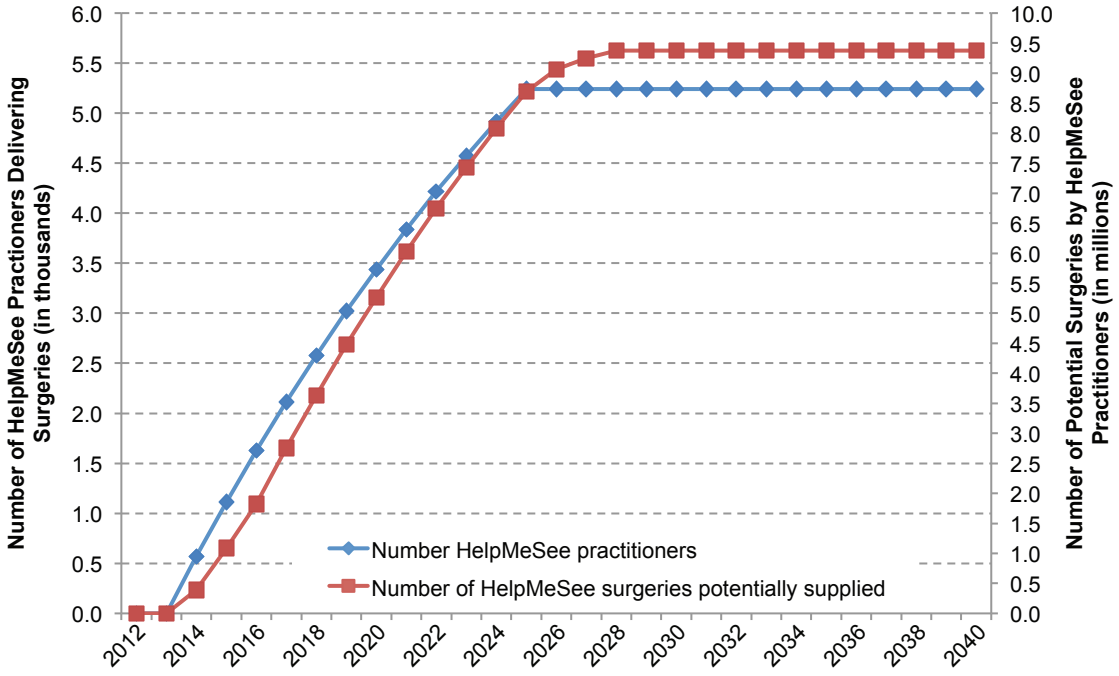
- **Growth of cataract surgical capacity in the four regions as a result of HMS.** Then we can say, given our forecasted prevalence of cataract-caused VI in these regions, whether or not HMS will be able to deliver the capacity to meet needs or demand for surgeries.
- **HMS's effect on actual number of surgeries and hence prevalence of cataract-caused VI, under different assumptions about uptake.** The evolution of prevalence into the future will depend primarily on two factors: (1) the rate of uptake, which operates directly as well as indirectly, since a given level of uptake in earlier years affects the cumulative backlog of cataract cases carried over into later years, affecting future prevalence; and (2) the growth of HMS surgical capacity.
- **Implications for the sustainability of individual surgical practices.** This is determined by the number of surgeries each practitioner can perform per year, which is a function of the total number of surgeries demanded and the total number of surgeons. Practitioners need a minimum level of surgeries both to build up and maintain their skills and to remain viable financially given the level of fee per surgery they can expect to be reimbursed by HMS.

Impacts on Number of Surgeons and Surgical Capacity

We forecast the evolution of the number of practitioners and surgical capacity under the assumptions listed above about number of trainees per year, graduation rates, learning curves for cataract surgery post-training, and attrition of practitioners. This is presented in Figure 6.1 for a single training center. Note that the supply of HMS practitioners and capacity is not the total supply, but rather is in addition to those cataract surgeons and surgical capacity that are outside of HMS; that is, the status quo supply.

The figure demonstrates that on the assumptions discussed, HMS learning centers should be capable of producing a very large number of practicing cataract surgeons quite quickly. A

Figure 6.1
HelpMeSee Supply of Surgeons and Surgical Capacity (for One Training Center)



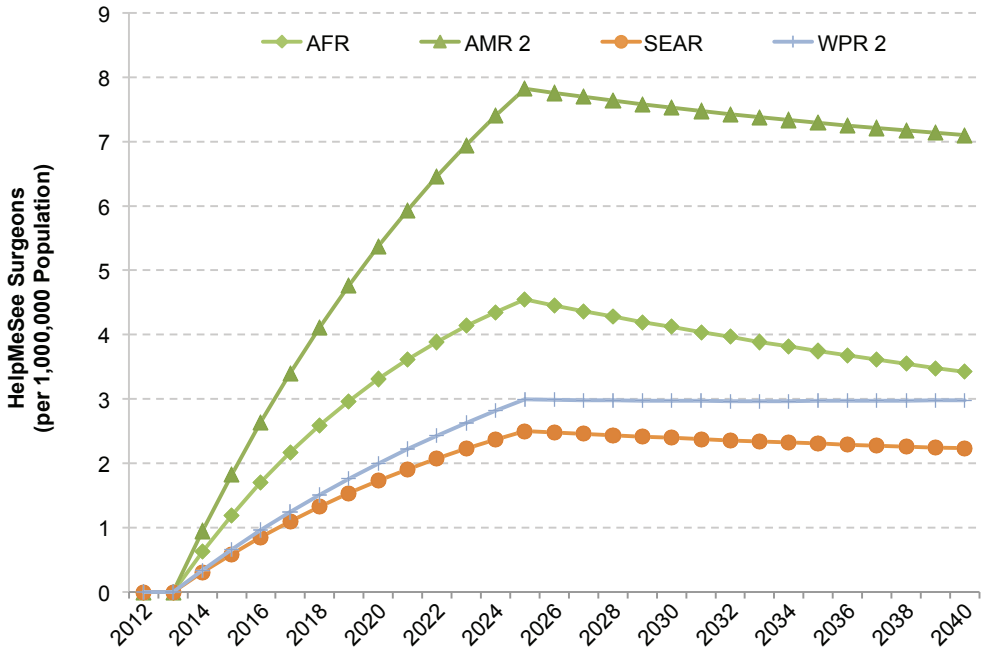
center starting in 2013 will have graduated some 2,579 surgeons by 2018 who have remained in practice (not left the business). By 2030 this number will be about 5,240. Once a training center has graduated 7,500 practitioners (i.e., approximately 5,240 after attrition is considered), the training center is assumed, as noted, to significantly lower the intake of trainees so as to maintain a constant supply of practitioners, offsetting those lost to attrition.

The number of potential surgeries per year (assuming a maximum of 2,000 per surgeon reached after four years by each practitioner) follows this progression, with capacity for almost 3.6 million surgeries per year in 2018 and about 9.4 million per year in 2030, again for one training center.

The rapid increase in surgical capacity suggested by these figures is driven by the short MSICS training period, expected to be possible through the use of the simulator and related courseware, and perhaps more so by the fact that MSICS training time does not include the years of medical school required to become an ophthalmologist. To the extent that the HMS training is prepared to take in significant numbers of individuals who are not ophthalmologists—or are nondoctors or individuals without a medical background—the time to train a doctor will not be a constraint to increasing cataract surgeon supply for HMS. This is an important potential advantage in terms of the ability to produce large numbers of cataract surgeons quickly.

To put the change in cataract surgical supply in perspective, Figure 6.2 shows the number of HMS surgeons per 1 million population for each continent region. The Vision 2020 initiative recommends that blindness prevention programs, including cataract surgical services, should cover geopolitical administrative units of approximately one million population (Lewallen et al., 2005). Given variation in cataract incidence and age composition, this is at best a

Figure 6.2
HelpMeSee Practitioners per 1,000,000 Population



rough guide (Lewallen et al., 2010). Further, the guideline refers to meeting needs for dealing with incident (emerging) cases so as to prevent blindness, not necessarily with clearing existing backlogs. Still, it is worth seeing how well the HMS program would meet this benchmark.

The patterns in the graph are driven by the assumption (from HMS) that there is one learning center in each region producing the same number of graduates, despite wide differences in population and prevalence across regions; hence the ratios for Latin America and Africa are much larger than for the two Asian regions. In reality, it may be possible to have more than one center in the more populous regions. Nonetheless, the calculations are instructive. Under the model assumptions, HMS is clearly capable of providing more than one cataract surgical provider per million population. In fact, the question arises whether the system would generate an oversupply of surgical capacity. This is taken up below.

Impacts on Prevalence of Cataract-Caused Visual Impairment

We turn now to the question of how HMS will potentially affect the number of people in each region with VI caused by cataracts. We start with AFR and AMR 2 in Figure 6.3. The figure shows forecasted prevalence of VI under the status quo scenario (i.e., no HMS, with a constant cataract surgery coverage rate), and under HMS scenarios, for uptake rates of 20 percent, 50 percent, and 80 percent. Again, these uptake percentages refer to the share of cataract-caused VI cases that are not operated on by other providers and are willing and able to be operated on by HMS. Actual operated cases will fall short of the potential uptake level if there are not enough HMS-trained practitioners. That is, the results shown take into account the supply of

HMS surgical capacity, determined by the number of practitioners in a given year, the practitioner learning curve, and maximum possible surgeries per year per surgeon.

As already seen, the AFR status quo cataract-caused prevalence is forecasted to increase rapidly in the future. Turning to the HMS intervention scenarios on the graphs, there are two distinct phenomena displayed in each uptake scenario. In the years just after 2014, when HMS surgeons are beginning to practice, the practitioners are largely clearing the existing cataract-caused VI backlog.[6] The inflection points in the graph indicate when the surgical demand from already existing cataract patients is cleared. Note that this is not the same as clearing the entire backlog of cataract cases; rather it means that the share of existing cases that are willing to be operated on by HMS have received the surgery (20 percent, 50 percent, or 80 percent depending on the scenario). After this point, only those with new incidences of cataract-caused VI have a need for surgery, and the same fixed uptake share of these are assumed to demand surgery. For example, consider the 80 percent uptake scenario in the Africa region, shown in Figure 6.3a. Prevalence of VI falls rapidly as surgical capacity increases. By the year 2026, existing cases willing to have surgery have been addressed, so prevalence falls to about 16 percent of that of the status quo forecast. This 16 percent that remains are the people who are not willing to receive surgery. Given the assumption that blind and low-vision cases are treated in proportion to their numbers in the population, prevalence of blindness itself is also reduced to 16 percent of the status quo prevalence. For the years after 2026, 80 percent of the cataract-caused VI incidence cases (who do not receive surgery elsewhere) receive HMS surgery.

The same interpretation applies to the other uptake scenarios. Note that the inflection point comes much sooner under the 50 percent scenario than for 80 percent (and sooner under 20 percent than 50 percent). This is because the backlog of cases willing to be operated on is smaller, hence cleared faster by the same number of surgeons. The increase in the gaps between the prevalence lines for the different uptake scenarios as time progresses also arises from the differing uptake assumptions.[7] The figure demonstrates that if uptake is high, the HMS program would have the potential to dramatically reduce the future prevalence of VI in Africa. For 80 percent HMS uptake, prevalence in 2030 in Africa will be about 5 million cataract-caused VI (and about 1 million blind) as compared with more than 32 million cataract-caused VI (8 million blind) for the status quo scenario. Even with just 50 percent uptake, prevalence will be about half that under the status quo.

These calculations, however, assume that individual surgical practices will continue to be viable at whatever level of surgeries per practitioner is implied by the combination of uptake (demand) and the number of surgeons. We examine this assumption below.

Figure 6.3b displays the results for Latin America. Because the initial prevalence (before 2014) is much smaller than that in the AFR region, but the same supply of surgical capacity is assumed, the HMS intervention arrives at the inflection points much sooner for all uptake

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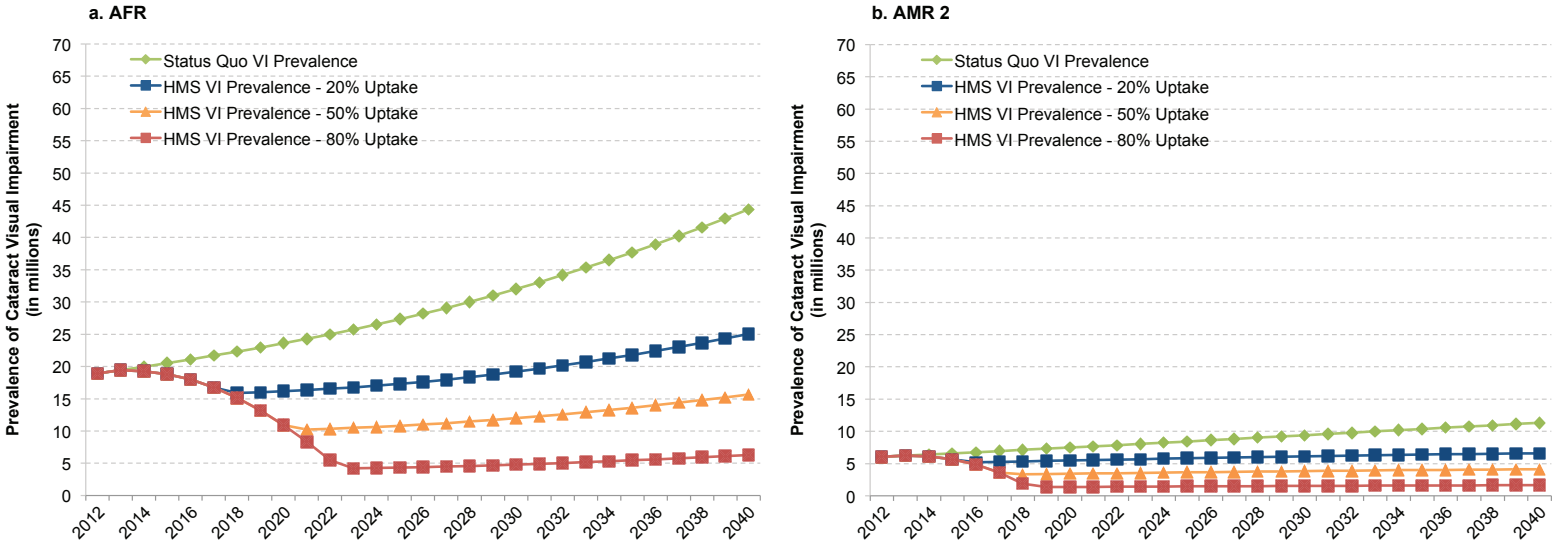
6 Mortality of individuals with cataract-caused VI also serves to partially "clear" the backlog of cases in the model.

7 Consider the AFR 80 percent uptake scenario. After its inflection point in 2026, 80 percent of all new cases will receive HMS surgery. The remaining 20 percent do not. Since fully 100 percent do not get HMS surgery under the status quo, incidence (unoperated new cases) in the 80 percent scenario is just 20 percent of the status quo incidence rate. In the AFR 50 percent uptake scenario, the inflection point is reached in 2022, after which 50 percent of incident cases receive HMS surgery. Hence the number of visually impaired non-operated people accumulates more rapidly than under the 80 percent uptake scenario, and the prevalence lines get further apart over time.

Figure 6.3
Cataract-Caused VI Prevalence for AFR and AMR 2, Status Quo and HelpMeSee Scenarios



rates. The reductions in prevalence are still large in proportional terms, but in absolute numbers the differences are small relative to Africa.

Figure 6.4 shows the cataract-caused VI forecasts for SEAR and WPR 2. The inflection points for both regions arrive much later than in AFR or AMR 2. This is due to the larger initial numbers of cases in these regions, so that it takes much longer to clear the backlog of cases willing to have surgery. For example, SEAR is forecast to have about 32 million people with cataract-caused VI (8 million blind) in 2012 whereas AFR will have about 19 million (5 million blind). Recall that we have assumed that HMS operates just one center in each region, with the same capacity (600 graduates per year). In practice, HMS expects to adjust the placement of centers and number of trained surgeons. Variations in the number of centers (or, possibly, their capacity) to suit regional needs would lead to a different picture.

In these two regions as well, with the rapid increase in surgeons assumed under the HMS scenarios, prevalence falls sharply relative to the status quo, especially for medium and high uptake. In SEAR, prevalence under both 80 percent and 50 percent uptake is about 27 million (7 million blind) in 2020 vs. 41 million (10 million blind) without HMS. By 2030, prevalence is reduced to 9 million (2 million blind) in the 80 percent scenario and 21 million (5 million blind) under the 50 percent scenario compared with 53 million (13 million blind) under the status quo (for 20 percent uptake it would be 34 million VI and 8 million blind). Similar, if slightly less dramatic, divergences are seen for WPR 2. Taking a global (four-region) view, with medium uptake (50 percent), HMS can reduce prevalence by 82 million cataract-caused VI cases (13 million blind) relative to the status quo in 2030.

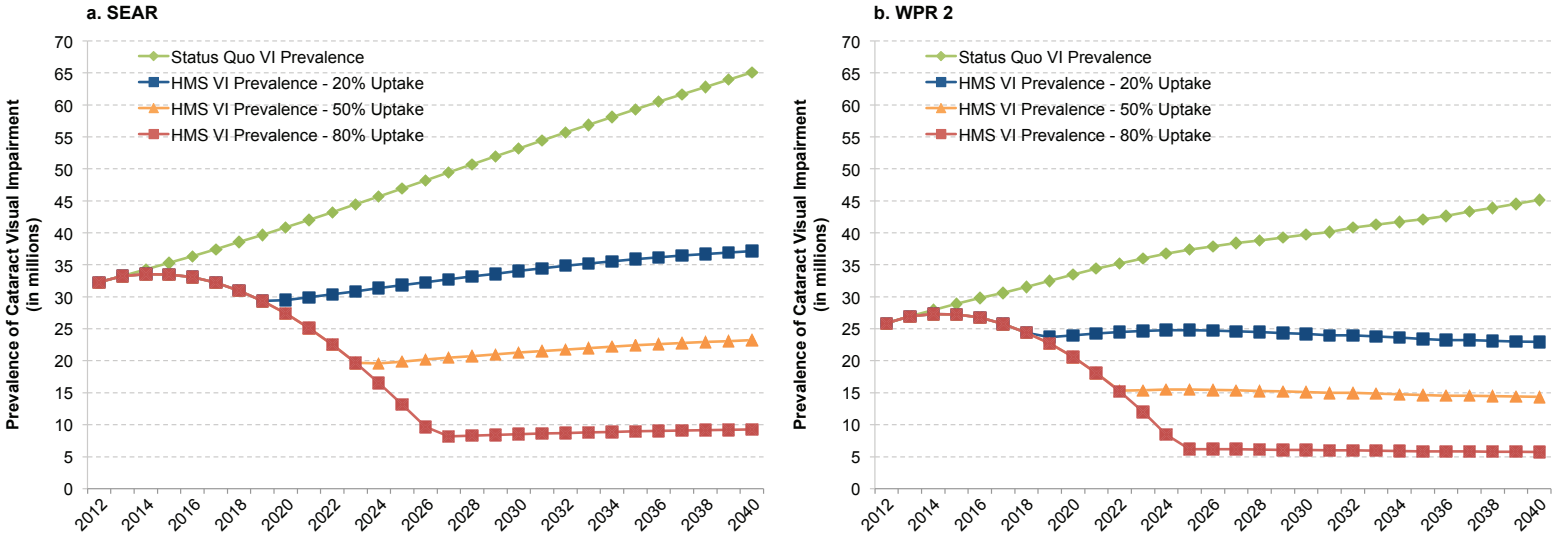
Sensitivity Analysis

Our estimates above already explore variation in assumptions about uptake. Here we consider the impacts on VI prevalence of different values for two other key assumptions in the model: rates of practitioner attrition and the annual intake of trainees. It is very hard to predict either of these factors with confidence: For example, we simply do not know whether each center will be able to attract 1000 qualified trainees per year in the initial years of the program. A shortage of donor resources would also make it difficult to reach these numbers.

For attrition, we examined the effects of increasing the rates at which practitioners quit their practices (or go out of business) from 5 percent annually to 10 percent and 15 percent. Results are shown in Appendix Figure B1. To keep the presentation simple, all the estimates assume a 50 percent uptake rate. Higher attrition does affect the number of years until the willing surgical backlog is cleared. In SEAR, for example, this point occurs in 2025 under 10 percent attrition (and in 2028 under 15 percent), compared with 2023 under the 5 percent assumption. However, once the backlog is eventually cleared and the main factor determining annual surgeries and hence prevalence is demand, attrition rates cease to make a difference. Again, this illustrates the importance of uptake rates for determining long run cataract-caused VI prevalence.

Appendix B, Figure B.2, shows the effect of varying the numbers of incoming trainees per center per year. We see essentially the same pattern as with higher attrition, in that a lower number of new trainees per year pushes back the date at which the willing surgical backlog is eliminated. Again, using SEAR as an example, taking in 500 trainees per year means that backlog is not cleared until 2029, six years later than in the 1,000 trainee case. Note that mathematically a reduction in the number of incoming surgical trainees is identical in effect to a reduction in graduation rates for a given number of incoming trainees: For example, cutting

Figure 6.4
Cataract-Caused VI Prevalence for SEAR and WPR 2, Status Quo and HelpMeSee Scenarios



the number of new trainees annually from 1,000 to 500 is equivalent to halving the completion rate from 60 percent to 30 percent. A noteworthy finding of this sensitivity analysis is that a slower building up of the stock of cataract surgeons does not reduce the ultimate ability of HMS to bring down the rates of cataract-caused VI to the minimum possible levels given demand; it only delays the attainment of that objective by several years.

Impacts on Disease Burden and Economic Productivity

In this section we present estimates of HMS impacts on disease burden as measured by DALYs and on economic productivity losses. The DALY and economic loss forecasts under different HMS uptake assumptions were calculated in the same way as for the status quo forecasts, as described in Chapter Five. Figures 6.5 and 6.6 display the DALY forecasts for the four regions.

The figures indicate by year the number of DALYs averted under HMS, that is, the difference in DALYs between HMS and status quo scenarios. This is a somewhat different measure than often reported in the literature, but it derives naturally from our use of prevalence rather than incidence DALYs. It is more standard to report the total DALYs averted as a result of an intervention over some period, typically ten years. We do this in Chapter Seven when we discuss the potential cost-effectiveness of HMS. For now, the figures give a sense of the potential benefits in terms of reduction in disease burden and how these differ across regions.

Similar to the prevalence forecasts, the DALY graphs have inflections at the points where the VI backlog (or the share of it willing to have HMS practitioner-performed surgery) is cleared. The HMS intervention in regions with larger starting (pre-HMS) DALY estimates take longer to arrive to the inflection points. The AMR 2 region has a much lower starting DALY estimate than AFR, SEAR, and WPR 2, due to the smaller VI prevalence in AMR 2. In WPR 2 and SEAR, where the disease burden is largest under the status quo, the HMS intervention would have the most impact in terms of averted DALYs.[8]

The economic productivity loss impacts, shown in Figures 6.7 and 6.8, show a similar pattern across regions and uptake assumptions.

As already seen in Chapter Five, under the status quo, SEAR and WPR 2 are forecast to have the greatest proportional economic productivity reduction due to cataracts in 2012, with WPR 2 thereafter rising faster due to faster projected economic growth. The annual percentage GDP losses averted by the HMS intervention are a function of the reduction in prevalence as well as the employment rate in a region. SEAR sees the most dramatic reductions in prevalence, which is reflected in a large benefit to GDP: For the 80 percent uptake scenario, the difference from the status quo in 2030 is about 0.6 of a percent of GDP in that year, or US$18 billion. For WPR 2, the GDP percentage gains are similar, reflecting high employment rates, but the absolute gains are much larger given the economic size of this region: GDP would be US$52 billion higher in 2030. For Africa, the percentage gains by 2030 are slightly less than 0.6 percent of GDP (US$9 billion) for the 80 percent uptake scenario.

[8] The difference in outcomes across scenarios (status quo, 20 percent, 50 percent, and 80 percent) is proportionately smaller than for VI prevalence itself in Figures 6.3 and 6.4 because the DALYs essentially assign a weight that is less than 1.0 to each VI case. This scales down the gaps between scenarios with different VI prevalence.

Figure 6.5
Forecasted AFR and AMR 2 Cataract-Caused DALYs, Status Quo and HelpMeSee Scenarios

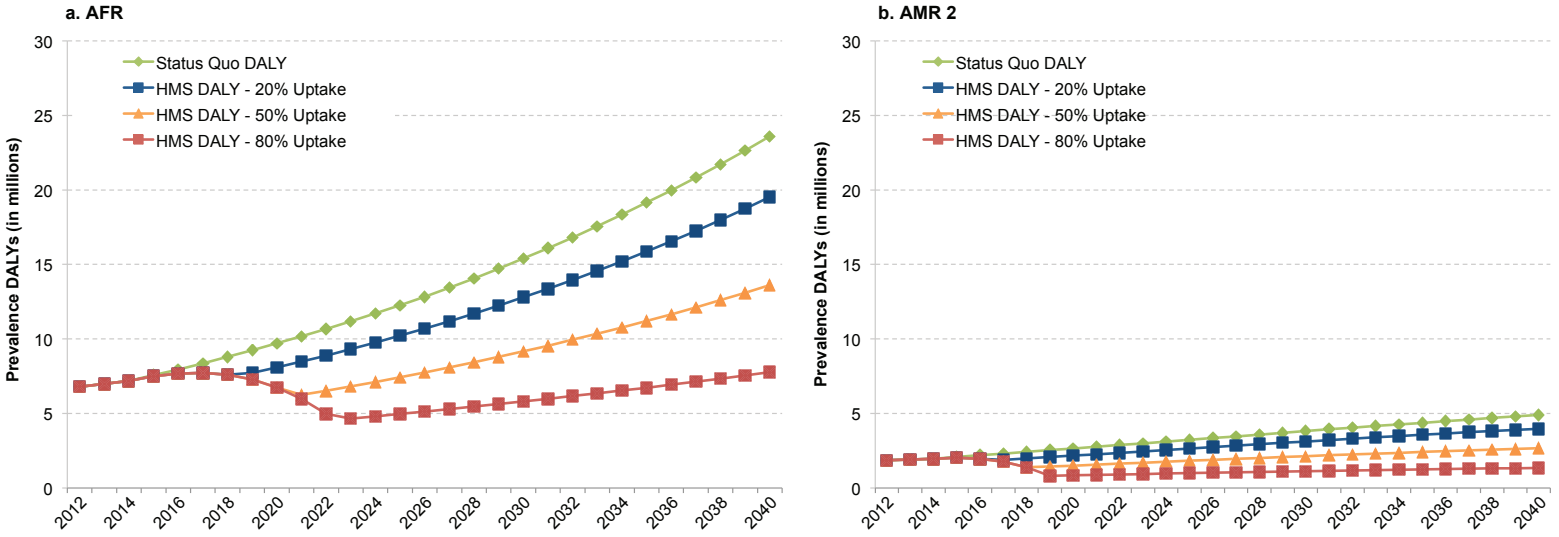


Figure 6.6
Forecasted SEAR and WPR 2 Cataract-Caused DALYs, Status Quo and HelpMeSee Scenarios

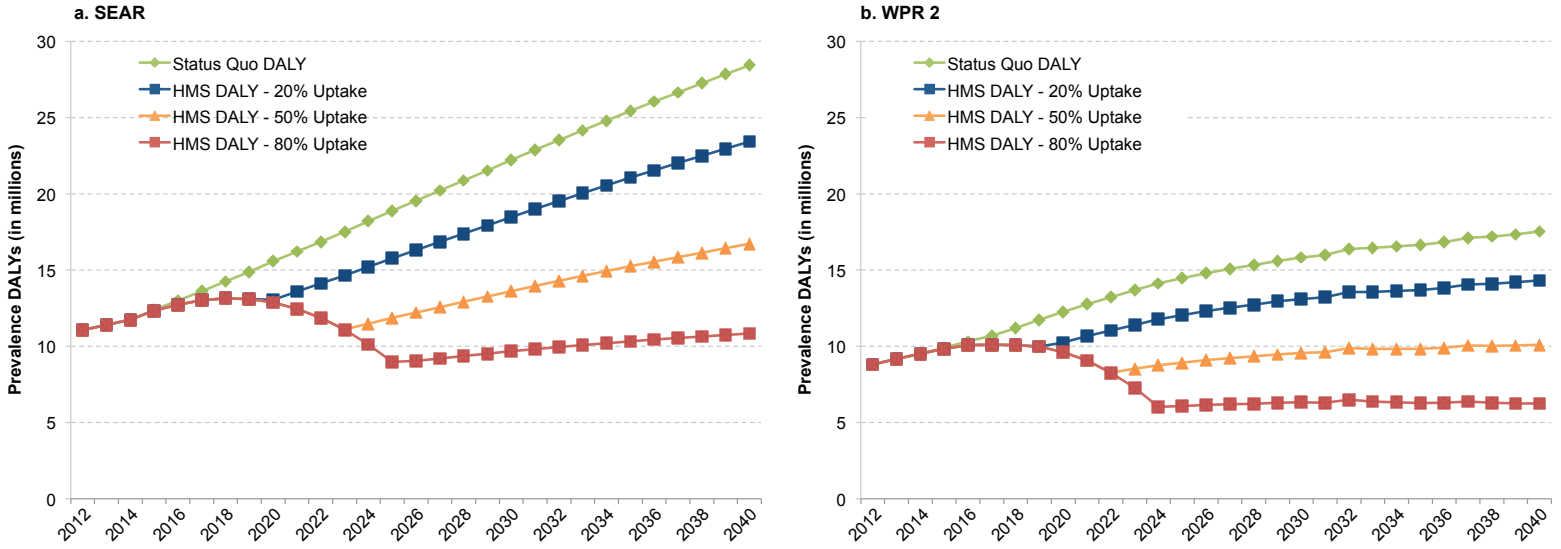


Figure 6.7
Economic Productivity Loss as a Percentage of Total GDP for AFR and AMR 2, Status Quo and HelpMeSee Scenarios

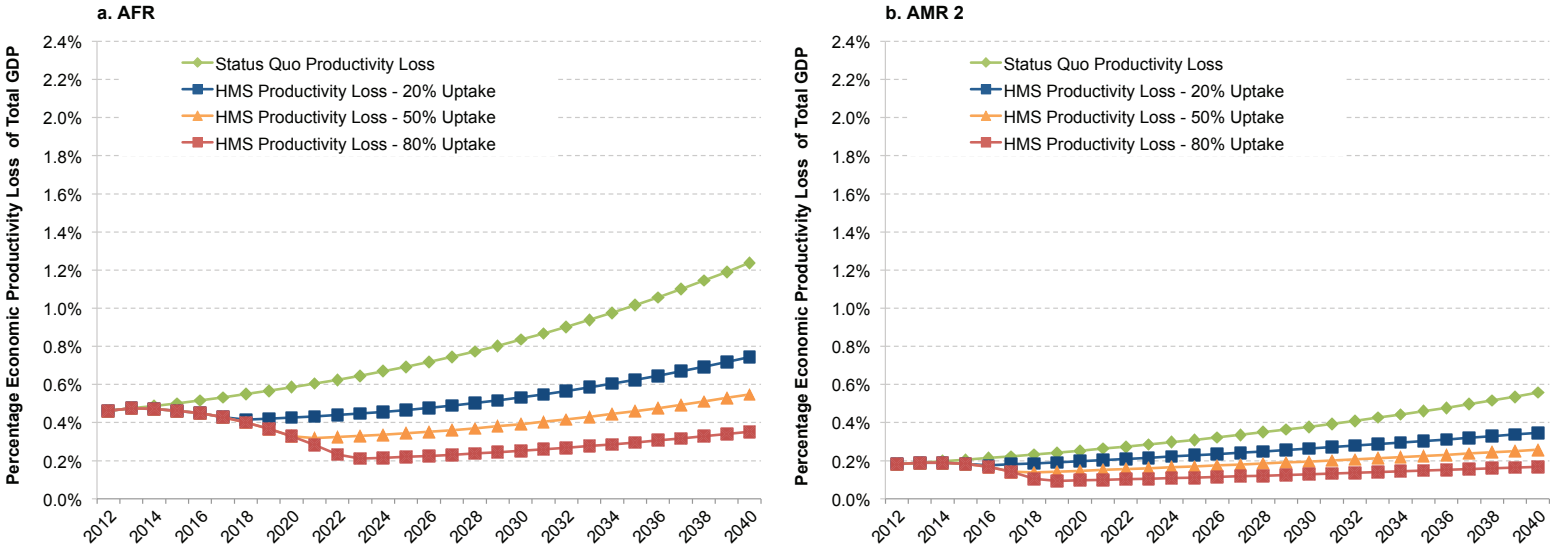
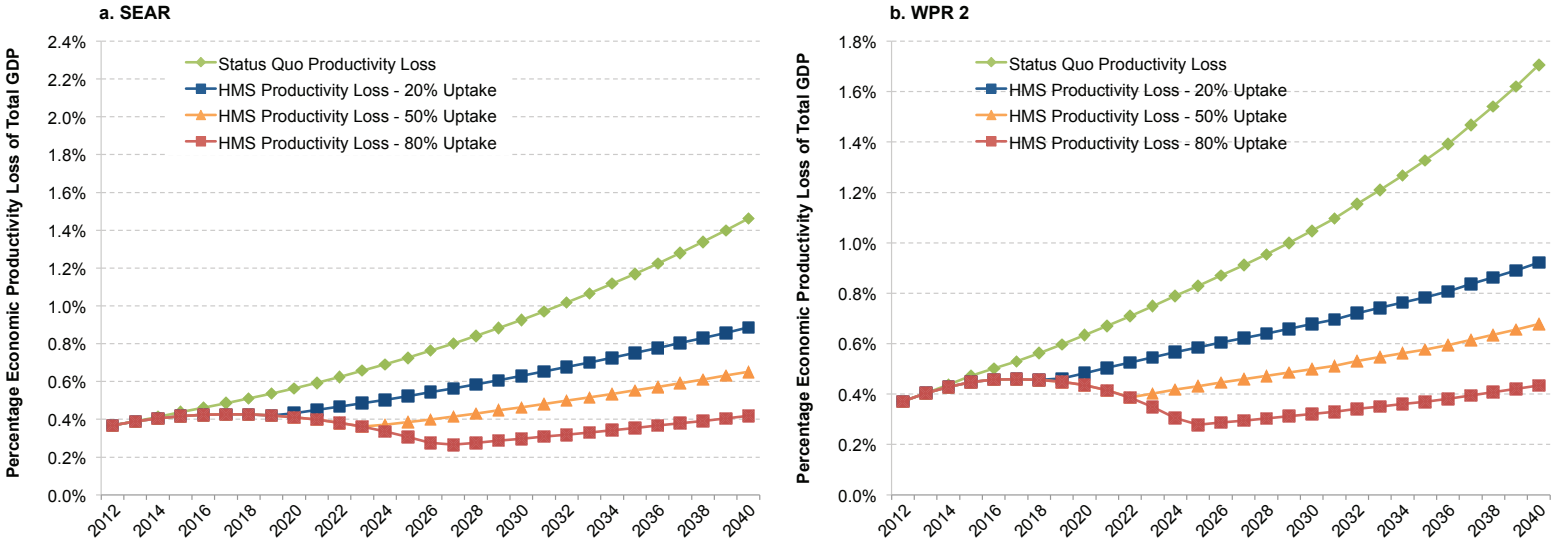


Figure 6.8
Economic Productivity Loss as a Percentage of Total GDP for SEAR and WPR 2, Status Quo and HelpMeSee Scenarios



Implications for the Viability of Individual Practices

The estimates above demonstrate that HMS learning centers have the potential to rapidly scale up capacity to deliver cataract surgeries, and that if uptake rates for these services are high or even in middle range (50 percent), there could be very large impacts on cataract-caused VI into the future. What the results presented so far do not show, however, is what this implies for the individual surgeon practitioners in terms of the potential number of surgeries they are able to perform—and based on that, the likely sustainability of their practices. We examine this issue here.

Figures 6.9 and 6.10 show the average number of surgeries per year per practitioner for the four regions. The number of surgeries per practitioner initially increases for any uptake assumption. This occurs because the number of surgeons is still increasing to the target number, and in effect, supply is less than demand (also, in the first few years, all surgeons are recent graduates, thus performing fewer than the eventual maximum number per year). Even at its peak, the average number of surgeries per practitioner per year falls short of the assumed 2,000 maximum. The main reason for this is that the stock of practitioners in any year is composed of lesser and more experienced surgeons, and those with fewer than four years of experience are not yet operating at their ultimate potential in terms of quantity.

A dramatic reduction in the annual number of surgeries per surgeon occurs once the backlog of existing cases is "cleared"—or more precisely, once all those with existing cataract-caused VI cases who are willing to be operated on by HMS have had surgeries. As indicated earlier, the share of the total backlog that is cleared, and when this happens, depends on the uptake assumption. Given the limits on surgical capacity, this process takes longest under 80 percent uptake because there are more patients seeking surgery. Once these cases have been taken care of, demand comes only from new (incident) cases and is much lower, as well as more steady over time. The number of operations performed per year per surgeon after this point will be higher for higher uptake scenarios, as a higher share of the new cases will demand surgery. It is important to keep in mind that the HMS uptake from new cases is not the total surgeries on incident cases, as it does not include surgeries performed by non-HMS providers, which is incorporated in the model.

When this turning point arrives depends not only on uptake rate but also on the ratio of surgeons to population and on prevalence rates. In SEAR, under 80 percent uptake, the "willing to be operated on" backlog is not cleared until around 2028. After that point, each surgeon would still perform close to 400 operations per year on average given the greater population per surgeon and higher incidence of new cases in this region. In Latin America, in contrast, the turning point comes some ten years sooner, and given low incidence, the number of cases per surgeon becomes very small.

These projections are somewhat crude, as in reality the drop-off would not be as sudden as depicted. Nonetheless, they point to a potential conflict between, on the one hand, the desire to turn out a large number of new cataract surgeons as rapidly as possible to close the cataract backlog, and, on the other, the need to ensure that these practitioners will have steady demand for their services into the future. Whether uptake is high or low, all existing cataract patients who are able and willing to receive surgery will have done so within a certain number of years (sooner if uptake is low). After this point, demand falls off sharply because new patients only come from new or incident cases (and HMS and other providers must share this smaller number of surgeries). For HMS practices to maintain demand for their surgical

Figure 6.9
Average Number of Surgeries per Practitioner for AFR and AMR 2

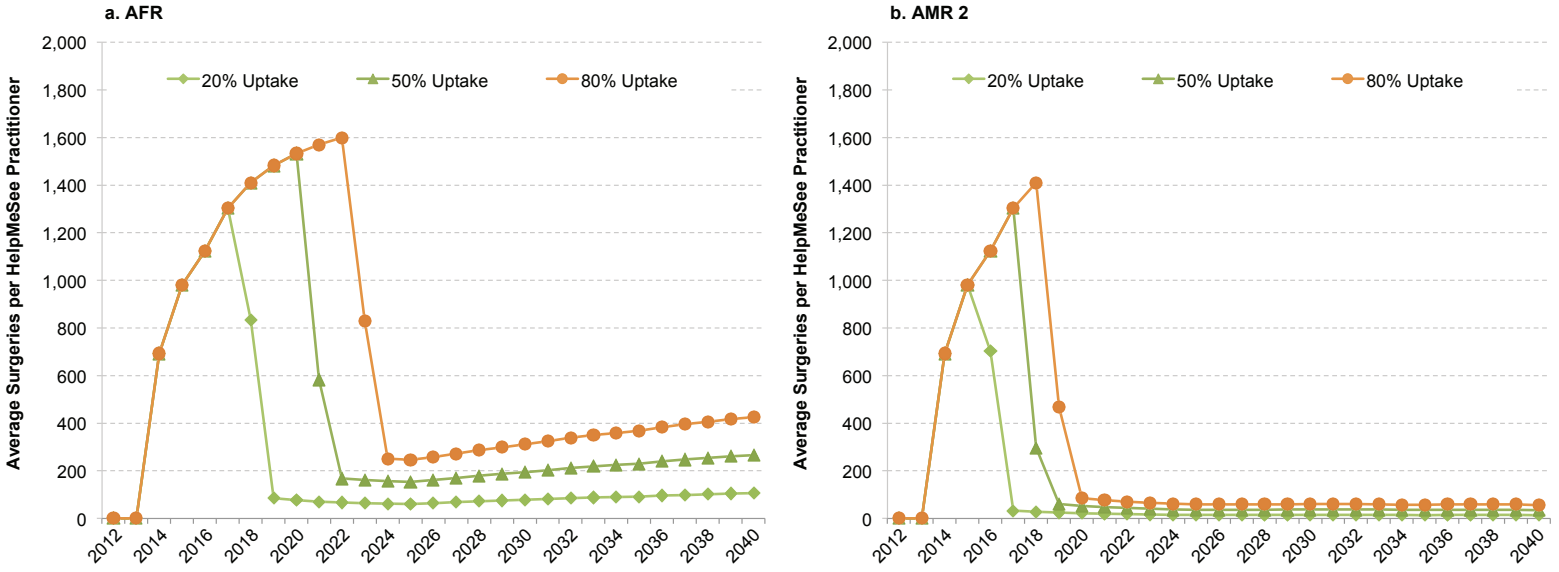
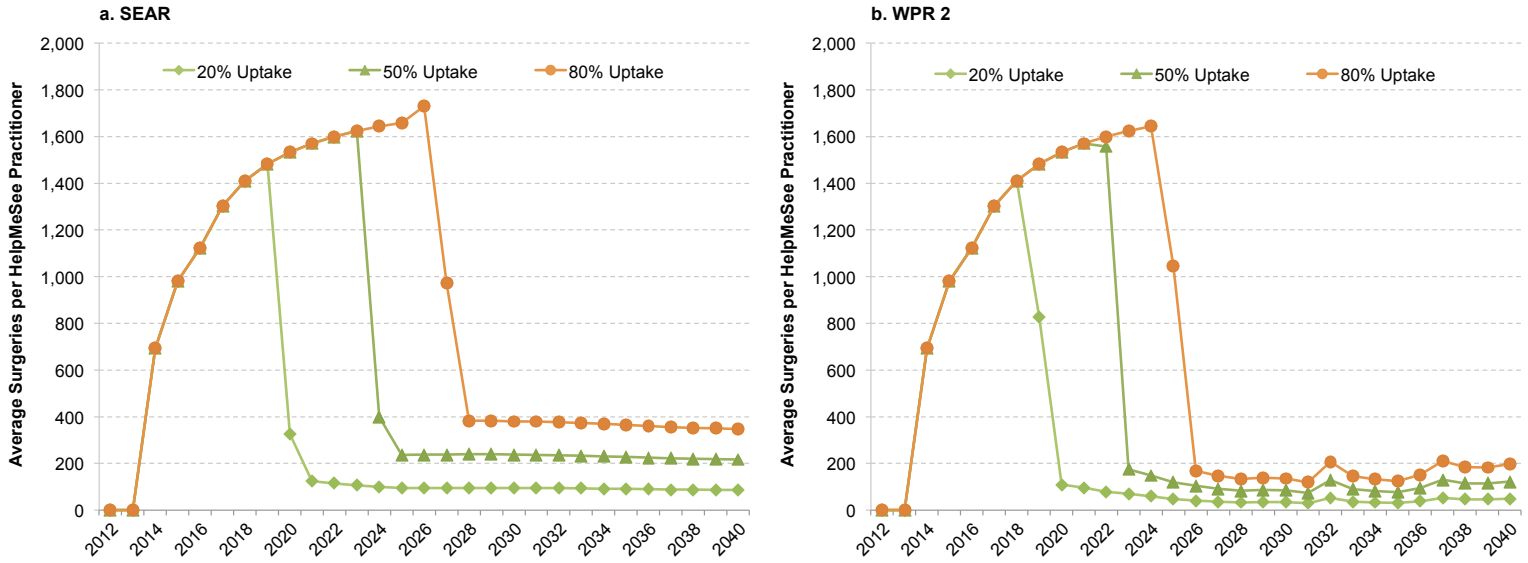


Figure 6.10
Average Number of Surgeries per Practitioner for SEAR and WPR 2



services, demand will have to increase substantially from individuals who have cataracts but do not yet have low vision (by the WHO criterion used in the forecast model to define the VI population). In developed economies, the vast majority of individuals with cataracts do seek surgery before severe VI sets in. We discuss the potential for this in developing countries in Chapter Eight.

Summary

This section examined the potential impacts of the HelpMeSee approach, considering the following outcomes: number of trained MSICS specialists; surgical capacity, or the total number of surgeries per year that can be performed in the HMS system; and actual surgeries performed and the impacts on cataract-caused VI. We find that, under HMS's assumptions about costs and training capacity and the availability of resources, the program will have the capacity to scale up cataract surgical capacity very rapidly, given the speed with which the simulator training produces surgeons. Assuming medium uptake (50 percent), HMS has the potential to substantially reduce prevalence by 82 million cataract-caused VI cases (including 13 million blind) in the four regions relative to the status quo in 2030.

By reducing cataract-caused VI, the program potentially will have significant impacts in the future on economic output. This reflects the large expected losses to national income of cataract-caused VI under the status quo. Further, under the same assumptions about HMS's expansion of surgical capacity, the program can also have very large impacts on DALYs: Over the ten-year period from 2014 to 2023, for uptake of 50 percent, about 16 million DALYs would be averted in Africa, 17.5 million in Southeast Asia, 16 million in the Western Pacific, and 7 million in Latin America.

Once the large supply of surgeons has been built up, the effects on VI prevalence and other outcomes will be determined mainly by the level of demand or uptake. The modeling suggests the potential for an oversupply of surgical capacity (and surgeons) once the cataract surgery backlog is eliminated or reduced as much as it can be, given uptake rates. At this point surgeons must rely solely on new cases of cataract-caused VI, possibly supplemented by increasing demand from those with less serious cataracts.

CHAPTER SEVEN

Analysis of Costs and Cost-Effectiveness

This section considers the costs of the HelpMeSee program and provides estimates of cost per surgery under different assumptions about uptake. We make use of detailed cost information provided to us by HMS. It is important to note that the findings depend on the validity of these cost assumptions. We compare HMS unit costs to those for Aravind, using information provided to us by Aravind for one of its main hospital centers, in Coimbatore, Tamil Nadu. We than calculate cost-effectiveness for HMS by combining the cost information with estimates of DALYs averted by the intervention.

Costs

Costs of HMS include startup costs (including both initial development and capital investments) and annual operating costs. It should be kept in mind that we are considering both the costs of the simulator training and the costs of providing surgeries. We have subdivided these costs into six groups:

- development of the simulator training hardware and software and associated curriculum development
- training center startup cost
- training center annual operating cost
- practitioner service delivery startup costs
- service delivery salary costs
- service delivery operating costs of surgical supplies.

Detailed HMS cost information is presented in Appendix B for these categories. HMS costs are incurred by HMS directly, the host country (which is expected to contribute the land and other tangible support for the learning center), or the practitioner. The startup and operating costs of the practices are defined as "practitioner costs" although in fact much of the initial costs will be financed by HMS, and, as indicated, surgeons will be paid on a fee-for-service basis by HMS for surgeries performed. For the purposes of our analysis, the ultimate bearer of the costs is not as important as ensuring that all relevant costs (costs to society) of the intervention are captured; the division into HMS and practitioner (and host country) costs is a convenient way of distinguishing costs by type.

For the initial cost to HMS (or its donors) of developing the simulator and the associated courseware and curriculum, we used HMS's estimate of US$25 million. Lacking any

standard guide, we annualize these research and development costs over 25 years, though we note that unit costs for surgery were not significantly affected by assuming different periods. Since we are estimating costs per regional center, we divided this cost evenly across the four regions. It might plausibly be argued that this investment will have many benefits beyond the use of simulators in the four regions covered in our analysis, including surgeon training in developed countries and spillovers into training for other types of surgery. While these potential returns should be factored into the benefits in our analysis, they would be exceedingly difficult to predict. Ultimately, inclusion of development costs did not greatly add to unit surgery costs, since this large expenditure is allocated over a very large number of surgeries over many years.

We note that, as in most such analysis, we do not attempt to include private costs incurred by patients and their families, such as transportation costs or lost earnings of the patient or caregiver incurred when seeking surgery. It is also important to note that we assume that the costs of each HMS-trained MSICS practitioner are the costs of operating an independent practice and other service delivery costs (provided to us by HMS). In reality, some graduates are expected to work for other organizations; for example, some ophthalmologists may already be working in hospitals and will stay with these providers. Clearly, assuming their costs (and costs per surgery) are the same as for independent practitioners is not correct. However, without accurate information on what the costs might be in the various locations these surgeons will work in—as well as the share of graduates who do not work as independent practitioners—we will rely on this assumption.[1]

HMS provided us with highly detailed estimates of the costs in the categories listed above, based on its own knowledge and consultations with experts. HMS was generally not able to obtain region-specific costs of each input into cataract training and surgery. Most supplies (e.g., lenses, microscopes) are freely traded internationally so prices do not vary significantly by region. For items such as land, buildings, and labor (e.g., nurses), which are not traded, significant price differentials may exist across countries and regions. We adjusted for regional differences by treating the provided costs as average costs over the four regions and adjusting for region using published estimates of relative costs across regions, making use of the estimates in Mulligan et al. (2003).

As is standard in cost-effectiveness studies such as ours, all costs in this section are expressed in international dollars (I$), unless otherwise indicated, to facilitate comparison of costs in different countries or regions. Costs in local currency units are converted to international dollars using purchasing power parity (PPP) exchange rates. Unlike market exchange rates, the PPP exchange rate shows the numbers of units of a country's currency needed to purchase, in that country, the same amount of goods and services that US$1 would buy in the United States. That is to say, an international dollar has the same purchasing power that the

[1] A separate problem is that if one is trying to project the financial sustainability (or alternatively, resource needs) for HMS as an organization, it is important to know what share of the new surgeons will actually require financial support from HMS. The more who do not (i.e., who work in other organizations), the lower the annual costs to HMS. However, our focus here is first, on unit costs of surgery for private practitioners, which would not be affected by the share of graduates not going into private practice. Second, we are interested in the cost-effectiveness of the HMS program. In contrast to the question of financial sustainability, here we do want to count all the costs of providing surgeries by HMS trained specialists, whether they are incurred by HMS or another organization (or patients). That is, all costs to society must be considered, as noted. In this analysis we assume for simplicity that the costs are similar across different delivery approaches.

U.S. dollar has in the United States, and as a result, costs from different countries expressed in international dollars are directly comparable (See Appendix C for more discussion).

The fact that the cost data obtained from HMS are not region specific, as just discussed, means that a number of additional steps and assumptions have to be made to derive regional cost estimates in international dollars. These steps are detailed in Appendix C. It should be noted here, however, that because numerous assumptions about costs are used in the calculations, it is appropriate to treat the estimates discussed in this section as very preliminary.

The cost per surgery for HMS in different regions depends significantly on the number of surgeries performed. As the number of operations increases, fixed costs associated with setting up training centers as well as individual practices are spread over more surgeries, reducing unit costs. Each practitioner also has annual operating costs such as rent and staff salaries that are spread over whatever number of surgeries they perform. The total number of surgeries depends on (1) the number of surgeons in practice, which increases sharply for a number of years while each learning center is working toward the goal of 7,500 surgeons graduated, and (2) the level of demand or uptake for HMS surgery services. Given these considerations, we calculate unit costs for each region by year and uptake assumption. Following WHO guidelines (Tan-Torres Edejer et al., 2003), startup costs for both the HMS learning centers and the individual practices are annualized over the first ten years of the project using a 3 percent interest rate. Detailed data for these calculations are presented in Appendix B.

Table 7.1 displays the costs per surgery delivered for the four regions and three uptake scenarios over the period.

A general pattern is that cost per surgery falls over time in the first several years of the program, as the annualized value of the large fixed costs are spread over a growing number of surgeries. The number of surgeries increases as more surgeons are trained and also as each

Table 7.1
Cost per Surgery Delivered by HelpMeSee by Region, Year, and Uptake Assumption (international dollars)

Region	Uptake	Year									
	(%)	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
AFR	20	182	114	96	83	115	921	1,000	1,064	1,117	1,152
	50	182	114	96	83	77	73	71	149	460	474
	80	182	114	96	83	77	73	71	69	68	110
AMR 2	20	319	195	246	4,494	5,285	6,031	6,808	7,354	7,945	8,537
	50	319	195	162	138	518	2,426	2,736	2,955	3,191	3,428
	80	319	195	162	138	126	332	1,718	1,855	2,003	2,151
SEAR	20	156	95	79	69	64	61	195	471	500	531
	50	156	95	79	69	64	61	59	57	56	56
	80	156	95	79	69	64	61	59	57	56	56
WPR 2	20	195	112	91	78	71	103	625	697	839	921
	50	195	112	91	78	71	67	65	63	63	382
	80	195	112	91	78	71	67	65	63	62	61

new practitioner increases the number of operations he or she is capable of performing per year until they reach the maximum after four years post training. In the early years, even with low (20 percent) uptake, the limiting factor is still supply relative to demand, so unit costs are driven solely by the increase in surgical supply.

Eventually, however, demand limitations are realized as the VI surgical backlog is cleared (or rather, as the share of the backlog that is willing to have surgery is cleared). In SEAR, this does not occur before 2023 except if uptake is low (20 percent); hence in the 50 percent and 80 percent scenarios, unit costs continue to fall to as low as I$56. A similar pattern is seen in WPR 2, although unit costs are higher due to higher resource costs such as salaries in that region.

In contrast, the turning point comes sooner in AMR 2, given low prevalence, so per-surgery costs quickly rise to very high levels. In AFR, this occurs by 2022 in the 50 percent uptake scenario. Obviously, these patterns in unit costs are mirroring the patterns over time in surgeries per surgeon seen in Chapter Six. If the table were extended to later years, unit costs would eventually rise to high levels in each region for all uptake assumptions.

Two points emerge from this exercise. First, based on HMS assumptions about costs of training and supporting practitioners, relatively low per-surgery unit costs can be achieved in the model, for an initial period whose length depends largely on level of uptake. Second, after the "willing to be operated on" backlog is cleared, unit costs rise sharply as demand comes solely from incident cases. It should be noted that this assumes that the practitioners are being supported so as to cover their operating costs (such as salaries) even if the number of surgeries they perform is low. More realistically, rather than covering operating costs for these surgeons indefinitely, after some point HMS will pay practitioners only on a fee-per-surgery basis. This would serve to prevent the sharp increases in unit costs observed in the table as demand for surgeries per practitioner declines; at least, the cost per surgery incurred by HMS would not rise sharply in this scenario since it would be paying a fixed price per surgery. However, if practitioners were to remain in business while carrying out fewer surgeries, they would still need to cover their costs for the rest of their time, perhaps by performing other vision-related services. Note also that the model does not incorporate demand from those with cataract-caused VI below the WHO threshold for poor vision. As discussed below, this would serve to increase the number of surgeries per practitioner, which would keep unit costs relatively low even once the initial backlog is cleared.

How do these per-surgery costs compare with estimates for other cataract surgery systems? Some of the studies cited in Chapter Two report very low unit costs—sometimes less than US$20—far lower than the figures in Table 7.1. However, these estimates are not fully comparable to those we present here. First, some of them do not use PPP exchange rates to convert to international dollars, and using PPP as we do here tends to increase the cost relative to simply converting all costs to dollars using market exchange rates. Second, our HMS estimates include the complete costs of training surgeons, which are not included in other estimates, as well as program costs, which are also often omitted. Training costs are expected to be significantly lower in the HMS model because of the use of the simulator. (We were not able to get costs of training in MSICS or other techniques for other systems.) More broadly, one could argue that for the other training and delivery systems that train only ophthalmologists in cataract surgery, the costs of prior general medical training for these individuals must be considered. To the extent that HMS trains nonmedical professionals, these prior costs would not be relevant in the HMS model. Or, to the extent that HMS trains medical personnel that

are not doctors (e.g., ophthalmologist nurses), the prior training costs would be lower than for doctors.

We are also able to compare HMS costs to those for Aravind, using the information on costs and surgeries performed for the hospital in Coimbatore provided to us by Aravind.[2] The estimated cost per surgery in Coimbatore is as follows:

- Hospital startup cost: I$19.16
- Hospital operating cost: I$104.18
- **Total cost per surgery: I$123.34.**

These estimates include annualized costs of land, buildings, and equipment, as well as operating costs. Since we only have the current value of capital, we had to make several assumptions to derive an annualized value for them; these and other aspects of the calculations are described in Appendix C. Since Coimbatore hospital provides a range of vision care in addition to cataract surgery, we allocated a portion of each type of cost to cataracts based on estimates from Aravind. The costs include training in cataract surgery conducted at the hospital as well as surgeries themselves. As with the HMS figures above, costs are in international dollars unless otherwise indicated, using rupee-dollar PPP exchange rates for nontraded inputs.

This Aravind eye hospital performs approximately 53,000 cataract surgeries per year. The I$123 per-surgery cost at Coimbatore is most appropriately compared with our HMS estimates for the SEAR region that includes India. For the years 2015 to 2020, the figure is substantially higher than the HMS cost per surgery; after that time, at least for the low uptake scenario, the drop in demand starts to increase per-surgery costs for HMS, again on the assumption that practitioners continue to be in business and have their costs covered by HMS. It is important to point out that some 75 percent of Aravind's surgeries are more expensive PHACO procedures. These raise unit costs substantially, but at the same time provide revenue from wealthier patients to support MSICS surgeries for poorer patients. Hence the comparison with HMS in part is capturing differences in the costs of the two procedures. Given this consideration and the difficulties noted above with respect to interpreting Aravind's cost data, the comparison, while suggestive, should be treated cautiously.

Cost-Effectiveness Analysis

Impact of HelpMeSee on Disability Adjusted Life Years and Productivity Loss

Tables 7.2–7.5 show DALYs averted and the economic productivity loss–averted estimates across uptake scenarios for the ten-year period 2014 to 2023. When summarizing impacts that are distributed across time into the future, it is standard to discount them back to their present value using a rate that ultimately should capture society's higher valuation of costs or benefits occurring now relative to those occurring in the future (hence this rate is called the "social dis-

[2] We are grateful to R.D. Thulasiraj and Deepa Krishnan for providing this information and for discussions about these data.

Table 7.2
Projected DALYs and Economic Productivity Loss Averted by HelpMeSee: AFR

Uptake (%)	Type	Discounted 10-Year Disability Adjusted Life Years (Millions of DALYs)	Discounted 10-Year Economic Productivity Loss (Billions of US$)
0	Status Quo	78.8	58.86
20	HelpMeSee Intervention	70.0	46.20
	Averted	**8.8**	**12.65**
50	HelpMeSee Intervention	62.9	40.93
	Averted	**16.0**	**17.93**
80	HelpMeSee Intervention	59.8	38.43
	Averted	**19.0**	**20.42**

NOTE: Averted equals the difference between status quo and HMS outcomes.

Table 7.3
Projected DALYs and Economic Productivity Loss Averted by HelpMeSee: AMR 2

Uptake (%)	Type	Discounted 10-Year Disability Adjusted Life Years (Millions of DALYs)	Discounted 10-Year Economic Productivity Loss (Billions of US$)
0	Status Quo	21.6	91.81
20	HelpMeSee Intervention	18.5	74.54
	Averted	**3.1**	**17.27**
50	HelpMeSee Intervention	15.0	61.26
	Averted	**6.6**	**30.55**
80	HelpMeSee Intervention	12.2	50.38
	Averted	**9.4**	**41.43**

NOTE: Averted equals the difference between status quo and HMS outcomes.

Table 7.4
Projected DALYs and Economic Productivity Loss Averted by HelpMeSee: SEAR

Uptake (%)	Type	Discounted 10-Year Disability Adjusted Life Years (Millions of DALYs)	Discounted 10-Year Economic Productivity Loss (Billions of US$)
0	Status Quo	126.9	115.86
20	HelpMeSee Intervention	114.9	95.96
	Averted	**12.0**	**19.90**
50	HelpMeSee Intervention	109.4	90.16
	Averted	**17.5**	**25.70**
80	HelpMeSee Intervention	109.4	90.16
	Averted	**17.6**	**25.70**

NOTE: Averted equals the difference between status quo and HMS outcomes.

Table 7.5
Projected DALYs and Economic Productivity Loss Averted by HelpMeSee: WPR 2

Uptake (%)	Type	Discounted 10-Year Disability Adjusted Life Years (Millions of DALYs)	Discounted 10-Year Economic Productivity Loss (Billions of US$)
0	Status Quo	100.3	350.38
20	HelpMeSee Intervention	90.1	287.07
	Averted	**10.2**	**63.31**
50	HelpMeSee Intervention	83.9	263.04
	Averted	**16.4**	**87.34**
80	HelpMeSee Intervention	82.9	260.13
	Averted	**17.4**	**90.25**

NOTE: Averted equals the difference between status quo and HMS outcomes.

count rate"). We discount both DALYs and productivity losses using a 3 percent discount rate following common practice in the literature.[3]

These tables demonstrate that the HMS intervention may avert large numbers of DALYs for AFR, SEAR, and WPR 2. When considering the dollar value of economic productivity loss averted, the impact in WPR 2 is several times greater than that of the next highest region, AMR 2. From these results, we estimate that a 50 percent uptake HMS intervention in WPR 2 would avert 16.4 million DALYs and US$90 billion dollars of economic productivity loss.

Cost-Effectiveness of the HelpMeSee Intervention

Cost-effectiveness is defined as the cost of averting one DALY, or equivalently, of gaining one year of healthy life. Using the calculations in the previous table and our information on HelpMeSee costs, Table 7.6 displays costs per DALY averted. These estimates are derived by dividing the value of the costs by the DALYs averted over the first five and ten years of the HMS intervention, with future costs and DALYs discounted as described above.

Table 7.6
Cost-Effectiveness of HelpMeSee: Estimated Cost per DALY Averted over Five and Ten Years (in I$)

Region	5 Years Uptake			10 Years Uptake		
	20%	50%	80%	20%	50%	80%
AFR	360	375	375	213	134	124
AMR 2	1,030	693	726	1,057	515	371
SEAR	333	333	333	134	114	114
WPR 2	386	386	386	174	129	129

NOTE: Future costs and DALYs discounted using 3 percent discount rate.

[3] Note that when we present costs or impacts for specific years in the future, as in Table 7.1, we do not discount. This presents a clearer picture of the patterns of actual costs or impacts over the years.

Table 7.6 presents a five-year horizon as well as the standard ten-year horizon, both starting in 2014. Cost-effectiveness is much higher (cost per averted DALY lower) in the ten-year perspective. This is because the impacts on DALYs are cumulative. Also, the level of uptake (20, 50, or 80 percent) generally matters little over the first five years because in most cases the number of surgeries (and thus, unit costs) is constrained not by demand but by the still limited supply of surgeons, as described earlier.

For three regions—SEAR, AFR, and AMR—cost-effectiveness estimates are somewhat lower (that is, costs per averted DALY are higher) than in earlier cost-effectiveness analysis of cataract surgery such as the major study by Baltussen et al. (2004). For example, Baltussen et al.'s estimates of cost-effectiveness for SEAR range, under various assumptions, from about I$57 to I$116. For HMS, over a ten-year interval, cost-effectiveness is I$114 to I$134, depending on uptake assumption. For WPR 2, the estimates for HMS are broadly similar to those of Baltussen et al. It should be kept in mind that our prevalence-based approach to calculating DALYs may affect comparability to earlier studies.

A standard threshold for describing an intervention as cost-effective is if the cost of gaining a year of healthy life (averting one DALY) is less than three times the per capita national income (WHO Commission on Macroeconomics and Health, 2001). Baltussen et al. (2004) further suggest calling an intervention "very cost-effective" if the cost of averting one DALY is less than the per capita income. By this standard, the HMS intervention is clearly very cost-effective over the first ten years. For example, for the ten-year period, cost per DALY for AFR ranges from I$124 to I$213 depending on uptake; this compares to per capita GDP for sub-Saharan Africa of I$2,258 in 2010 using PPP exchange rates (World Bank online statistics). The criterion is easily met for the other three regions as well.

It is important to keep in mind that while cost-effectiveness appears high over the ten-year period (2014–2023), in some cases this is before the backlog cases are cleared, hence before demand limitations start to reduce surgeries per surgeon and thus raise costs per surgery (and consequently, increase the cost per DALY averted). In other cases, depending on region and uptake assumption, that process has started but is still outweighed by the impacts of cumulating DALYs. Further out into the future, the HMS program, if it continued to financially support the same number of full-time practitioners, would seem significantly less cost-effective.[4]

Summary

This chapter considered the costs of the HelpMeSee program and estimated the cost per surgery under different assumptions about uptake. Cost per surgery varies depending on regional differences in input costs and on assumptions about uptake, which determines how costs such as training and annual salaries are spread over surgeries. Costs per surgery fall rapidly in the first several years of the program as the large fixed costs are spread over a growing number of surgeries and as the practitioners become more productive. They rise after the willing surgical backlog is cleared and the annual number of operations decline. Because of differences in assumptions and in the costs that are included, comparisons with published estimates of unit

[4] As discussed below in Chapter Eight, it may be possible, after the backlog is cleared, for practitioners to turn from full-time to part-time cataract surgery practice while also supporting themselves with other eye-related services. In this case, there would not be a need to support their full salary costs in the face of declining demand. The cost per surgery therefore would not rise to the extent shown in the figures.

costs are difficult. However, we compared HMS unit costs to those for Aravind, using information provided to us by Aravind for one of their centers in Coimbatore. With due considerations to comparability issues, the per-surgery cost at Coimbatore appears higher than the HMS cost per surgery for the period 2015–2020, after which falling demand increases unit costs for HMS, on the assumption that all practitioners stay in business and have their costs covered by HMS.

Cost-effectiveness analysis, combining cost information with estimates of DALYs averted by the intervention, indicates cost per DALY averted ranging from I$114 in Southeast Asia to I$515 in Latin America. This is well below the per capita GDP in the same regions, suggesting that the HMS intervention could be very cost-effective. In later years, however, this conclusion may not hold as costs per surgery rise due to falls in demand as the surgery backlog is closed or reduced.

CHAPTER EIGHT

Potential Challenges to the HelpMeSee Approach

The modeling analysis in the previous two sections showed that, under HelpMeSee's assumptions about costs and training capacity, the program would have the capacity to rapidly scale up cataract surgical capacity. Under optimistic assumptions about uptake, this capacity can largely close the backlog of surgical cases, and even under less optimistic assumptions, it can significantly lower prevalence of cataract-caused VI relative to the status quo.

It is equally important to consider possible obstacles to the success of the HMS approach, and we now turn to this topic. With the exception of the problem of excess surgical capacity that may emerge once the backlog of cases is taken care of, the formal modeling is not well suited to evaluate these issues. Instead, the issues discussed below arise from evidence on existing (if quite different) cataract surgery models around the world and from discussions with experts in the field.

Mobilization and Screening

Mobilization (education and marketing of cataract surgery to the population) and screening (testing for cataracts and referring for surgery) make up two of the three basic components of cataract surgery systems, the third being the surgery itself. The literature points to the importance of aggressive outreach to increase uptake of screening and cataract surgery among poor populations. The review of successful high-volume cataract models in Chapter Three suggests several common elements to these models. First, outreach efforts and screening are organized on a large scale and use medical professionals such as ophthalmic nurses to screen definitively for cataracts. Approaches include outreach coordinated with local organizations combined with screening camps, as in Tilganga and Aravind, or highly organized referral systems using the local health infrastructure, as in Project Vision and He Hospitals. Second, the provision of surgery is often directly linked to the screening. This occurs either through convenient—and often free—transportation from the screening location to surgery, as in Aravind and several African examples discussed in Lewallen and Thulasiraj (2008), or through having surgeries performed in camps. This appears to be important in rural areas where the population is widely dispersed, as uptake may be considerably lower if patients return to their homes after testing and later have to make their way on their own to a hospital or other location for surgery.

With regard to mobilization or outreach, HMS plans for the first decade of the program to assist practitioners through mass media campaigns at the national level. This is important, because individual practitioners obviously would not be able to conduct such a mobilization on their own. Still, as currently outlined by HMS, the surgeons will be responsible for outreach

and screening at the local level; some funds will be provided initially by HMS for this purpose. Surgeons will be trained on outreach methods while attending the HMS learning centers, and they will be expected to work closely with local organizations and community groups in the areas they serve to coordinate outreach, with these activities presumably being the direct responsibility of one of the several other individuals on his or her staff.

HMS believes that an "itinerant" outreach model, where the surgeon and/or trained staff periodically visit areas within reach, will be practical and cost-effective. There is certainly an incentive for the surgeons to pursue these activities, which will bring in patients. However, catchment areas for practices that serve rural populations will often be wide. In these settings it is not clear how feasible it will be for individual practices to carry out mobilization and (especially) effective screening. It may not be practical for one of the nurses, or the surgeon himself or herself, to travel throughout the catchment area to screen (and mobilize) patients, since maintaining a high volume of surgery may require these staff to be in the office.

However, the alternative of foregoing extensive screening and outreach, and relying instead on patients to come to the office to get screened, has significant risks. It requires people to travel potentially long distances to the practitioner before they know if they will benefit from the visit; that is, before they know if they have operable cataracts. This may significantly limit the number of individuals with VI who are willing to come to the practitioner. In contrast, other established systems of cataract surgery organize screenings or referral by medical personnel to filter out nonoperable individuals before sending individuals to the surgical facility.[1]

On the other hand, the HMS practitioners are expected to be considerably more "local" than a typical hospital—with a practice in a town, perhaps, rather than a large urban area. This will make it easier for people with vision problems to come for screening, but the travel involved still may be significant for many patients and their helpers. For example, making one's way to a district center as opposed to a major city is still not a trivial proposition for very poor rural people, and especially for those with VI. In sum, it remains unclear whether individual HMS practitioners will be able to organize outreach and screening in such a way as to ensure adequate demand for their services, hence high patient volume. These considerations suggest that integrating the HMS system into an organized system of outreach and screening that is not under the direction of individual practitioners may be advisable.[2]

Another consideration for uptake is that unlike hospital-based models such as Aravind, the individual practitioner in the HMS model is not expected to provide overnight stays for patients through the next day follow-up. It is possible that some practitioners could decide to offer this, but doing so may be impractical or costly for small practices. This means that patients and their caregivers who do not live relatively nearby will have to find accommodations on their own, which will reduce demand to some extent. Again, this may be offset by a relatively wide dispersion of HMS practitioners, which would make them geographically more accessible.

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[1] The comparison with SmileTrain is instructive. There is no ambiguity, presumably even for a layperson, in diagnosing cleft palate, so it is largely clear whether the condition is "operable" hence whether a trip to a distant hospital will be beneficial.

[2] The planned decentralized He system discussed in Chapter Three will also feature small independent surgical facilities, but these will be integrated into rural China's existing and fairly well-developed primary care and referral system.

Quality and Supervision

As emphasized in our review of successful cataract surgery systems, high quality of surgical outcomes is essential not just on its own terms, but to ensure high uptake and hence the sustainability of cataract surgical centers or practices. We discuss three distinct but related potential concerns about quality in the HMS model: (1) ability of the simulator training approach to produce skilled surgeons; (2) the quality of nondoctor cataract surgeons; (3) the adequacy of approaches for remote monitoring.

Ability of the Simulator Approach to Produce Skilled Surgeons

The success of the simulator as a training tool will depend on its ability to accurately reproduce the feel of surgery on real eyes, so as to be a viable substitute for actual surgery during the training process. The simulator must also be capable of presenting the trainee with a wide range of realistically simulated surgical complications. A number of consulted ophthalmology experts had concerns that, while the simulator is a potentially useful educational tool, it would simply not be a match for real experience on actual patients. From a technical standpoint, it should be noted that any experiences these experts may have had in this area presumably was not with high-fidelity simulators of the kind that HMS is developing. In principle, the simulator in being designed precisely to capture the physical feel and experience of real surgeries, as well as to simulate a wide range of complications (more than the trainee would encounter in standard training on a much smaller number of real eyes), much as the flight simulator has successfully done in aviation training. Some experts also pointed out that no simulator could capture the pressure of performing actual surgeries. While this is undoubtedly true, it was noted in Chapter Four that the HMS training program will also require each trainee to participate in and lead a minimum number of live surgeries as part of the program (with the number determined by their initial experience), to be carried out in affiliated hospitals.

The realism of the simulator and its ability to incorporate complications and contingencies are highly technical questions of engineering involving haptic feedback, visual displays, and integrated software that are beyond the scope of the present study to evaluate. Any such assessment must ultimately await the actual development and production of a prototype, which is under way.

Nondoctors as Cataract Surgeons

The training of nondoctors to be MSICS surgeons is perhaps the most controversial aspect of HMS's approach—at least among the ophthalmologists consulted. Possible legal or cultural barriers to this are discussed below. HMS does not envision training only or mostly nonphysicians or nonmedical professionals. On the contrary, the expectation is that most trainees in the early stages would be ophthalmologists or others such as nurses with an ophthalmological background—or possibly other nonphysician medical professionals. HMS estimates that perhaps 60 percent of its trainees overall will be ophthalmologists. However, the availability of ophthalmologists—and ophthalmologists who are willing to become MSICS practitioners—is clearly limited in some regions: not so much in China, perhaps, but clearly in Africa, where the shortage is one not just of ophthalmologists who perform cataract surgery but of any ophthalmologists whatsoever. To overcome the shortage in these areas, nondoctors will most likely make up a significant share of trainees and HMS practitioners. Indeed, as noted in Chapter Three, nondoctors are already performing large numbers of cataract surgeries in Africa. There

is little direct evidence on the quality of surgical outcomes for these practitioners, though as also discussed, annual surgeries per practitioner are quite low.

The key objection raised by a number of experts was not that nondoctors, or even nonmedical professionals, could not be trained to perform MSICS and generally obtain successful outcomes; it was that such individuals could not be adequately trained to deal with complicated cases or complications arising during or after surgery, such as corneal edema or hyphema. Another concern noted was that nondoctors may be unable to diagnose some conditions properly, such as trachoma, and may perform cataract surgery when not medically indicated. Generally, those experts who were critical of reliance on nondoctors did agree that nondoctor surgeons could have a role to play as surgeons, even a significant role, in areas where doctors are in short supply. However, they stressed the need for continued supervision by doctors—as, for example, where an ophthalmologic surgeon manages a team of nondoctor surgeons and is there to handle any complications or more difficult cases that arise. Note that such a set-up conflicts directly with the HMS approach of geographically dispersed independent surgeon practitioners, with supervision and review handled remotely.

In view of these issues, it will be especially important to assess the performance of independent nonphysician surgeons through HMS internal monitoring and external evaluations.

Monitoring Performance

Ensuring high-quality cataract surgery is of utmost importance. Poor-quality surgery can do more harm than good, potentially causing the individual to lose his or her limited remaining eyesight. Further, as noted, repeated evidence of poor outcomes reduces the overall willingness of the population to have surgery. For HMS, the fact that many or even most surgeons will function independently, rather than within a larger hospital or other health facility, raises particular challenges to effective oversight and quality control. Further, oversight is all the more important for the many HMS surgeons who will not be trained doctors or even medical professionals. From the point of view of motivation, an effective system of outcomes monitoring is essential if practitioners are to be incentivized to maintain the quality of surgeries, not just their quantity.

As described in Chapter Four, HMS plans to use two approaches to ensure high-quality surgical outcomes: (1) remote monitoring by transmission to the learning centers of data and images capturing patients before and after surgery, and (2) on-site audits. Several of the consulted experts expressed doubt that photographic images would be precise enough to record all the information necessary, such as data on complications. For example, the technology may be appropriate for retinal scans but not for photos of corneal surfaces so that edema persisting after surgery will not be detected. This may limit the ability of doctors or technicians (not to mention software programs) at the HMS center to provide useful feedback to surgeons in the field, as well as to judge the quality of surgical outcomes. It was noted that the remote monitoring approach of SmileTrain, which is being used as a model by HMS, faces fewer challenges in the sense that good outcomes of cleft surgery are more unambiguously captured by photographs. On the other hand, with cleft surgery, infection is a serious postoperative possibility for a longer period than for sutureless MSICS.

As with the simulator design, an evaluation of the technical aspects of remote monitoring is beyond the scope of this study. We may note, however, that practical considerations in applying the technology may be a more important concern than the technology itself. One potential problem in some areas will be a lack of adequate mobile phone or Internet connectiv-

ity (although these areas are shrinking). The alternative of putting data on CDs and transporting them to a location where they can be uploaded might be difficult or cumbersome in these areas. Relative to Internet communication, this would also make it more difficult for HMS to provide timely feedback to the MSICS practitioners.

Additional operational considerations include the workload and capacities of staff in the HMS centers that will do the monitoring and provide feedback. HMS assumes that existing staff at the centers will be adequate to do this monitoring with the additional help of experienced ophthalmologists from affiliated hospitals. HMS plans to turn out 600 surgeons (out of 1,000 entering trainees) per center each year with a target of some 30,000 surgeons for all four to six centers. Routine monitoring of all of these surgeons potentially imposes a huge ongoing workload. If ophthalmologists are needed to review these records, it may be difficult to engage the necessary personnel. However, as discussed in Chapter Four, HMS plans to have practitioners submit digital records, including pre- and postoperative photography, which will be processed with software that compares results against standards. Pre- and postoperative visual acuity and postoperative corneal clarity, among other things, will be graded. Staff at the centers would only become actively involved when results are suboptimal or there are complications. International staff will also be on call to assist remotely with complications. With software-based monitoring and a low rate of expected complications (5 percent or less), the demands on expert staff time will be minimized.

On the other hand, this clearly places a very heavy reliance on routine monitoring by the software, which is untried, at least in this context. This aspect of the HMS approach to monitoring needs to be carefully evaluated. Further, the frequency of site visits for auditing, and who would conduct these visits, has not yet been worked out by HMS, and the costs of this activity are not included in our estimates above.

The Surgeon-Entrepreneur Model

HMS proposes a system whereby MSICS surgeons function as individual business owners. The idea behind this strategy is that profit-making practitioners will be incentivized to perform high-volume surgery that is also (given the importance of reputation and trust) high-quality surgery. Further, a decentralized system of small individual practices will effectively bring cataract services closer to people than possible with centralized operations such as Aravind, and in principle will be able to serve a larger number of individuals.

On incentives, the HMS approach clearly addresses a major constraint to increasing the overall volume of cataract surgeries. As discussed above, the problem is both a lack of surgeons and a lack of incentives for existing surgeons to perform low-cost MSICS—and to provide this service to underserved rural populations. Like other doctors, highly trained ophthalmologists who perform cataract surgery normally prefer to live in large urban centers; they may not find cataract surgery among the more lucrative aspects of their practices or they may find PHACO, which is financially beyond the reach of the poor, to be more profitable than MSICS. In the HMS model, practitioners are trained only in cataract surgery (and only in MSICS) so they clearly have a strong incentive to increase the number of cataract surgeries they perform. Given a guaranteed rate of reimbursement per surgery from HMS, they may also have an incentive to set up practice outside of the largest urban centers, thereby reaching traditionally underserved populations whose lack of ability to pay would deter other cataract surgical practitioners.

The key question is whether reliance on incentives in the context of a system of small independent practices can achieve the same high-volume, high-quality output as achieved by established, more centralized approaches—and even achieve many more surgeries overall than those systems. The HMS model strongly incentivizes surgeons but also places a significant burden on them. In addition to conducting high surgery volume, the surgeon as the firm owner is responsible for all aspects of the business—management, hiring, marketing, screening, logistics, and equipment maintenance. He or she will be trained by HMS in both personnel and overall business management, and will hire two nurses, an office manager, and a supplies manager to perform different functions. In principle, this will reproduce the all-important division of labor and task specialization, although on a much smaller scale than the centralized cataract systems, However, at least initially, managing these employees and directing the business (as well as planning, even if not directly implementing, an outreach and screening strategy) will doubtless require significant attention on the part of the surgeon, taking away from time for performing surgeries. In contrast, more system-oriented or centralized approaches such as Aravind and Tilganga completely remove these responsibilities from the surgeon's hands. In addition, centralized management in these systems creates scale efficiencies that will not be realized in individual practices.

Cataracts-Only Practices

A characteristic that distinguishes the HMS model from all other systems considered earlier is that it is focused solely on cataract surgery, not other aspects of vision care. In contrast, the other approaches, at least to some degree, integrate cataract treatment with general ophthalmologic care; for example, treatment of infections and other diseases such as glaucoma. Stand-alone cataract services have the potential advantage that the practitioner is naturally incentivized to perform cataract surgery and not diverted to other activities. However, there are potential risks to this approach. First, as noted, it will be essential for HMS practitioners to be well trained to recognize other eye conditions, some of which will occur with cataracts, and to be able to make appropriate referrals for these patients. The remote monitoring of practitioners in combination with on-site audits will have to be able to ensure both that the practitioner recognizes other conditions and that he or she does not attempt to treat them. One reason this is important is that, depending on the setup for feeding patients to the HMS practitioner, a large number of people with vision problems unrelated to cataracts will likely come to him or her for care.

This sets up another potential concern with the model. Consider the extreme case where there is no prior screening of patients. Assume as well that most visitors to an HMS-trained MSICS practitioner are people who have vision or eye problems but do not know the cause, or if they can be helped. Among those who turn out to have cataracts, the large majority will be treatable, while those who do not have cataracts will not be helped, although some presumably can be referred elsewhere. This creates the possibility of negative—if undeserved—reputational effects through frequent "disappointment": Even though the HMS surgeon is acting completely as he or she is supposed to by only dealing with cases he or she is trained to do, the community may observe a pattern of people going to the service and not being helped. Knowing that one would at least get an appropriate referral for other problems can help, but the likelihood of not being treated still may discourage others from coming to the practitioner,

especially if long distances are involved. In contrast, systems such as Aravind conduct screenings where individuals can have a range of eye problems treated, with operable cataract patients referred for surgery.

The extent to which this a problem for HMS practitioners (i.e., the extent to which disappointment occurs relative to more general eye care systems) depends on the kinds of problems people will bring to the practitioner. On the one hand, significant vision loss other than that caused by cataracts is usually not reversible (for example, vision loss resulting from glaucoma and diabetic retinopathy). People with low vision who come to HMS practitioners would not have significantly poorer chances of getting their vision restored than they would have from the other care systems discussed in Chapter Three. On the other hand, doctors with more general training can stop the progression of serious conditions such as glaucoma. Many people may also come to the practitioner for other eye problems such as infection or irritation; thus there may be a significant share of clients potentially experiencing disappointment at not getting care or being referred elsewhere. A partial solution is to try to market HMS practitioner services in a way that makes it clear that the service is only for those who are actually visually impaired. This will narrow the pool of patients to those who may potentially be helped by the HMS practitioner. Still, some visually impaired patients, for example those with glaucoma whose vision loss could be halted with appropriate treatment, will be told they must travel to a medical doctor or other facility for care.

The problem could also be avoided in principle if the HMS practitioner were integrated into a strong system of professional screening and referral (beyond what the practitioner could carry out on his or her own) such that the screening carefully allocated only operable patients to the practitioner. The He system in China discussed in Chapter Three, which otherwise shares a number of features in common with the HMS model, is instructional in this regard. As noted earlier, this would prevent unnecessary travel for conditions that cannot be treated by the HMS practitioner. Note that even in this case, it would be better for uptake of cataract surgery if the screening also treated or referred other eye conditions, since even "local" screenings will often involve significant travel for many rural residents. If people were aware that all (or many) vision problems will be dealt with, they would be more likely to travel to screenings, and then to the HMS practice if indicated.

Long-Term Viability of Surgical Practices

The modeling exercise in Chapter Six points to a further issue associated with cataract-only providers: the possibility that the very success of the HMS program will eventually make many of them no longer necessary—or at least, will reduce the number of surgeries per year to the point where the practices of many MSICS providers are no longer viable financially given that payment from HMS is made on a per-surgery basis. For example, for Africa with 80 percent uptake, the point where the operable backlog is cleared will occur in 2023; for the less optimistic assumption of 50 percent uptake it will occur somewhat earlier, in 2021. Once the backlog clears, uptake in the model comes solely from incident (new) cases. In the model, these are the cases each year that progress to VI as defined above.

HMS has indicated that once the backlog of more serious cases (bilateral and unilateral cataract-caused blindness) is cleared, surgeons can move on to less advanced cataract cases—approaching the situation in advanced countries where cataracts are usually treated well before

progression to severe impairment. It should be noted that the conclusions in Chapter Six are based on model assumptions whereby uptake already includes individuals with low vision (using the WHO definition), not just the bilaterally blind. Therefore any additional demand would have to come from cataract cases where vision is impaired but visual acuity remains better than 20/60, the WHO cutoff for VI used in the projections. In developed countries, the threshold for surgery appears to be highly variable and depends on subjective perceptions of impairment. One common benchmark is when visual acuity has declined to below the level legally required to hold a driver's license, or 20/40 in the United States. The result in the United States is a robust demand for cataract surgery, with up to 3 million surgeries performed per year, implying an exceptionally high cataract surgical coverage rate.

In many developing countries, especially in poor and rural contexts, the subjective threshold for impairment is probably significantly higher. These populations do not drive, for example, and normally do not (or cannot) read very much. It is not clear, therefore, that there would be very large numbers of additional cataract patients to be had once all WHO-defined visually impaired cataract cases (or the percentage determined by the uptake assumption) are operated on. On the other hand, other factors may lead to growing demand for better vision among those with cataracts who are not very highly impaired, although it would be unrealistic to expect this to match the U.S. situation in the near future. Cell phone usage is experiencing explosive growth even in rural areas of poor countries, and using a cell phone requires that the user can see the numbers on the screen. Further, as more and more people with severe impairment are successfully treated, those with less progression of their cataracts may also come to demand surgery.

If demand were to increase substantially from this group to offset the drawing down of the backlog, the surgeries must still be paid for. Poor people in developing countries tend to be very sensitive to costs, so their willingness to pay for early or "preventative" cataract surgery (estimated to be about US$35 per eye, a sizable sum) may be limited. Even for those with blindness or low vision, we have been assuming that donors (via HMS) will largely subsidize the provision of surgeries through reimbursements to MSICS practitioners. It is not obvious that such funding would be forthcoming for an intervention that alleviates only mild VI, given competing health care demands for these resources and relative cost-effectiveness. Yet, since many or most of these early cases would eventually progress to blindness in the affected eye, a case can be made that early or "preventative" cataract surgery is also cost-effective, especially as additional early productivity losses would be prevented.[3] The potential for expanding the uptake of cataract surgery among those below the WHO VI threshold is an important question for future research.

It should be noted, however, that practitioners may have other options in the face of reductions in demand for surgical services after a successful campaign to clear existing poor vision cases. MSICS practitioners who are ophthalmologists or have general training in vision care (such as ophthalmological nurses) could potentially expand other aspects of their practices unrelated to cataracts. For those without such a background, who are trained only in cataract removal, the long-term consequences would potentially be more serious. It may be the case

[3] The cost-effectiveness of preventative cataract surgery will depend substantially on the share of cases that would progress to severe VI or blindness in the absence of surgery. Information on this is lacking for developing counties, but well over 60 percent of people with 20/40 cataracts would be expected to progress to 20/60 or worse within five years. We thank Dr. Glenn Strauss of HMS for discussion on this issue.

that many such individuals would still be willing to undergo the training if it yielded a good income for a reasonable length of time, say ten to 12 years. Recruitment effort could even be directed at older "mid-career" nurses and others. There may also be possibilities to adapt to changing circumstances while staying in the field. For example, with some additional training, nonphysician HMS practitioners could move into some aspects of primary eye care such as providing care for minor eye conditions (e.g., dry eye), enhancing their referral capabilities for more serious conditions in arrangements with larger care organizations, or providing optometry services such as testing and eyeglass provision.[4] The possibilities for these adaptations will depend heavily on the local licensing environment with respect to these services.

Legal and Regulatory Environment

Countries have different laws and regulations governing medical and vision care—determining who can operate a medical practice, and who can perform surgery. In perhaps half of the countries in Africa, nondoctors are currently not allowed to perform surgery.[5] The simulations previously discussed ignore this constraint. To the extent that HMS will rely on training of nondoctors, this presents an obvious obstacle. In a smaller share of countries, regulations make it difficult or impossible to establish a private practice, and such practices are the essence of the HMS delivery model. A different barrier is the potential reluctance of a significant share of the population to trust nondoctors for something as apparently skill-intensive as eye surgery, even if the practitioners are in fact well trained and competent.

It is not clear exactly how much of a barrier legal factors will present to HMS, although presumably there are many countries where the HMS model will be able to operate as designed once cooperation is established with the health authorities. In other contexts, flexibility would seem to be important. For example, the training could be limited to doctors for certain countries. If the HMS model is seen to perform very well in some countries, it may persuade others to adjust their stance toward private practices or nondoctor surgeons.

The barrier posed by a population's reluctance to accept nondoctors as surgeons is very difficult to predict. Much will depend on the quality of initial surgeries, since competence and reputation has proved to be a key determinant of uptake.

[4] As with cataract surgery provision itself, it will be necessary but potentially challenging to ensure that independent practitioners do not provide unnecessary vision care services to generate revenue.

[5] We thank Susan Lewallen for pointing this out to us.

CHAPTER NINE

Summary of Findings and Conclusions

HelpMeSee is developing an innovative system for cataract surgery training and delivery in developing countries, with the objective of eliminating or greatly reducing cataract-related blindness. It is distinguished from existing systems of cataract surgery in several significant ways: (1) the use of high-fidelity simulators, adapted from commercial aviation training systems, and specialized courseware to rapidly train large numbers of MSICS cataract surgeons; (2) surgical training not just of ophthalmologists but, when necessary, nondoctors; and (3) a system of independent MSICS practitioners who will operate on their own with HMS technical assistance, technical support, and oversight (although not all graduates will elect to become independent practitioners). These specialists are expected to serve populations, especially in rural areas, that are currently not well served by standard urban hospital-based services. The HMS approach will reimburse surgeons based on actual operations performed, incentivizing practitioners to seek out treatable cataract cases in these populations. Their training will cover not just surgical technique but all aspects of practice management and outreach approaches.

This study has attempted to provide an assessment of the potential for the HMS approach to achieve its objectives. We modeled the impacts of the introduction of four HMS learning centers in the Continent Regions of AFR, SEAR (including India), WPR 2 (including China), and AMR 2. Comparing outcomes under HMS to the status quo scenario (where the cataract surgery coverage rate is assumed constant) we considered the impacts on the supply of cataract surgeons and surgical capacity, on prevalence of cataract-caused VI, on DALYs, and on economic productivity. In forecasting the effects of the program, we considered different scenarios for uptake of HMS: low (20 percent of those with cataract-caused VI, not treated elsewhere), medium (50 percent) and high (80 percent).

Below we summarize the main findings of the study and discuss the need for and benefits from a pilot study to assess the HMS approach. The main findings as follows:

- Under HMS's assumptions about costs and training capacity and the availability of resources to train a planned 30,000 new MSICS surgeons, the program will have the capacity to scale up cataract surgical capacity very rapidly, reflecting the speed with which the simulator training produces surgeons. Once this large supply of surgeons has been built up, the effects on VI prevalence will be determined mainly by the level of demand or uptake. Under optimistic assumptions (an uptake of 80 percent) HMS can largely close the backlog of surgical cases in the four major regions studied, resulting in 21 million cases of cataract-caused VI in 2030 (including 5 million cataract-caused blindness cases) compared with 134 million cases (including 26 million blind) under the status quo. With medium uptake (50 percent), HMS can substantially reduce prevalence by 82 mil-

lion cases relative to the status quo in 2030. Under low uptake (20 percent), impacts on prevalence are correspondingly modest.

- By reducing cataract-caused VI, the program potentially will have significant impacts on future economic output. This reflects the large expected losses to national income of cataract-caused VI under the status quo. SEAR sees the most dramatic reductions in prevalence under HMS, leading to a large benefit to gross domestic product (GDP) under high-uptake scenarios: for the 80 percent uptake scenario, the difference from the status quo in 2030 is about 0.6 of a percent of GDP for that year, or about US$18 billion. For WPR, the proportional gains to GDP are similar, reflecting high employment rates, but the absolute or dollar gains are much larger given the economic size of this region: GDP would be US$52 billion higher in 2030. For AFR, the percentage gains by 2030 are also more than half a percent of GDP (US$9 billion) for the 80 percent uptake scenario.
- Under the assumptions about HMS's expansion of surgical capacity, the program can have very large impacts on DALYs: over the ten-year period from 2014 to 2023, for uptake of 50 percent, about 16 million DALYs would be averted in AFR, 17.5 million in SEAR, 16 million in WPR, and 7 million in AMR 2. Cost-effectiveness ratios, or the cost per DALY averted, range in international dollars from $114 in SEAR to $515 in AMR 2, assuming 50 percent uptake and calculating over a ten-year period. This is well under the per capita GDP of these regions, and the same holds for the other two regions. By this benchmark, the HMS program could be very cost-effective. In later years, however, this conclusion may not hold as costs per surgery rise due to falls in demand as the surgery backlog is closed or reduced.

The HMS approach also faces a number of potentially important challenges:

- There appears to be a potential for a significant surplus of surgical capacity (and surgeons) once the cataract surgery backlog is eliminated or reduced as much as it can be given uptake rates. When this occurs depends on regional variation in prevalence as well as assumptions about uptake; it will happen later if uptake is high, since more backlog cases will be addressed. For 50 percent uptake, this point is reached in 2021 in AFR, 2024 in SEAR, 2023 in WPR, and 2017 in AMR 2. After that point, practitioners must rely solely on new cases of cataract-caused VI, or increased demand from those with less advanced cataracts. With regard to the latter, in the United States and other rich countries, where populations are also well insured, there is a very robust demand for cataract surgery from individuals who are mostly well below the WHO threshold for low vision. In poorer countries, the subjective threshold for desiring (and being willing to pay for) surgery is currently significantly higher. This may change as cataract surgery becomes more common and incomes rise. However, the prospects for this are uncertain, so there remains a possibility that the rapid scale-up of MSICS surgical capacity will eventually lead to redundancies among MSICS specialists. This will pose a problem for practitioners who do not have broader ophthalmological training in other, nonsurgical areas of vision care. However, in some contexts, even these specialists may be able to successfully adapt by turning to the provision of care for minor eye conditions, performing more referral functions for larger care organizations, or providing optometry services. The possibilities for these adaptations will depend heavily on the local licensing environment with respect to these services.

- Several aspects of the service delivery approach may pose challenges to the HMS model. Ensuring that outreach and screening efforts are adequate to bring large numbers of patients to individual practitioners is a key issue. While HMS is planning to conduct education outreach campaigns, at present it appears that arranging for the screening of individuals for operable cataracts will be the responsibility of the practitioner. This and other aspects of managing a practice may impose a significant burden on practitioners who are expected at the same time to perform high-volume surgery. In most successful existing cataract systems, all management as well as screening functions are out of the hands of the surgeons.
- Related to the foregoing, the link between screening and surgery in the HMS approach remains to be spelled out. In a number of other systems, for example, transportation to surgery is provided at the screening for patients diagnosed with operable cataracts. Patients generally do not have to travel very far—for example, they typically go to relatively local screenings—to learn if they can be operated on. Unless HMS practitioners can organize such screenings by appropriately trained staff, individuals with poor vision may be reluctant to come to the practitioner's office, since they do not know if they can benefit from surgery. This will be offset to the extent that the distribution of surgeons under HMS allows them to be more locally accessible to rural populations, which will encourage visits.
- HMS practitioners will be trained only to perform MSICS. This has benefits from the point of view of the gains in proficiency from specialization, as shown by existing successful cataract surgery systems. However, unlike other systems, treatment will not be provided for other eye conditions, so all such cases will have to be referred. This may create a situation where a significant share of clients are disappointed, with negative reputational and demand impacts, even though the HMS practitioners are appropriately refraining from treating conditions beyond their training. Whether this is a problem in practice depends on who comes to the HMS practitioner. "Disappointment" may occur frequently if people travel to the practitioner for a broad variety of eye problems, such as infections, that the HMS practitioner cannot treat. Marketing strategies need to be designed to ensure, to the extent possible, the appropriate kind of demand, i.e., from visually impaired individuals. This will narrow the pool of patients to those who may potentially be helped by the HMS practitioner. Still, some visually impaired patients, such as those with glaucoma whose vision loss could be halted with appropriate treatment, will be told they must travel to a medical doctor or other facility for care.
- Monitoring of performance is a particular concern under a system of geographically dispersed individual practitioners. An effective system of surgical outcomes monitoring is essential if practitioners are to be incentivized to maintain the quality as well as the quantity of surgeries. Apart from incentives, oversight is especially important for the many HMS surgeons who will not be trained doctors or even medical professionals. HMS is developing a technology-driven approach to this issue, relying on sophisticated imaging and other forms of verification. Some of these approaches are in use in other medical contexts (e.g., with SmileTrain), but they have yet to be tested for remote monitoring of cataract surgeon performance. Also untested are the plans for supplying dispersed local practitioners with lenses and other essential surgical supplies.

With respect to these potential challenges to the HMS model, it should be stressed that at this stage in the development of the program we are by and large only able to suggest these as potential obstacles to its success. That is to say, these conclusions do not arise either from our modeling (other than for the overcapacity issue) or from specific empirical evidence, e.g., evidence about the type of delivery system for cataract surgery proposed by HMS. This is largely unavoidable when considering an approach that diverges so significantly from existing systems for cataract surgery. It has not been yet been piloted or implemented, so there is little in the way of evidence from evaluations that are directly relevant, and modeling, as we have noted, can take one only so far. Rather, the enumeration of concerns derives from our reading of the literature and discussions with experts in the field. What these concerns imply is that the HMS model should be carefully piloted and assessed before fully scaling up the approach. HMS recognizes this and is planning a pilot study that would involve assessments by external experts. We discuss this plan below.

We should also note a different limitation of the study. An appropriate comparison of HMS and alternative approaches would consider outcomes for the latter if they had the same level of resources assumed for the HMS program (to create four learning centers for training and support of up to 30,000 surgeons). We are unable to perform such an analysis; the data requirements would be formidable and include detailed data on training costs and surgery delivery costs of the sort we have for HMS. It would also have to account for constraints on the supply of candidates for surgical training. As we noted in the context of Aravind in India, these may at some point limit the ability to produce more surgeons or to do so quickly. Therefore, such an analysis would have to go even beyond a standard comprehensive cost-effectiveness comparison of different interventions, as it would have to incorporate expected limits to supply of key inputs. This would have been well beyond the bounds of this study.

Learning from a Pilot Study

As noted, HMS is planning a pilot study. Given how innovative many of the aspects of the HMS approach are, such a pilot is very important. It is expected that this will involve approximately 100 trainees, about 80 percent of whom would be ophthalmologists, including some who have MSICS experience and who would enhance their skills to increase the quality and volume of surgeries. Some of this initial cohort are expected to stay in their current practices (e.g., in hospitals) while others may choose to become HMS-supported independent practitioners. As noted, the pilot will be carried out before the regional centers are opened. This group of trainees in effect would constitute the first HMS class. The objective of the pilot is to assess the effectiveness of the simulator and courseware training approach. In addition to its own evaluation, HMS plans to have external evaluators measure these outcomes. The pilot will not assess other aspects of the HMS model, such as the monitoring and quality control system, supplies procurement, payment systems, and outreach. However, as indicated, HMS will follow and support this "graduated" cohort and will continuously monitor and evaluate these practices.

As such, the pilot plays a limited but essential role, which is to establish the effectiveness of the training approach that is the basis of the HMS program. This is indeed the first order of business in assessing the HMS model. However, the other aspects of the approach just described also need to be carefully assessed. Many of these are new, as least for cataract

surgery systems. They include the sophisticated remote monitoring of outcomes, the reliance on independent MSICS practitioners, and a supply chain system to serve myriad dispersed practitioners. If these and other aspects of the HMS model are not going to be evaluated in a pilot study, but only after going to scale (i.e., after setting up the high-capacity learning centers), careful ongoing monitoring is essential, with adjustments to the model made as needed. A judicious approach would be to first set up (after a successful pilot) one full-fledged training center in one region, and allow several years to assess how the various components of the complete HMS model perform.

Another limitation of the pilot as currently planned is that it involves the training of existing ophthalmologists with little or no surgical experience, and improving the skills of a smaller number of existing MSICS surgeons. It is logical to first pilot on this group of individuals who already possess significant relevant skills, so as to be able to establish the effectiveness of the simulator training and the courseware. Then, the focus can shift to nondoctors, and nonmedical professionals, whose training will be more challenging. Indeed, such a progression was recommended by a number of the experts consulted for this study. As noted, the quality of outcomes for nondoctors and their ability to handle complicated surgical cases was a major concern voiced by some of the experts the study team spoke with. It would be advisable to follow the initial pilot with a similar size cohort of nondoctors and nonmedical professionals. This would establish the effectiveness of the training approach for this group, or point to areas for improvement. This should be done before considering going to scale in the training of nondoctors. Careful subsequent monitoring of quality outcomes and the effectiveness of remote monitoring systems for this group of MSICS specialists will be essential.

Finally, the simulator may have significant benefits as a training tool for other cataract systems that otherwise have relatively little in common with HMS, such as the centralized systems of training and delivery of Aravind and Tilganga. As noted early in the report, the use of the simulator as a training tool is separable from the other innovations of the HMS approach, that is, the private-practice model and the training of nonophthalmologist surgeons. If the HMS pilot study demonstrates the pedagogical effectiveness of the simulator, it would be worth exploring whether the simulator technology can increase training output and efficacy in more standard cataract surgery systems as well.

APPENDIX A

Modeling Approach, Methodology, and Data Sources

This appendix presents the modeling approach, methodology, and data elements used for forecasting. The details of forecasting prevalence, economic productivity loss, and DALYs are discussed.

Forecasting Status Quo Cataract-Caused Visual Impairment

To forecast prevalence, we follow the general forecasting methods described in Access Economics (2010). We first use U.S. Census Bureau forecasts of population by country and age group. These population forecasts are in age groups of five years and are provided through 2050. The age groups are summed by region to form three large age categories—less than 15 years, 15–50 years, and greater than or equal to 50 years of age—so we can apply blindness prevalence estimates in Resnikoff et al. (2004), which were calculated for these groupings. Their estimates are displayed in Table A.1.

The formal structure of the model is as follows. Let B_t be the blindness forecast for year t. Let $P_t^{<15}$, $P_t^{15–49}$, and $P_t^{\geq 50}$ be the population forecasts for the three age groups. Let $p^{<15}$, $p^{15–49}$, and $p^{\geq 50}$ denote the Resnikoff et al. estimates of blindness prevalence in Table A.1. Equation A.1 is then the forecast of blindness population for year t:

$$B_t = p^{<15} P_t^{<15} + p^{15–49} P_t^{15–49} + p^{\geq 50} P_t^{\geq 50} \tag{A.1}$$

To calculate the blindness caused by cataracts, we multiply the total blindness B_t by the percentage of visual impairment caused by cataracts c shown in Table A.1. In Resnikoff et al., these estimates are only for blindness but we have assumed here that they also apply to low vision, as Access Economics (2010) also does. To estimate cataract-caused blindness B_t^C, we multiply the blindness forecast by the percentage caused by cataracts c as in Equation A.2:

$$B_t^C = cB_t \tag{A.2}$$

Resnikoff et al. do not provide estimates of low-vision prevalence by age group but they provide total estimates of low vision. From this we derived total-low-vision-to-total-blindness ratios as shown in Table A.1. Let r be the low-vision-to-blindness ratio. Equation A.3 then is the cataract-caused low-vision forecast L_t^C for year t:

$$L_t^C = rB_t^C \tag{A.3}$$

The total VI forecast VI^C for year t is the sum of the blindness and low-vision forecast:

$$VI_t^C = L_t^C + B_t^C \tag{A.4}$$

Table A.1
Modeling Input Estimates of Cataract-Caused Blindness and Low-Vision Prevalence

Region	Blindness Prevalence[a]			Low Vision to Blindness Ratio[b]	Percentage of Visual Impairment Caused by Cataracts[a] (%)
	Age <15 (%)	15≤ Age ≤49 (%)	Age ≥50 (%)		
AFR D	0.12	0.20	9.00	2.94	50
AFR E	0.12	0.20	9.00	2.90	55
AMR A	0.03	0.10	0.40	5.81	5
AMR B	0.06	0.15	1.30	5.46	40
AMR D	0.06	0.20	2.60	4.48	59
EMR B	0.08	0.15	5.60	3.33	49
EMR D	0.08	0.20	7.00	2.93	49
EUR A	0.03	0.10	0.50	5.80	5
EUR B	0.05	0.15	1.22	5.43	30
EUR C	0.05	0.15	1.20	4.08	24
SEAR B	0.08	0.15	6.30	2.29	58
SEAR D	0.08	0.20	3.40	3.41	51
WPR A	0.03	0.10	0.60	4.79	5
WPR B	0.05	0.15	2.62	3.27	51
Global	0.07	0.16	3.43	3.40	48

[a] Directly Sourced from Resnikoff et al. (2004).

[b] Derived from Resnikoff et al. (2004).

Forecasting Cataract-Caused Visual Impairment Under HelpMeSee

To forecast prevalence under the HMS intervention, we must estimate both the supply of HMS surgeries and the demand for surgeries.

We first estimate the number of surgeries supplied per year. HMS indicates that that they will accept 1,000 trainees in their program for each center per year, and estimate that approximately 60 percent will graduate, resulting in about 600 practitioners per year. These surgeons will have both a learning curve and an attrition rate. HMS estimates that experienced practitioners will be able to perform 2,000 surgeries per year provided demand is available, consistent with practice at high-volume systems such as Aravind. Courtright et al. (2007) estimate the surgical learning curve for eye surgeries. We use the relative shape of Courtright et al.'s learning curve, fix the maximum number of surgeries at 2,000 per year after four years of practice, and estimate the maximum surgical rate per practitioner for less than four years of experience. Table A.2 displays the learning curve for an HMS practitioner. This learning curve is a scaled version of Courtright et al.'s, so as to lead to a maximum number of surgeries of 2,000 per year after four years of experience.

As indicated in the text, we assume a 5 percent attrition rate for the HMS practitioners in our main model estimations.

Table A.2
Learning Curve Assumed for HelpMeSee Practitioners

Years of Experience	Surgical Capacity (Surgeries per Year)
1	693
2	1,284
3	1,433
≥4	2,000

To estimate the total number of surgeries supplied in a given year, we must estimate the total number of practitioners in business and the potential surgeries supplied. Let G_t be the number of practitioners that HMS graduates in year t and let SP_t be the total number of HMS surgical practitioners practicing surgeries in year t. Therefore SP_t is

$$SP_t = G_t + (1-0.05)SP_t - 1 \tag{A.5}$$

where $(1-0.05)$ is the probability that a practitioner does not go out of business in the year. For $t <$ year 2014, SP_t and G_t are equal to zero because HMS's intervention does not produce practitioners until 2014. Let S_t be the total supply of surgeries for year t. Equation A.6 estimates S_t, the surgery supply, by considering the supply of practitioners and the learning curve:

$$S_t = 693G_t + 1{,}284(1-0.05)G_{t-1} + 1{,}433(1-0.05)^2 G_{t-2} + 2{,}000(1-0.05)^3 SP_{t-2} \tag{A.6}$$

Next, we estimate the demand for HMS surgeries. We first estimate the "net" incidence for blindness I_t^B and low vision I_t^L as the difference between status quo prevalence estimates as in Equations A.7 and A.8:

$$I_t^B = B_t^C - B_{t-1}^C \tag{A.7}$$

$$I_t^L = L_t^C - L_{t-1}^C \tag{A.8}$$

Equations A.7 and A.8 do not indicate the total incidence for the year because there are also cataract surgeries performed under the status quo. Here we are implicitly modeling the new cataract cases that are not handled by existing providers and thus are potentially available for HMS practitioners to treat. We assume that HMS does not capture market share from existing surgical centers.

To estimate the prevalence under the HMS intervention, we need estimates of overall and VI-related death rates by continent region. We also need to know how the death rates change over time. We use the U.S. Census Bureau's crude death rate forecasts by country to estimate the continent region death rate forecasts. Let d_t be the U.S. Census Bureau death rate forecast for year t. McCarty et al. (2001) estimate that the death rates for VI is about 2.34 times that of the death rate for those without visual impairment; in our estimation, we assume this to be true. Therefore, given our VI forecasts (Equation A.4), we can estimate VI death rates d_t^{VI} and

non-VI death rates d_t^{NVI} over time. Equation A.9 displays the estimate for d_t^{NVI} and Equation A.10 displays the estimate for d_t^{VI}:

$$d_t^{NVI}=d_t P_t/[(P_t-(VI_t^C/c))+2.34(VI_t^C/c)] \quad \text{(A.9)}$$

$$d_t^{VI}=2.34 d_t^{NVI} \quad \text{(A.10)}$$

In Equation A.9, (VI_t^C/c) is the number of people who are visually impaired due to any cause, P_t is the total population, and $(P_t-(VI_t^C/c))$ is the number of people who are not visually impaired.

Let $VI_t^{C,HMS}$ be the resulting VI prevalence in year t, $B_t^{C,HMS}$ be the resulting blindness in year t, and $L_t^{C,HMS}$ be the resulting low vision in year t under the HMS intervention. An important aspect to consider is the uptake fraction λ. As indicated in the text, we run scenarios for three different uptake percentages: 0.2, 0.5, and 0.8.

Let $W_t^{B,HMS}$ be the number of blind people who are willing to receive HMS surgeries in year t. Let $W_t^{L,HMS}$ be the number of low-vision people who are willing to receive HMS surgeries in year t. In 2013, $W_{2013}^{B,HMS}$ is equal to $\lambda B_{2013}^{C,HMS}$, and $W_{2013}^{L,HMS}$ is equal to $\lambda L_{2013}^{C,HMS}$. Similarly, let $N_t^{B,HMS}$ be the number of blind people who are not willing to receive HMS surgeries in year t. Let $N_t^{L,HMS}$ be the number of low-vision people who are not willing to receive HMS surgeries in year t. In 2013, $N_{2013}^{B,HMS}$ is equal to $(1-\lambda)B_{2013}^{C,HMS}$, and $N_{2013}^{L,HMS}$ is equal to $(1-\lambda)L_{2013}^{C,HMS}$. In subsequent years, $N_t^{B,HMS}$ is equal to $(1-\lambda)I_{t-1}^{B}+(1-d_t^{VI})N_{t-1}^{B,HMS}$ and $N_t^{L,HMS}$ is equal to $(1-\lambda)I_{t-1}^{L}+(1-d_t^{VI})N_{t-1}^{L,HMS}$.

The supply of surgeries is modeled as being distributed evenly across the cataract-caused blind and low-vision population. For example, if 20 percent of the cataract-caused VI population is blind and 80 percent has low vision, we model that 20 percent of the surgeries supplied by HMS practitioners are performed on blind patients and 80 percent are performed on low-vision patients. To model this effect, we need estimates for every year of the proportion of cataract-caused VI people who are blind. Let q_t^B be the proportion of cataract-caused VI patients who are blind at year t. We define q_t^B as equal to $(W_{t-1}^{B,HMS}(1-dt^{VI})+\lambda I_{t-1}^{B})/((W_{t-1}^{B,HMS}+W_{t-1}^{L,HMS})(1-d_t^{VI})+\lambda(I_{t-1}^{B}+I_{t-1}^{B}))$. We then define the proportion of cataract-caused VI patients who have low vision q_t^L as equal to $(1-q_t^B)$.

Equations A.11, A.12, and A.13 display how the willingness estimates are updated:

$$W_t^{B,HMS}=max\{2[\lambda I_{t-1}^{B}+W_{t-1}^{B,HMS}(1-d_t^{VI})]-q_t^B S_{t-1},0\}/2 \quad \text{(A.11)}$$

$$W_t^{L,HMS}=max\{2[\lambda I_{t-1}^{L}+W_{t-1}^{L,HMS}(1-d_t^{VI})]-q_t^L S_{t-1},0\}/2 \quad \text{(A.12)}$$

$$W_t^{VI,HMS}=W_t^{B,HMS}+W_t^{L,HMS} \quad \text{(A.13)}$$

Then, to estimate the total prevalence, $B_t^{C,HMS}$ is the sum of $N_t^{B,HMS}$ and $W_t^{B,HMS}$; $L_t^{C,HMS}$ is the sum of $N_t^{L,HMS}$ and $W_t^{L,HMS}$; and $VI_t^{C,HMS}$ is the sum of $B_t^{C,HMS}$ and $L_t^{C,HMS}$. As noted in the text, we assume that all cataract-caused VI patients need bilateral cataract surgery. This may be an overestimate of demand, but recall that classification of VI is on the eye with better vision. We have found no literature that has global estimates of bilateral or single cataract. The model

allows the number of surgeries, hence blindness, to be limited by supply of surgeries or by demand. In Equation A.13, $W_t^{VI,HMS}$ is the number of cataract-caused visually impaired people who are willing to receive HMS surgery.

The above assumes that demand is simply the number of cataract-caused VI cases. In practice, many such individuals are unable or unwilling to have surgery. We therefore modify the model for different assumptions about uptake, defined here as the share of cataract-caused visually impaired who are willing to receive HMS surgery.

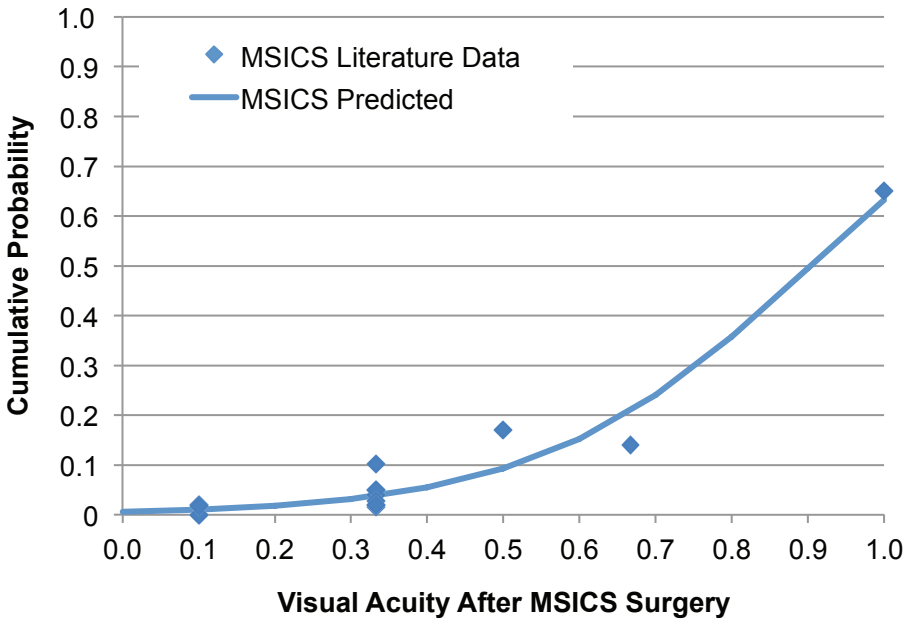
Note that these equations do not include the small share who have had poor outcomes due to cataract surgeries performed by HMS practitioners. We must estimate these cases so that they contribute to our estimate of VI prevalence as well as economic productivity loss. We collected data on MSICS VA outcomes after surgery from the literature (Ruit et al., 2000; Hennig et al., 2003; Ruit et al., 2006) and fit a statistical logit regression model to the collected data reported in these studies. Using the fitted model, we predict the probability of having adequate vision, low vision, or blindness after MSICS surgery. Figure A.1 displays the collected data and the predictive values of the logit model. The vertical axis of Figure A.1 is the probability that VA will be less the given VA. As an example, the probability that an MSCIS patient has VA less than 0.5 (i.e., 20/40) after surgery is approximately 0.1.

Let F be the cumulative probability and VA be the visual acuity. We fit the following model to these data:

$$F(VA)=\{1+exp[-1(5.1-5.6VA)]\}^{-1} \quad \text{(A.14)}$$

Using this model, we predict that the probability of adequate vision is 0.962, low vision is 0.030, and blind is 0.008.

Figure A.1
Predictive Model of Visual Acuity After MSICS Surgery



We use these probability estimates to estimate the total VI population that contributes to economic productivity loss. Equations A.15 and A.16 display the modified equations to estimate the blindness and low vision including those who had poor outcomes from HMS surgeries.

$$B_t^{C,HMS\prime} = B_t^{C,HMS} + 0.008 min\{2[\lambda I_{t-1}^{B} + W_{t-1}^{B,HMS}(1-d_t^{VI})], q_t^{B} S_{t-1}\}/2 \quad \text{(A.15)}$$

$$L_t^{C,HMS\prime} = L_t^{C,HMS} + 0.030 min\{\lambda I_{t-1} L + W_{t-1}^{L,HMS}(1-d_t^{VI}),\ q_t^{L} S_{t-1}\}/2 \quad \text{(A.16)}$$

Forecasting Economic Productivity Loss

To estimate the economic productivity loss, we generally follow the method described in Smith et al. (2009). The approach is applied both to the status quo and HMS scenarios. Smith et al. provide a method for estimating economic productivity loss that uses region-specific values for disability weights for the visually impaired (d_B for blind and d_L for low vision), labor force participation rates *LFPR*, and employment rates *ER*, defined as the share of the those in the labor force who are actually employed, i.e., not unemployed. We expand Smith et al.'s method by forecasting many years into the future and incorporating GDP per capita growth. There are several assumptions made to estimate the economic productivity loss.

First, the disability rates, *LFPR*s, and *ER*s remain constant over time. This may not be true in reality, but we were unable to find forecasted changes of these weights over time. These assumed rates are displayed in Table A.3 and A.4.

Second, the GDP per capita growth follows the schedule specified in Mathers and Loncar (2006) and is shown in Table A.5.

Third, caretakers of blind people lose 10 percent of their productivity annually, and caretakers of low-vision people lose 5 percent of their productivity annually (following Smith et al.).

Those under 15 are assumed not to be productive economically. As noted in the text, this simplification has little impact on results since cataract blindness and VI is so strongly associated with older age. For each year, the unadjusted economic productivity loss due to cataract-caused blindness (UE_t^B) and cataract-caused low vision (UE_t^L) are estimated using equations A.17 and A.18 below. Equation A.19 is the VI unadjusted economic productivity loss. This is estimated separately for ages 15–49 and age 50 and over, allowing for different labor force participation rates (as well as prevalence of cataract blindness and VI) of these age groups. The "a" and "b" notation after equations A.17–A.19 denote estimates for ages 15–49 and age greater than or equal to 50, respectively.

$$UE_t^{B,15-49} = B_t^{C,HMS\prime}[c(p^{15-49}P_t^{15-49})/B_t^{C}](0.10+d_B)GDP_t \quad \text{(A.17a)}$$

$$UE_t^{B,\geq 50} = B_t^{C,HMS\prime}[c(p^{\geq 50}P_t^{\geq 50})/B_t^{C}](0.10+d_B)GDP_t \quad \text{(A.17b)}$$

$$UE_t^{L,15-49} = L_t^{C,HMS\prime}[rc(p^{15-49}P_t^{15-49})/L_t^{C}](0.05+d_L)GDP_t \quad \text{(A.18a)}$$

$$UE_t L^{\geq 50} = L_t^{C,HMS\prime}[rc(p^{\geq 50}P_t^{\geq 50})/L_t^{C}](0.05+d_L)GDP_t \quad \text{(A.18b)}$$

$$UE_t^{VI,15–49} = UE_t^{B,15–49} + UE_t^{L,15–49} \quad \text{(A.19a)}$$

$$UE_t^{VI,\geq 50} = UE_t^{B,\geq 50} + UE_t^{L,\geq 50} \quad \text{(A.19b)}$$

In these equations, $[c(p^{15–49}P_t^{15–49} + p^{\geq 50}P_t^{\geq 50})/B_t^C]$ and $[rc(p^{15–49}P_t^{15–49} + p^{\geq 50}P_t^{\geq 50})/L_t^C]$ are the proportion of cataract-caused blind people who are older than 15 and the proportion of cataract low-vision people older than 15 respectively. GDP_t is the GDP per capita at year t. The disability weights used are those provided in Mathers et al. (2003):

To estimate GDP_t, we use the 2009 GDP per capita estimates from the United Nations as displayed in Table A.4 (United Nations Statistics Division, 2010).

We then use the estimates for GDP growth rate given in Mathers and Loncar (2006):

Let g_t be the GDP growth rate as specified in Table A.5 for year t. Let *GDP2009* be the 2009 GDP per capita estimate in Table A.4. Equation A.20 is the GDP per capita estimate for year t given that $t \geq 2010$.

$$GDP_t = (1 + g_t - 1)GDP_{t-1} \quad \text{(A.20)}$$

Next, we calculate the adjusted economic productivity loss AE_t^{VI} using the *LFPR* and *ER*, following the approach of Smith et al. However, we want to allow for the fact that the older and younger age groups in the model (15–49 and 50 and older) will have different participation rates, namely, participation is normally lower among the older group. This is important for modeling the economic impact of cataracts, since it is older adults who are more likely to have cataracts. (Smith et al. deal with this issue by reporting two separate sets of results, one assuming those 50 or older contribute the same as those 16–49, the other assuming no economic contribution from those 50 or older.) We derive participation rates using information provided by region in Kapsos (2007). Kapsos (in his Table A.4.2) provides these rates for highly disaggregated age groupings, e.g., 50–54, 55–59, 60–64, 65+. Our participation rates for age 15–49 and 50 and over are calculated as weighted averages of the rates for these subgroups, with the population weights derived from the forecasted population. We do not have separate information by age and region for the rate of employment of those in the labor force, so we assume the

Table A.3
Low-Vision and Blindness Disability Rates Used to Calculate Economic Productivity Loss

Region	Low-Vision Disability Rates	Blind Disability Rates
AFR	0.2790	0.5940
AMR 1	0.2550	0.5110
AMR 2	0.2616	0.5440
EMR	0.2636	0.5550
EUR	0.2569	0.5210
SEAR	0.2684	0.5670
WPR	0.2694	0.5619
Global	0.2665	0.5560

Table A.4
GDP per Capita by Region

Continent Region	2009 GDP per Capita (in 2010 US$)
AFR	1,194
AMR 1	43,168
AMR 2	6,998
EMR	3,497
EUR	22,218
SEAR	1,289
WPR A	40,500
WPR B	4,033
Global	8,478

same rates from Smith et. al. for both age groups. (Table A.6 lists the *LFPR* and *ER* used in this adjustment.)

Therefore, the adjusted economic productivity loss is:

$$AE_t^{VI} = ER \cdot (LFPR^{15-49} \cdot UE_t^{VI,15-49} + LFPR^{\geq 50} \cdot UE_t^{VI,\geq 50}) \quad \text{(A.21)}$$

where $LFPR^{15-49}$ and $UE_t^{VI,15-49}$ are the labor force participation rate and unadjusted economic productivity loss, respectively, for ages 15–49, and $LFPR^{\geq 50}$ and $UE_t^{VI,\geq 50}$ are the equivalent figures for ages 50 and above.

Table A.5
Assumed GDP Growth Rates

	Years		
Continent Region	2002–2005	2006–2015	2015–2040[a]
AFR	0.020	0.021	0.025
AMR A	0.030	0.030	0.030
AMR BD	0.020	0.024	0.027
EMR	0.029	0.026	0.025
EUR	0.059	0.036	0.030
SEAR	0.047	0.042	0.033
WPR A	0.023	0.024	0.025
WPR B	0.064	0.054	0.037

[a] Mathers and Loncar (2006) only assume through 2030; we extrapolated the assumption to 2040.

Table A.6
Labor Force Participation Rates by Age Group and Employment Rate for Each Continent Region

	Labor Force Participation Rate		
Continent Region	Age 15–49	Age≥50	Employment Rate
AFR	0.750	0.692	0.715
AMR 1	0.771	0.453	0.923
AMR 2	0.725	0.486	0.872
EMR	0.539	0.399	0.677
EUR	0.738	0.332	0.862
SEAR	0.621	0.517	0.872
WPR 1	0.839	0.465	0.932
WPR 2	0.830	0.500	0.944

Forecasting HelpMeSee Disability Adjusted Life Years Averted

As mentioned in Chapter Six in the section on disease burden and economic productivity, we calculate DALYs using a prevalence-based rather than incidence-based method. To do this, we first estimate the YLL and the Years Lost Due to Disability YLD. The basis of calculating the YLL in the prevalence method is a comparison for each year of the status quo population size with the population under the assumption that there is no visual impairment (the No-VI scenario). VI makes a difference to population because it contributes to early mortality. Then we take the population difference between the status quo and the No-VI cases (and, for analysis in Chapters Six and Seven) the HMS and No-VI cases to estimate the number of person years lost in a given year. To calculate the YLD, we multiply the prevalence by the disability weights for a given year as suggested by Murray (1994). The details of this approach are discussed below.

For this comparison of DALYs under different scenarios, we cannot use the U.S. Census Bureau forecast of status quo population and VI prevalence as described earlier. Although those forecasts are likely very accurate, they do not include forecasts of the population without VI (the Census Bureau estimates incorporate mortality from VI and many other factors). Recall that total population forecasts are needed to estimate the DALYs. Therefore, we have to use a method to forecast population that, while less sophisticated than the Census Bureau's method, allows us to produce population estimates that differ only due to VI-related mortality and not due to differing forecasting methods. The U.S. Census Bureau forecasts are very complex, and take into account multiple advanced population phenomena including immigration, emigration, fertility trends, and mortality trends that our method of forecast does not consider. Without actually running the same complex model, we cannot create a population forecast that differs from the Census Bureau estimates only through VI mortality. Therefore, for purposes of estimating DALYs, we use the simpler method to forecast both the status quo population and the population given no VI (and population under HMS). In fact, the status quo forecasts using this method ended up being quite similar to those using the Census Bureau forecasts in Chapter Five of this report.

To get these population estimates, we first estimate the population dynamics including birth rates and mortality rates. We estimate the mortality rate using the overall death rates

forecasted by the U.S. Census Bureau as described earlier in the this Appendix. We use the U.S. Census Bureau estimates of birth rates b_t over time.

Given the death rates and the Census Bureau's population forecast for 2014, we can forecast the population F given that there is no VI for t greater than 2014:

$$F_t^{NVI}=F_{t-1}^{NVI}-d_t^{NVI}F_{t-1}^{NVI}+b_tF_{t-1}^{NVI}=F_{t-1}^{NVI}(1-d_t^{NVI}+b_t) \quad \text{(A.22)}$$

Equation A.23 forecasts the population under the status quo:

$$F_t^{SQ}=F_{t-1}^{SQ}+b_tF_{t-1}^{SQ}-FVI_{t-1}^{SQ}d_t^{VI}-(F_{t-1}^{SQ}-FVI_{t-1}^{SQ})d_t^{NVI} \quad \text{(A.23)}$$

In Equation A.23, FVI is the forecasted VI and is estimated as specified in the following:

$$FVI_t^{SQ}=FVI_{t-1}^{SQ}+i_t^{VI}F_{t-1}^{SQ}-d_t^{VI}FVI_{t-1}^{SQ} \quad \text{(A.24)}$$

In Equation A.24, i^{VI} is the VI incident rate due to all causes (i.e., proportion) calculated from the status quo estimates of prevalence (i.e., $i_t^{VI}=VI_t^C/c-VI_{t-1}^C/c$). Therefore, the status quo population with cataracts $F_t^{SQ,C}$ is estimated as:

$$F_t^{SQ,C}=FVI_t^{SQ}-F_t^{SQ,NC} \quad \text{(A.25)}$$

$F_t^{SQ,NC}$ is the forecast population of VI cases with no cataracts and is estimated as Equation A.26.

$$F_t^{SQ,NC}=F_{t-1}^{SQ,NC}+i_t^{VI}(1-c)F_t^{SQ}-d_t^{VI}F_{t-1}^{SQ,NC} \quad \text{(A.26)}$$

Estimates of the population forecasts under the HMS are similar to the status quo just described. The main difference is that, under the HMS intervention, cataract-caused VI forecast must consider the effect of the surgeries performed by the practitioners. Equation A.27 displays the overall population forecast under the HMS intervention scenario:

$$F_t^{HMS}=F_{t-1}^{HMS}+b_tF_{t-1}^{HMS}-FVI_{t-1}^{HMS}d_t^{VI}-(F_{t-1}^{HMS}-FVI_{t-1}^{HMS})d_t^{NVI} \quad \text{(A.27)}$$

Equation A.28 displays the forecast of VI due to all causes FVI_t^{SQ}.

$$FVI_t^{HMS}=FVI_{t-1}^{HMS}+i_t^{VI}F_{t-1}^{HMS}-d_t^{VI}FVI_{t-1}^{HMS}-min\{R_{t-1}^{HMS,C}+i_t^{VI}c\lambda F_{t-1}^{HMS},S_{t-1}\} \quad \text{(A.28)}$$

$R^{HMS,C}$ is the remaining cataract-caused VI population from year 2014. Over time, as the surgeries are delivered, this remainder decreases until it is eventually zero. This remainder is estimated as:

$$R_t^{HMS,C}=max\{(1-dt^{VI})R_{t-1}^{HMS,C}-S^{t-1},0\} \quad \text{(A.29)}$$

Therefore, the estimates for the population with cataract-caused VI and VI caused by something other than cataracts are Equations A.30 and A.31 respectively:

$$F_t^{HMS,C} = FVI_t^{HMS} - F_t^{HMS,NC} \quad \text{(A.30)}$$

$$F_t^{HMS,NC} = F_{t-1}^{HMS,NC} + i_t^{VI}(1-c)F_t^{HMS} - dt^{VI}F_{t-1}^{HMS,NC} \quad \text{(A.31)}$$

Using Equations A.22 through A.31, YLD is estimated as the number of cases of cataract-caused blindness and low-vision multiplied by the appropriate disability rate in Table A.3.

Finally, YLLs for the status quo and HMS intervention for a given year are estimated as:

$$YLL_t^{SQ} = F_t^{NVI} - F_t^{SQ} \quad \text{(A.32)}$$

$$YLL_t^{HMS} = F_t^{NVI} - F_t^{HMS} \quad \text{(A.33)}$$

As indicated, the sum of YLL and YLD for a given year is the sum of DALYs for that year from cataract-related VI. For estimating the effect on DALYs of the HMS intervention over a given time interval (say ten years), we add up the DALYs for each year with HMS and without it (the status quo). The DALYs are a function of the prevalence under each scenario. Future DALYs are discounted at 3 percent. The difference between these cumulative measures for the status quo and HMS scenarios is the number of DALYs averted (or healthy life years gained) over the period as a result of the intervention.

APPENDIX B

Sensitivity Analysis—Practitioner Attrition and Trainee Intake

Figure B.1
Cataract-Caused VI Prevalence Under Different Annual Attrition Rate Assumptions (for 50% HMS Uptake Rate)

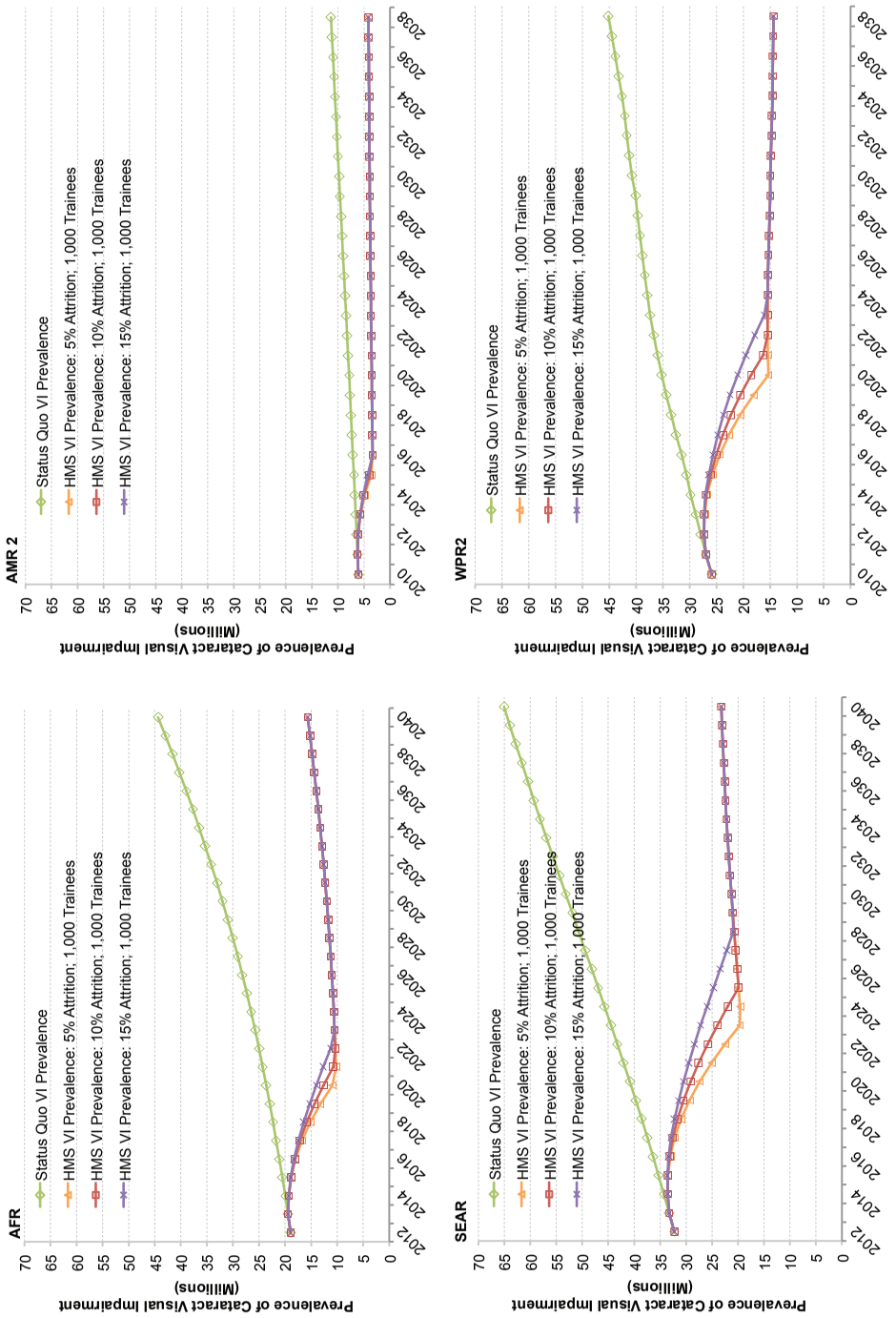
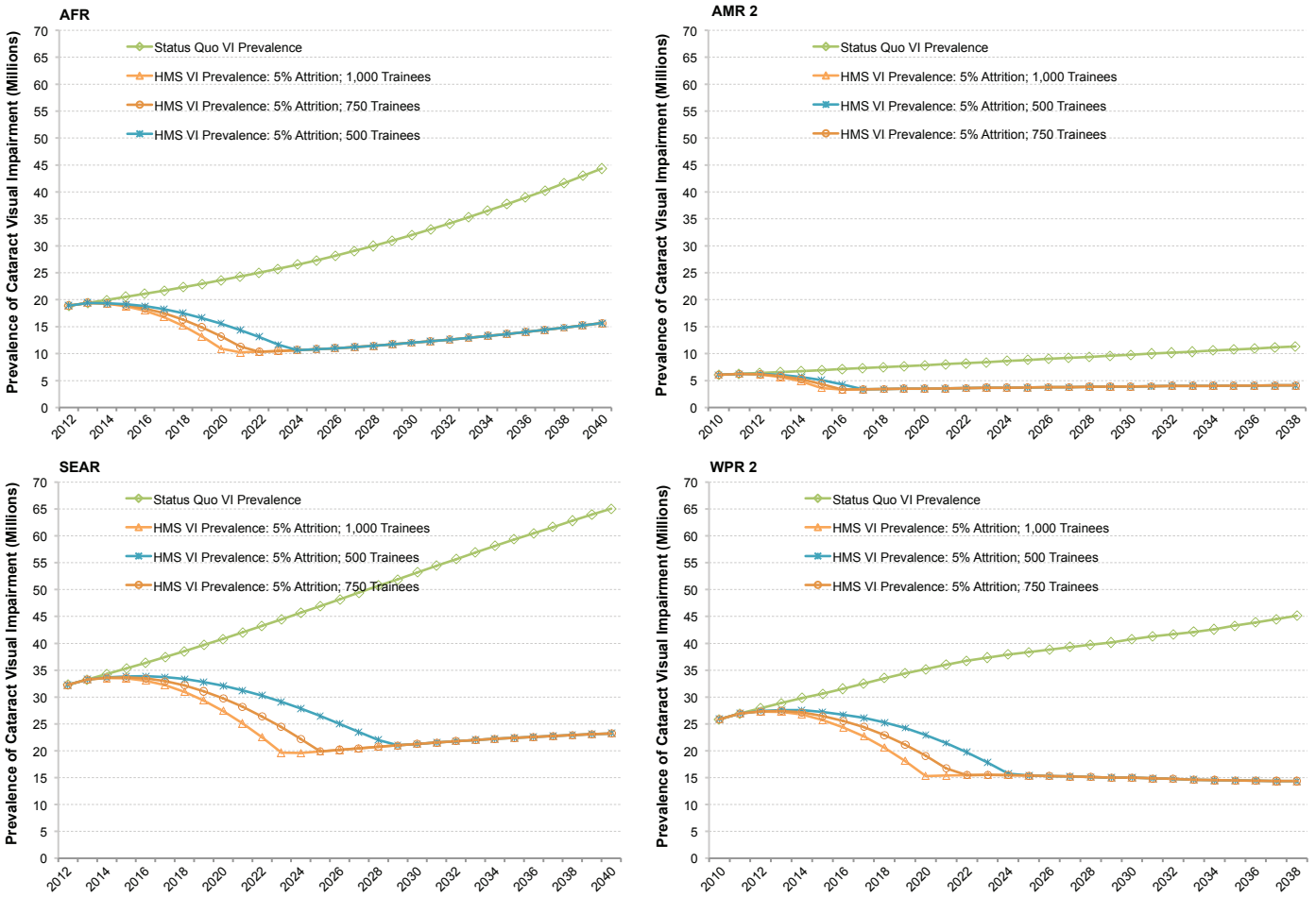


Figure B.2
Cataract-Caused VI Prevalence Under Different Annual Trainee Intake Assumptions (for 50% HMS Uptake Rate)



APPENDIX C

Detailed Input Costs and Methodology

This appendix reports the cost estimates from HMS and discusses the derivation of Aravind costs used for the cost-per-surgery comparisons in Chapter Seven. We have subdivided these costs into six groups:

- Training Center Startup Cost
- Training Center Annual Operating Cost
- Service Delivery Startup Costs
- Service Delivery Salary Costs
- Service Delivery Operating Costs of Surgical Supplies
- Simulator Research and Development Startup Costs.

Tables C.1–C.6 show these costs.

Table C.1
Training Center Startup Cost

Item	Number needed per center	Cost per item (US$)	Total Cost (US$)	Economic Life (years)	Annualized Cost (US$)	Intended Payer	Cost Category for Adjustment
Infrastructure							
Land purchase (sq.ft)	110,000	5	550,000		16,500	Host Country	Building
Construction of building	60,000	30	1,800,000	12	180,832	Host Country	
Backup generators (200 KV)	2	18,000	36,000	12	3,617	Host Country	
Simulators needed	12	250,000	3,000,000	12	301,386	HMS	
Water well	1	50,000	50,000	12	5,023	HMS	
Information technology setup	1	520,000	520,000	12	52,240	HMS	
Live surgery operating theater equipment[a]	2	30,000	60,000	12	6,028	HMS	
Transportation							
Full-sized vehicles	3		72,000	10	8,441	HMS	
Bicycles/motorcycles	20		72,000	10	8,441	HMS	
Total			**6,160,000**		**582,507**		

[a] For projected monthly volume of 300 cases.

Table C.2
Training Center Annual Operating Cost

Item	Annual Cost (US$)	Intended Payer	Cost Category for Adjustment
Facility			
Utilities (water, electricity, Internet)	30,000	HMS	
Simulator maintenance	24,000	HMS	
Student visas (US$22/student)	11,800	HMS	
Advertising, financial aid, capital fund raising	2,268,000	HMS	
Facility maintenance	108,000	HMS	
Food (students and staff six days per week)	816,000	HMS	
Staff			
Faculty (surgical and nonsurgical instructors)	864,000	HMS	Salary
Administrative	240,000	HMS	Salary
Recruitment/student services	36,000	HMS	Salary
Dormitory maintenance and food prep staff	28,800	HMS	Salary
Security staff	24,000	HMS	Salary
Surgical			
Surgical nurse	18,000	HMS	Salary
Scrub nurse	9,600	HMS	Salary
Instrument tech	6,000	HMS	Salary
Live surgical costs	1,320,000	HMS	Supplies
Transportation			
Vehicle maintenance	36,000	HMS	
Total	**5,840,200**		

Table C.3
Service Delivery Startup Costs

Item	Quantity Needed	Projected Unit Cost (US$)	Total Cost per Practitioner (US$)	Economic Life (years)	Annualized Cost (US$)	Intended Payer	Cost Category for Adjustment
Office							
Office space (rent or owned)(sq.ft.)	1,000	30	30,000	12	3,014	Practitioner	Building
Operating room space(sq.ft)	800	30	24,000	12	2,411	Practitioner	Building
Land (optional) (sq.ft)	5,000	2	10,000		300	Practitioner	
Business equipment	basic	1,000	1,000	10	117	Practitioner	
Furniture	basic	500	500	12	50	Practitioner	
Generator (depending on local infrastructure)		2,000	2,000	12	201	Practitioner	
Water well (depending on local infrastructure)		3,000	3,000	12	301	Practitioner	
Ophthalmic Examination Equipment							
Patient exam chair	2	150	300	10	35	HMS	Supplies
Surgeon exam chair	2	80	160	10	19	HMS	Supplies
Writing desk	2	80	160	10	19	HMS	Supplies
Snellen & E visual acuity chart	3	4	12	10	1	HMS	Supplies
Scan optics pinhole occluder	2	68	136	10	16	HMS	Supplies
Pen light	4	12	48	10	6	HMS	Supplies
Kowa portable slit lamp	2	4,000	8,000	10	938	HMS	Supplies
Keeler standard professional combi set[a]	1	1,047	1,047	10	123	HMS	Supplies
Perkins hand-held tonometer	2	1,080	2,160	10	253	HMS	Supplies
Sonomed 300A A scan	1	2,492	2,492	10	292	HMS	Supplies
Nidek manual keratometer	1	2,690	2,690	10	315	HMS	Supplies
Nidek KM 500 auto keratometer	optional	5,444	5,444	10	638	HMS	Supplies

Table C.3—Continued

Item	Quantity Needed	Projected Unit Cost (US$)	Total Cost per Practitioner (US$)	Economic Life (years)	Annualized Cost (US$)	Intended Payer	Cost Category for Adjustment
Surgical							
Takagi OM5 operating microscope with beam splitter	1	11,139	11,139	10	1,306	HMS	Supplies
Aurolab wet field cautery unit & cables	1	203	203	10	24	HMS	Supplies
Mayo stand	2	238	476	10	56	HMS	Supplies
I.V. pole	2	141	282	10	33	HMS	Supplies
Operating table	2	3,525	7,050	10	826	HMS	Supplies
Surgeon operating stool with casters	2	51	102	10	12	HMS	Supplies
Instrument trays with lid	5	24	119	10	14	HMS	Supplies
Ambu bag (TTM)	2	63	126	10	15	HMS	Supplies
Nelcor pulse oxymeter and sensor	2	1,867	3,734	10	438	HMS	Supplies
Patient head rest (Reuben pillow)	2	423	846	10	99	HMS	Supplies
Surgical supplies—nondisposable			150	10	30	HMS	Supplies
Total			**117,376**		**11,903**		

[a] Includes direct ophthalmoscope, retinoscope, charger, and lithium batteries.

Table C.4
Service Delivery Annual Operating (Salary) Cost per Surgeon per Year

Item	Annual Cost (US$)	Intended Payer	Cost Category for Adjustment
HelpMeSee practitioner	9,000	HMS	Salary
Nurse	8,000	HMS	Salary
Front office manager	3,500	HMS	Salary
Supplies manager	3,500	HMS	Salary
Total	24,000		

Table C.5
Service Delivery Operating Costs of Surgical Supplies (Cost per Surgery)

Item	Cost Per Surgery (US$)	Intended Payer	Cost Category for Adjustment
Surgical supplies	5	HMS	Supplies
Surgical disposables and consumables	8	HMS	Supplies
Surgical instruments—disposable	9	HMS	Supplies
Total	22		

These costs have different intended payers. Some costs are to be paid by a local host country or organization. HMS will pay most of the costs, while the practitioners are responsible for some of their delivery startup costs and are expected to cover their operating costs with fee reimbursements from HMS.

Tables C.1 and C.3 show the startup costs for the training center and surgical practices, respectively. WHO recommends that, for cost-effectiveness analysis, startup costs be spread out over the economic lifespan of the items. The economic life estimates in these two tables come from the California State Board of Equalization (2008) publication economic lives in assessor's handbook. Based on the WHO recommendation, we estimate the annualized value of the asset using a 3 percent interest rate. Let PV be the present value of the asset at time of purchase and let N be the economic life of the asset. The annualized value A of the asset as recommended by WHO is:

$$A = PV \cdot \{[1-(1+0.03)^{(-N)}]/0.03\}^{(-1)} \quad \text{(C.1)}$$

Equation C.1 is for capital assets excluding land. Since land does not lose value, WHO recommends annualizing the cost of land by using the opportunity cost (rental rate). In the absence of reliable data on land rental rates for different regions, we use 3 percent as the opportunity cost interest rate and 3 percent as the annual discount factor. Because the interest rate and discount factor are the same, the annualized land cost is 3 percent that of the purchase cost.

Putting Costs in International Dollars and Adjusting for Regional Differences

As noted in the text, we convert costs to international dollars to facilitate comparison of costs in different countries and regions. Costs in local currency units are converted using PPP exchange rates. Unlike market exchange rates, the PPP exchange rate shows the numbers of units of a country's currency needed to purchase, in that country, the same amount of goods and services that US$1 would buy in the United States. Thus, an international dollar has the same purchas-

Table C.6
Simulator Research and Development Startup Costs

Item	Total Cost (US$)	Economic Life (years)	Annualized Cost	Annualized Cost per Region	Intended Payer
Simulator research and development	$25,000,000	25	$1,435,697	$358,924	HMS

ing power that the U.S. dollar has in the United States, and as a result, costs from different countries expressed in international dollars are directly comparable.

If one has input costs in local currencies, then, the procedure is just a matter of converting to international dollars using published PPP rates. This is only done for goods or services that are not considered tradable, that is, items such as local labor, rent, land, maintenance, and food. Since these items are not easily traded across countries (for example, labor does not freely migrate), price difference across countries will exit. PPP adjusts for differences across countries in these items. In contrast, internationally traded goods are items that are known to be imported, or could have been imported, such as medical equipment, supplies and pharmaceuticals. Since these inputs can be traded freely internationally, a single international price applies.[1] Therefore they are already effectively in international dollars and directly comparable, so for these items the PPP adjustment is not made.

The cost data provided to us by HMS are already in dollars, not local currencies. However, we assume that when individuals were consulted to translate local currency into dollars for HMS, it was done using market exchange rates. Therefore the costs for nontraded inputs need to be put in international dollars. This is done by multiplying the dollar cost by the ratio of the PPP rate to the market exchange rate.

Applying the conversion of input costs to international dollars is complicated by the fact that we were not able to obtain region-specific input cost data from HMS. Instead, the HMS costs in Table C.1 through C.5 were gathered from multiple sources and regions. We assume, therefore, that the figures overall represent an average of costs over the four regions in which HMS will be locating the training centers. This assumption allows us to derive an "average" PPP for the four regions (or specifically, an average ratio of PPP to market ER) which is then used to convert the figures to international dollars. HMS has said the likely locations for the initial centers (one per region) are India (SEAR), China (WPR2), Ethiopia (AFR) and Mexico (AMR). We obtain the ratio of PPP to market ER for these four countries from the World Bank's online statistics and calculate the simple average of this ratio. This, in turn, is used to convert the average costs of nontraded inputs from HMS into international dollars.

As noted, these costs—now expressed in international dollars—are to be considered averages over the four regions. We now want to allow for the differences in costs across regions as we want to calculate costs and cost-effectiveness by region. For example, labor costs for trained health personnel are much higher in mostly middle-income WPR2 than in mostly low-income Africa (again this issue concerns only nontraded goods, primarily salaries and buildings). Mulligan et al. (2005) provide estimates of unit costs for key health care inputs across WHO regions, including staff salaries (for five levels of health care workers, building costs per square meter, and inpatient visit costs). We are able to use this information to convert our average costs for specific nontraded inputs into region-specific costs by using the ratio of each region's cost of the input to the average cost for all the regions. Specifically, we used the relative difference of the staffing costs (of level-three health care workers, e.g., registered nurses) to adjust salary costs, the relative difference of the building costs to adjust for building expenses, and

[1] This is not completely accurate, since transport costs will lead to differences across countries or regions. The present analysis ignores this complication.

the relative difference of inpatient visit costs to adjust all other nontradable items (labeled as "supplies" in the preceding tables).[2]

Because numerous assumptions about costs are used in the above calculations, it is appropriate to treat the estimates as very preliminary.

Aravind Costs

The list of costs that Aravind provided included detail on assets (land, buildings, and equipment), administrative and utility costs, staff salaries and operating costs for the year ending March 2011. For Aravind's assets and land costs, we annualized the costs in the same way as described above. The costs were provided in rupees and converted to international dollars, using PPP exchange rates for nontraded inputs and market exchange rates for traded inputs as discussed above with reference to HMS costs.

[2] One could more simply just use PPPs to generate region specific prices from the average for a given input. However, the PPPs are based on prices of a large basket of goods and services. The estimates in Mulligan et al. are better to use as they provide specific measures of cost differences for individual health inputs.

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