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| Citation          | Goldie, Sue J., Steve Sweet, Natalie Carvalho, Uma Chandra Mouli Natchu, and Delphine Hu. 2010. Alternative strategies to reduce maternal mortality in India: a cost-effectiveness analysis. PLoS Medicine 7(4): e1000264. |
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| Published Version | doi:10.1371/journal.pmed.1000264                                                                                                                                                                                                                                    |
| Citable link      | http://nrs.harvard.edu/urn-3:HUL.InstRepos:4553340                                                                                                                                                                                                                 |
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Alternative Strategies to Reduce Maternal Mortality in India: A Cost-Effectiveness Analysis

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Abstract

Background: Approximately one-quarter of all pregnancy- and delivery-related maternal deaths worldwide occur in India. Taking into account the costs, feasibility, and operational complexity of alternative interventions, we estimate the clinical and population-level benefits associated with strategies to improve the safety of pregnancy and childbirth in India.

Methods and Findings: Country- and region-specific data were synthesized using a computer-based model that simulates the natural history of pregnancy (both planned and unintended) and pregnancy- and childbirth-associated complications in individual women; and considers delivery location, attendant, and facility level. Model outcomes included clinical events, population measures, costs, and cost-effectiveness ratios. Separate models were adapted to urban and rural India using survey-based data (e.g., unmet need for birth spacing/limiting, facility births, skilled birth attendants). Model validation compared projected maternal indicators with empiric data. Strategies consisted of improving coverage of effective interventions that could be provided individually or packaged as integrated services, could reduce the incidence of a complication or its case fatality rate, and could include improved logistics such as reliable transport to an appropriate referral facility as well as recognition of referral need and quality of care. Increasing family planning was the most effective individual intervention to reduce pregnancy-related mortality. If over the next 5 y the unmet need for spacing and limiting births was met, more than 150,000 maternal deaths would be prevented; more than US$1 billion saved; and at least one of every two abortion-related deaths averted. Still, reductions in maternal mortality reached a threshold (~23%-35%) without including strategies that ensured reliable access to intrapartum and emergency obstetrical care (EmOC). An integrated and stepwise approach was identified that would ultimately prevent four of five maternal deaths; this approach coupled stepwise improvements in family planning and safe abortion with consecutively implemented strategies that incrementally increased skilled attendants, improved antenatal/postpartum care, shifted births away from home, and improved recognition of referral need, transport, and availability/quality of EmOC. The strategies in this approach ranged from being cost-saving to having incremental cost-effectiveness ratios less than US$500 per year of life saved (YLS), well below India’s per capita gross domestic product (GDP), a common benchmark for cost-effectiveness.

Conclusions: Early intensive efforts to improve family planning and control of fertility choices and to provide safe abortion, accompanied by a paced systematic and stepwise effort to scale up capacity for integrated maternal health services over several years, is as cost-effective as childhood immunization or treatment of malaria, tuberculosis, or HIV. In just 5 y, more than 150,000 maternal deaths would be averted through increasing contraception rates to meet women’s needs for spacing and limiting births; nearly US$1.5 billion would be saved by coupling safe abortion to aggressive family planning efforts; and with stepwise investments to improve access to pregnancy-related health services and to high-quality facility-based intrapartum care, more than 75% of maternal deaths could be prevented. If accomplished over the next decade, the lives of more than one million women would be saved.

Please see later in the article for the Editors’ Summary.

Citation: Goldie SJ, Sweet S, Carvalho N, Natchu UCM, Hu D (2010) Alternative Strategies to Reduce Maternal Mortality in India: A Cost-Effectiveness Analysis. PLoS Med 7(4): e1000264. doi:10.1371/journal.pmed.1000264

Academic Editor: Zulfiqar A. Bhutta, Aga Khan University, Pakistan

Received September 14, 2009; Accepted March 12, 2010; Published April 20, 2010

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Funding: John D. and Catherine T. MacArthur Foundation #07-89007-0 00GSS. The funder had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

Competing Interests: The authors have declared that no competing interests exist.

Abbreviations: bEmOC, basic emergency obstetrical care; cEmOC, comprehensive emergency obstetrical care; EmOC, emergency obstetrical care; GDP, gross domestic product; MDG, Millennium Development Goal; MMR, maternal mortality ratio; PPH, postpartum hemorrhage; SBA, skilled birth attendant; TFR, total fertility rate; YLS, year of life saved

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Introduction

Approximately one-quarter of all pregnancy- and delivery-related maternal deaths worldwide occur in India, which has the highest burden of maternal mortality for any single country [1,2]. Although the inclusion of maternal mortality reduction in the United Nations' Millennium Development Goals (MDGs) reflects the importance of improving maternal health as a key mechanism in reducing poverty and promoting social and economic growth, global progress has been suboptimal [2–4]. Several factors may be changing the landscape for maternal health in India in particular [3]. These factors include more information on maternal mortality measures [6,7], an increasing number of studies evaluating interventions [8], renewed determination on the part of the maternal health and public health communities [9], and, most importantly, the emergence of maternal mortality reduction as a clear priority on the Indian national political agenda [5,10–12].

Despite consensus on the need for universal access to high-quality intrapartum and emergency obstetrical care (EmOC), uncertainties remain about how to adapt “ideal recommendations” to specific situations [8,13]. The need for an adequate supply of skilled providers, functional referral and transport, and well-equipped facilities for EmOC will prove a formidable barrier in the near-term for countries with weak health systems, as well as for states with inadequate health delivery infrastructure and for communities in predominantly rural areas [13]. This challenge will be particularly relevant for India, with its largely rural population, and striking disparities between states. For example, while Kerala reports a maternal mortality ratio (MMR) of fewer than 100 maternal deaths per 100,000 live births, rural Uttar Pradesh and Rajasthan report MMRs of more than 400 [14,15].

To most effectively leverage India’s national commitment to reducing maternal mortality, identifying evidence-based strategies that consider the local context is imperative. Our analysis is motivated by questions that include: What are the fundamental drivers of the effectiveness, cost-effectiveness, and affordability of a package of interventions to reduce maternal mortality? Because adequate facilities, health infrastructure, and skilled human resources will not be readily available in all settings, can we provide interim guidance to policy makers? While no single empirical study can provide clear answers to these questions, a modeling approach within a decision-analytic framework can extend empiric information by extrapolating outcomes beyond the time horizon of a single study, can facilitate synthesis of multiple data sources in an internally consistent and epidemiologically plausible way [16], and may be adapted to specific settings so that existing infrastructure, resources, and political realities can be considered.

Previous model-based studies have provided important insights into the potential high public health value of reducing maternal deaths, however, many of these have not considered the full range of interventions to reduce maternal mortality, such as family planning, safe abortion, and intrapartum care [7,17,18]. Some have only focused on single interventions [19–21], others have not included costs [22], and recent analyses that did assess multiple strategies did not explicitly model critical barriers to life-saving referral, such as recognition of referral need and accessible transport [23,24]. Taking into account the costs, feasibility, and operational complexity of alternative interventions, we extend this body of work to estimate the clinical and population-level benefits associated with a comprehensive set of strategies to improve the safety of pregnancy and childbirth in India.

Methods

Analytic Overview

The best available data were synthesized using a computer-based model that simulates the natural history of pregnancy and relevant comorbidities, aggregates individual outcomes to the population level, and reflects setting-specific epidemiology. Separate models were adapted to urban and rural India using data on antenatal care, family planning, facility births, and skilled birth attendants (SBAs), and information about access to transport, referral facilities, and quality of care. Model outcomes include clinical events (e.g., pregnancies, live births, maternal complications), measures of maternal mortality (e.g., MMR, proportionate mortality ratio [i.e., proportion of deaths that are pregnancy-related among women aged 15–45 y], and lifetime risk of maternal death), population outcomes (e.g., life expectancy), and economic costs.

We evaluated alternative approaches to reducing maternal mortality in settings in India that differ according to underlying maternal risk, health, and socioeconomic status. Interventions can be provided individually or packaged into integrated services. Following standard recommendations for economic evaluation [25], strategies are first ranked in terms of increasing costs and benefits; those that are less effective and more costly than an alternative strategy are considered inefficient, and those that cost less than the status quo are considered “cost saving.” For all other strategies, we calculate an incremental cost-effectiveness ratio, defined as the additional cost of a specific strategy divided by its additional clinical benefit, compared with the next least expensive strategy. We considered interventions with cost-effectiveness ratios of less than the per capita gross domestic product (GDP) (US$1,068) to be very cost-effective as suggested by the Commission on Macroeconomics and Health. Sensitivity analyses are conducted to assess the impact of parameter uncertainty.

The Model

The computer-based Global Maternal Health Policy Model simulates the natural history of pregnancy (both planned and unintended) and pregnancy- and childbirth-associated complications (Figure 1). This model defines health states to reflect important characteristics that affect prognosis, quality of life, and resource use. The time horizon incorporates a woman’s lifetime and is divided into equal time increments during which women transition from one health state to another. Nonpregnant girls enter the model and in each time period may become pregnant depending on age, use of contraception, and clinical history (Figure 1, upper panel). Once pregnant, women have a chance of spontaneous abortion (i.e., miscarriage), induced abortion, or continued pregnancy. A proportion of induced abortions will be unsafe (i.e., surgical or medical abortion conducted by untrained personnel). Labor and delivery may be associated with a direct complication of pregnancy (e.g., hypertensive disorders of pregnancy, obstructed labor, hemorrhage, sepsis). Case fatality rates are conditional on the type and severity of complication (e.g., moderate sepsis requiring antibiotics versus severe hemorrhage requiring blood transfusion) and underlying comorbidity (e.g., anemia). Nonfatal complications include neurological sequelae, rectovaginal fistula, severe anemia, and infertility (Figure 1, upper panel). In addition to death from maternal complications, women face an annual risk of death from age-specific all-cause mortality.

Strategies in the model to reduce maternal mortality consist of improving coverage of effective interventions, which may be provided individually or packaged as integrated services. In addition to family planning, antenatal care (i.e., prenatal care) and treatment of anemia, safe abortion, and postpartum care, the model includes both intrapartum interventions that reduce the incidence of a complication (e.g., misoprostol for postpartum hemorrhage [PPH], clean delivery for sepsis), as well as those that
Figure 1. Schematic of the model. Upper panel: Model simulates the natural history of pregnancy (both planned and unintended) and pregnancy- and childbirth-associated complications. Case fatality rates for complications depend on severity and comorbidity. General intervention categories (open red boxes) include family planning for spacing or limiting births, antenatal or prenatal care (and treatment of anemia), safe abortion, intrapartum care (e.g., active management of labor), basic and comprehensive EmOC, and postpartum care. Interventions can reduce the incidence or severity of a complication or can reduce the case fatality rate through appropriate treatment. Lower panel: Model reflects the intervention pathway during labor and delivery, including location (home, birthing or health center, bEmOC, cEmOC), attendant (family member, traditional birth attendant [TBA], or SBA), and three potential barriers to effective treatment in the event of a complication, including recognition of referral need, transfer (e.g.,
reduce the case fatality rate through appropriate management in a referral facility (Figure 1, upper panel).

The effectiveness of interventions to either reduce the incidence of complications or to reduce case fatality rates associated with complications depends, in part, on access to specific services (e.g., trained SBA) and to specific levels of facilities (e.g., comprehensive EmOC [cEmOC] with capacity for blood transfusion). Accordingly, the ultimate impact of interventions depends on several setting-specific factors. These include delivery site, presence of birth attendant, quality and type of referral facility, as well as successful referral when necessary. The model therefore explicitly considers the location of delivery, type of assistance, access to basic or comprehensive obstetrical care, and the ability to overcome a series of barriers around the timing of delivery (e.g., recognition of referral need, reliable transport, timely treatment at an appropriate referral facility); these factors collectively determine the health services a woman can access and the specific interventions that would be included (Figure 1, lower panel).

Delivery setting is differentiated by provider (e.g., family member, traditional birth attendant [TBA], or SBA) and by site (e.g., home versus facility). Facility levels are categorized as (1) birthing centers or health centers, which cannot provide all services necessary to qualify as a basic emergency obstetrical care (bEmOC) facility, but are staffed with SBA who provide expectant management of labor and more reliable referral when necessary than with delivery at home; (2) facilities with bEmOC capacity (e.g., first referral units); and (3) facilities with cEmOC capacity (e.g., district hospitals) [26,27]. Facilities capable of bEmOC are assumed to be capable of administering injectable antibiotics, oxytocics, and sedatives or anticonvulsants, and performing manual removal of placenta, removal of retained products, and assisted vaginal delivery. Facilities capable of cEmOC also are able to provide blood transfusion, cesarean section, and management of advanced shock.

This model also allows us to evaluate phased approaches that involve scaling up access to services over time; the stepwise investments in infrastructure required to assure high-quality intrapartum care are designated as “upgrades.” In addition to reducing unmet need for family planning and unsafe abortion, four consecutively implemented strategies increased skilled attendants, improved antenatal/postpartum care, incrementally shifted births away from home, and improved the availability and quality of EmOC. For women delivering at home or in birthing centers, these “upgrades” also improved recognition of referral need, access to transport, and expedient referral to an appropriate facility (Figure 2).

All models were built using TreeAge Pro 2008 (TreeAge Software Inc.) and analyzed using IBM/Lenovo Dual-Core VT Pro Desktop computers running Microsoft Windows XP, using Microsoft Excel 2007 and Visual Basic for Applications 6.5 (Microsoft Corp.). We used Monte Carlo simulation to generate the number of per woman events such as pregnancies, live births, facility-based births, and maternal complications.

**Data**

Selected parameters and assumptions used in the model are provided in Tables 1 and 2 [7,14,15,17,22,23,28–73]. Additional details are provided in Text S1. Initial estimates of incidence and case fatality rates associated with pregnancy-related complications were obtained from published data, and a plausible range for sensitivity analysis was based on review of the literature. Case fatality rates were adjusted based on complication severity (e.g., life-threatening complications requiring cEmOC) and underlying severity of anemia (Table 1; Text S1). The effectiveness of interventions to reduce the incidence of complications (e.g., active management of labor) was estimated from published studies using methods detailed in Text S1. The effectiveness of interventions to reduce case fatality rates was from published studies and assumed treatment in an appropriate facility; a wide plausible range was used for sensitivity analyses (Table 1; Text S1). Data on facility births, SBA, family planning for spacing or limiting births, and antenatal care were from country-specific surveys [28].

For women delivering at home or in a birthing center, the probability of successful referral depended on overcoming three potential barriers [74]: (1) delay in recognizing referral need; (2) delay in transfer to referral facility (means of transport and interfacility care en route); (3) delay in receiving appropriate care at the appropriate EmOC facility such as inadequate staffing and supplies, inexpedient attention (e.g., delay to collect fees), and/or non-evidence-based or substandard care. Assumptions about the latter two delays were based on survey data (e.g., National Family Health Survey [NFHS-3] [28,75], District Level Household Survey [DLHS] [76], and Facility Survey [26]), state-level facility surveys [77,78], government reports [27], and published studies (Text S1) [14,15,79–83].

Model performance was assessed by comparing the distribution of direct causes of maternal mortality, life expectancy, proportionate mortality ratio, MMR, and total fertility rate (TFR) to empiric data [2,14,15,28,29,32,38,84–87] in rural and urban India. Model validation was assessed by using state-specific data from Rajasthan and Uttar Pradesh as model inputs, and comparing model-projected indicators of maternal mortality with survey-reported outcomes [14,15]. In addition, a secondary analysis assessing all strategies evaluated in the base case was conducted in Uttar Pradesh. Details of this process are included in Text S1.

**Costs**

Selected costs used in the model are provided in Table 3 [18,25,80,88–94]. Details are provided in Text S1. With the exception of facility costs, salaries, and transport costs, resource requirements to deliver interventions and the costs of maternal complications were estimated from the United Nations Population Fund’s (UNFPA) Reproductive Health Costing Tools Model (RHCTM) [88]. The RHCTM uses an ingredients approach to estimate direct costs (including drugs, supplies, and personnel requirements) of 45 reproductive health interventions, as well as investments required for scale-up. We obtained personnel costs (salaries) and facility costs from public access country-specific databases [25,89], and drugs and supply costs from the UNICEF Supply Catalogue and Management Sciences for Health (MSH) International Drug Price Indicator Guide [90,91]. We leveraged public access sources and published studies to inform assumptions about the financial requirements for improving transport and scaling up facility- and human-resource capacity [7,30,80,92,93]. We assessed the face validity of model input values and established a plausible range for sensitivity analysis by comparing estimates to...
Discussion of results and model validation.

**Results**

**Model Validation**

Model-estimated life expectancy for a 15-year-old female was 55 years compared to the World Health Organization’s (WHO) estimate of 55.1 years. The distribution of maternal deaths by cause closely approximated published regional estimates. Model-generated estimates of total fertility rate (TFR) and maternal mortality rate (MMR) for India, stratified for rural and urban status, closely approximated survey-reported values. Model predictions for India, stratified for rural and urban status, closely approximated survey-reported values.

**Enhanced Family Planning and Safe Abortion**

Increased family planning to reduce the unmet need (for spacing and limiting births) by amounts ranging from 25% to 100%, reduced maternal deaths by amounts ranging from 7.0% to 28.1% in rural India and 5.8% to 23.5% in urban India. In rural India alone, the cost savings for a single birth cohort of 15-year-old girls in 2010 that would be expected to accrue over their reproductive lifespans ranged from US$111.4 million to US$448.2 million. Reducing the unmet need, coupled with provision of safe abortion, provided synergistic benefits and saved additional costs.

**Interventions Packaged as Integrated Services**

Our results suggest that reaching the MDG 5 goal of a 75% reduction in maternal mortality would require investments targeting the intrapartum period, in addition to family planning and safer abortion. Without these additional strategies, the model predicts a ceiling on the level of maternal mortality reduction achievable, ranging from 32% in urban India to 34% in rural India.

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**Table: Stepwise improvements in scaling up maternal services**

| Stage                                      | Rural India | Urban India |
|--------------------------------------------|-------------|-------------|
| Facility based births (health center, bEmOC or cEmOC) | 45%         | 60%         |
| Coverage of home deliveries (skilled birth attendant present) | 75%         | 80%         |
| Recognition of referral need by SBA (includes willingness of woman/family to be referred) | 25%         | 40%         |
| Transport availability (home to referral facility) | 60%         | 75%         |
| Transport availability (health center to bEmOC/cEmOC or bEmOC to cEmOC) | 65%         | 75%         |
| Availability of quality EmOC (staff/supplies, prompt evaluation, appropriate clinical management) | 85%         | 90%         |

Figure 2. Stepwise improvements in scaling up maternal services. Four strategies that scale up access to critical maternal health services in consecutive phases are designated as upgrade 1, upgrade 2, upgrade 3, and upgrade 4. Shown are the percent increases in facility-based delivery, SBAs, recognition of referral need (by SBA at birthing/health center), transport (to appropriate referral facility), and availability/quality of EmOC (including adequate staff/supplies, appropriate clinical treatment, immediate attention), for rural and urban India. Shifts from home births assume a 70% shift to health centers/birthing centers and a 30% shift to EmOC; routine births in EmOC, we assume 90% bEmOC and 10% cEmOC. Alternatives evaluated in sensitivity analysis (Results and Text S1). doi:10.1371/journal.pmed.1000264.g002
Table 1. Selected model parameters: Incidence and mortality of pregnancy and delivery-related complications, and impact of interventions.

| Parameter | Hemorrhage | Obstructed Labor | Hypertensive Disorders | Sepsis | Unsafe Abortion |
|-----------|------------|------------------|-----------------------|--------|----------------|
| Probability of event [15,29,31–44] | 0.114 | 0.047 | 0.035 | 0.050 | 0.128* |
| Range | 0.051–0.228 | 0.030–0.074 | 0.025–0.050 | 0.043–0.060 | 0.050–0.250 |
| Probability of morbidity [28,30,45–48] | 0.008 | 0.022 | 0.001 | 0.400 | 0.120 |
| Range | 0.006–0.010 | 0.018–0.026 | 0.001–0.001 | 0.320–0.480 | 0.096–0.144 |
| CFR [7,49–51] | 0.010 | 0.007 | 0.017 | 0.013 | 0.003 |
| Adjusted CFR | 0.023 | 0.019 | 0.021 | 0.028 | 0.009 |
| Range | 0.007–0.030 | 0.005–0.025 | 0.012–0.027 | 0.009–0.036 | 0.002–0.012 |
| Attributable mortality [29] | 46.2% (9%–73%) | 14.1% (3%–52%) | 13.7% (9%–18%) | 17.4% (0%–20%) | 8.6% (0%–20%) |
| Model-projected attributable mortality | 40.6% | 16.8% | 12.3% | 20.4% | 9.8% |

Impact of interventions

| Decreased incidence [34,37] | 50%, 75%* | — | — | 25%, 50% | — |
| Range | 25%–91% | — | 25%–50% | 0%–60% | 0%–100% |
| Decreased CFR [7,17,50,52–64] | 75% | 95% | 59% | 90% | 98%* |
| Range | 60%–90% | 76%–100% | 45%–95% | 63%–93% | 50%–100% |

Table 5 shows the health and economic outcomes associated with interventions packaged as integrated services; these included phased approaches that scale up access to intrapartum services over time in rural (upper section) and urban India (lower section), coupled with incremental improvements in family planning and safe abortion. The four stepwise “upgrades” incorporated improvements in available SBAs for home births, recognition of referral need, transport, and availability/effectiveness of EmOC, as well as shifts from home- to facility-based delivery.

Compared to the status quo in rural India (upper section, Table 5), our model predicted that integrated strategies coupling family planning and safe abortion with four consecutive “upgrades” would be expected to reduce maternal deaths by 17.3% to 77.1%, the MMR to less than 200, proportionate mortality ratio by 14% to 4%, and lifetime risk of maternal mortality from one in 78 to one in 282. Compared to the status quo in urban India (Table 4, lower section), similar reductions in maternal deaths were predicted; although the number of absolute lives saved would be lower, the MMR, lifetime risk, and proportionate mortality ratio would be expected to decline to 113, one in 553, and 2.3%, respectively, with the most intensive strategy (upgrade 4).

Because the stepwise improvements in each component of the integrated package (intrapartum care, family planning, and safe abortion) were assumed to occur in consecutive phases, the incremental cost-effectiveness ratio for each “upgrade” strategy was calculated as the difference in costs relative to the difference in effects, compared with the preceding next best strategy. While the initial strategy was cost saving in both urban and rural India,
incremental cost-effectiveness ratios ranged from US$150 to US$300 per YLS in rural India and from US$150 to US$350 per YLS in urban India. Cost-effectiveness ratios are also expressed as percent of the per capita GDP (US$1,068). Even the most intensive and effective strategic package was well below 50% of the per capita GDP.

In contrast to these integrated strategies, implementing only the stepwise intrapartum care upgrades—without family planning and safe abortion—was less effective and less cost-effective. The incremental cost-effectiveness ratios ranged from US$490–US$1,060 in rural India and US$200–US$990 per YLS in urban India (Text S1).

### Integrated Safe Motherhood Interventions in Rural Uttar Pradesh

Figure 4 (upper panel) displays the health outcomes associated with stepwise approaches to improve maternal health in rural Uttar Pradesh. The vertical axis (from bottom to top) shows outcomes associated with increased access to family planning and safe abortion; the horizontal axis (from left to right) displays outcomes associated with investments in high-quality health-center–based intrapartum care (e.g., facility, attendance, referral, transport, EmOC). In Figure 4 (upper panel) the cell located in the far left lower corner represents current conditions in rural Uttar Pradesh.

### Table 2. Selected model parameters and assumptions: Coverage of interventions and maternal health indicators by setting.

| Parameter | India | India, Urban | India, Rural | Rajasthan | Uttar Pradesh, Rural |
|-----------|-------|--------------|-------------|-----------|----------------------|
| **Coverage of contraception (%) [28]** | | | | | |
| Family planning (any method) | 56.3 | 64.0 | 53.0 | 47.2 | 39.7 |
| Modern methods | 48.5 | 55.8 | 45.3 | 44.4 | 25.2 |
| Pill | 6.4 | 7.0 | 6.2 | 4.5 | 5.2 |
| IUD | 3.7 | 6.1 | 2.4 | 3.6 | 3.2 |
| TOL | 76.9 | 67.7 | 81.9 | 77.0 | 66.7 |
| Condom | 10.9 | 17.9 | 7.3 | 12.8 | 24.6 |
| Unmet need | 13.2 | 10.0 | 14.6 | 14.6 | 23.8 |
| **Coverage of prenatal care (%) [28]** | | | | | |
| Prenatal care | 50.7 | 73.8 | 42.8 | 41.2 | 22.6 |
| Treatment for anemia* | 22.3 | 34.5 | 18.1 | 13.1 | 6.7 |
| **Delivery location (%) [28]** | | | | | |
| Total skilled delivery | 48.3 | 75.2 | 39.1 | 41.0 | 23.8 |
| Facility deliveryb | 40.7 | 69.4 | 31.1 | 29.6 | 17.5 |
| Home delivery with SBAb | 12.8 | 19.0 | 11.6 | 16.2 | 7.6 |
| **Assumptions for available transport/interim care to appropriate facility (%) [65,66]** | | | | | |
| From home to EmOC | 30.4 | 44.4 | 24.4 | 24.4 | 18.1 |
| Range | 20–40 | 35–55 | 15–35 | 20–40 | 15–30 |
| From HC or BC to EmOC | 54.8 | 68.8 | 48.8 | 48.8 | 36.1 |
| Range | 40–65 | 60–80 | 40–60 | 30–55 | 25–45 |
| From bEmOC to cEmOC | 67.0 | 81.0 | 61.0 | 61.0 | 45.1 |
| Range | 55–80 | 70–90 | 50–70 | 50–70 | 35–55 |
| **Assumptions for available facility, staff/supplies, quality of care (%) [67,68]** | | | | | |
| EmOC | 50.0 | 67.5 | 42.5 | 42.5 | 31.5 |
| Range | 40–60 | 55–80 | 30–55 | 30–55 | 20–40 |
| **Maternal health indicators** | | | | | |
| TFR [28] | 2.68 | 2.07 | 2.98 | 3.21 | 4.13 |
| Model-projected TFRc | 2.70 | 2.07 | 2.97 | 3.24 | 4.13 |
| Model-projected MMRc | 440 | 407 | 520 | 524 | 633 |

See [14,15,28,65–68,71].

*aCase fatality rates (CFRs) were adjusted based on complication severity (e.g., life threatening complications requiring cEmOC) and underlying severity of anemia [71].

See Text S1.

 articulated care upgrades—without family planning and safe abortion—was less effective and less cost-effective. The incremental cost-effectiveness ratios ranged from US$490–US$1,060 in rural India and US$200–US$990 per YLS in urban India (Text S1).
Each of the other cells represents a unique strategy; the reduction in maternal deaths expected with each strategy, relative to current conditions, is shown. For example, a strategy that reduced the unmet need by 75%, increased safe abortion to 60%, and implemented improvements to intrapartum care consistent with upgrade 3, reduced maternal deaths by 57%.

In Figure 4 (upper panel) each cell is also color-coded to reflect the cost-effectiveness profile associated with the particular strategy. Strategies that only employed family planning and safe abortion (vertical axis, from bottom to top) were generally cost saving, but reduced mortality by a maximum of 40%. Strategies that only invested in intrapartum care improvements

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### Table 3. Selected model input costs.

| Cost Components | Base Case | Range* |
|-----------------|-----------|--------|
| **Family planning** [25,88] | | |
| Oral contraceptives | 10.64 | 6.03–15.96 |
| Injectable contraceptives | 10.20 | 4.92–15.30 |
| Condoms | 8.40 | 3.79–12.60 |
| Intrauterine device | 9.17 | 2.58–13.76 |
| Female sterilization | 18.98 | 9.49–28.47 |
| Male sterilization | 12.67 | 6.34–19.01 |
| **Antenatal care** [25,88] | | |
| Four visits | 17.82 | 8.54–25.61 |
| **Abortion** [25,88,94] | | |
| Incomplete abortion | 8.90 | 4.45–17.80 |
| Elective abortion | 21.87 | 10.94–43.74 |
| Postabortion complications | 43.40 | 21.70–86.80 |
| **Delivery** [25,88] | | |
| Home (TBA, SBA) | 4.52, 6.44 | 0–9.66 |
| Facility (birthing center, bEmOC, cEmOC) | 14.46, 24.58, 32.54 | 7.23–48.81 |
| **Community-based interventions** | | |
| Misoprostol (home, birthing center) | 0.99 | 0.75–2.00 |
| SBA training | 3.40 | 0.62–5.00 |
| **Transportation costs** | | |
| Home to facility | 3.62–8.13 | 1.81–12.20 |
| Birthing/health center/bEmOC to referral facility | 4.88–7.14 | 2.44–10.71 |
| **Management of complications** [25,88] | | |
| Obstructed labor | 70.16 | 12.76–139.38 |
| Maternal hemorrhage | 67.99 | 18.40–212.51 |
| Puerperal sepsis | 47.92 | 23.15–111.02 |
| Severe pre-eclampsia/eclampsia | 65.85 | 33.50–153.62 |
| **Postpartum care** [25,88] | | |
| One visit | 4.99 | 1.04–7.49 |

See [18,25,80,86–94]. Estimates of costs under current standard of care (2006 US$). Estimates for the base case were country-specific and from UNFPA’s Reproductive Health Costing Tools Model (RHCTM) [88] and WHO CHOICE/public databases [25,89–91], unless otherwise specified. Costing details and methods for converting costs to 2006 US$ are provided in the Text S1.

*Ranges for sensitivity analyses established on the basis of assumptions and other published literature documented in the Text S1.

*Postabortion complications assumed to require manual vacuum aspiration, treatment of sepsis in 25%, surgical repair in 25% [92].

*Total costs reflect skill level of attendant, level of facility, and drugs and supplies. For example, delivery at birthing center (US$14.46) includes personnel (US$6.44), facility (US$4.52), and drugs and supplies (US$3.50). Other assumptions documented in the Text S1.

*Community-based interventions evaluated in sensitivity analysis included SBA-administered misoprostol to reduce incidence of PPH in deliveries at home and in birthing centers. Costs for misoprostol (US$0.99) and training (upper bound, US$3.40) based on assumptions presented in Sutherland and Bishai [18]; these costs represent the incremental costs above routine SBA delivery.

*Transport costs include those incurred from home to a referral facility (bEmOC or cEmOC), and those incurred between facilities when necessary (e.g., bEmOC to cEmOC). Assumptions based on literature [80,93,94] and public access data described in the Text S1.

*Estimates shown represent average total costs using case-specific unit costs weighted by severity. Complications requiring surgery (e.g., cesarean section), blood transfusion, intensive hemodynamic support assumed to require cEmOC. Details of unit cost assumptions for facility-specific treatment documented in Text S1.

*Postpartum care includes examination, iron/folate supplementation, and counseling.

*TBA, traditional birth attendant.

*doi:10.1371/journal.pmed.1000264.t003
were generally associated with the highest cost-effectiveness ratios (i.e., least attractive), reflecting the higher costs required for infrastructure improvements. An overarching strategic approach that moves along the diagonal, from the lower left corner to the upper right corner, was most effective and cost-effective; the cost savings from enhanced family planning and safe abortion offset the resources required to improve intrapartum care.

### Sensitivity Analyses

For deliveries at home and in birthing centers in rural Uttar Pradesh, removing only one “delay” in accessing EmOC had minimal impact (<5%) on lowering maternal mortality and was not cost-effective (e.g., US$700–US$4,900 per YLS) (Figure 4, lower panel). In contrast, an integrated strategy that made modest improvements in all components (e.g., SBA, referral, transport, and quality) reduced mortality by 22%. Cost-effectiveness of an

### Table 4. Health and economic outcomes of family planning to reduce the unmet need for limiting and spacing births, and safe abortion, in rural and urban India.

| Strategy | Lifetime Deaths per 100,000 Women | Reduction in Maternal Deaths | Proportionate Mortality Ratio | Lifetime Risk of Death Due to Maternal Complications | Model-projected Savings for a Single Birth Cohort of 15 y olds (US$) | Cost Savings for a Single Year (Current Distribution of 15–45 y Olds in India) (US$) |
|----------|----------------------------------|------------------------------|------------------------------|-----------------------------------------------------|-------------------------------------------------|-------------------------------------------------|
| **Rural India, current conditions (TFR, 2.97)** | | | | | | |
| Family planning | | | | | | |
| Reduce unmet need 25% (56.7%) | 1,435 | 7.0% | 15.4% | 1 in 70 | 111,357,615 | 60,200,655 |
| Reduce unmet need 50% (60.3%) | 1,327 | 14.0% | 14.4% | 1 in 75 | 223,221,615 | 120,611,563 |
| Reduce unmet need 75% (64.0%) | 1,218 | 21.1% | 13.4% | 1 in 82 | 335,439,615 | 181,233,496 |
| Reduce unmet need 100% (67.6%) | 1,109 | 28.1% | 12.3% | 1 in 90 | 448,188,615 | 242,067,230 |
| Safe abortion | | | | | | |
| Increase safe abortion 50% | 1,517 | 1.7% | 16.2% | 1 in 66 | 48,080,115 | 42,078,125 |
| Increase safe abortion 75% | 1,473 | 4.5% | 15.8% | 1 in 68 | 130,739,115 | 114,289,234 |
| Increase safe abortion 95% | 1,433 | 7.1% | 15.4% | 1 in 70 | 214,460,115 | 167,790,590 |
| **Urban India, current conditions (TFR, 2.07)** | | | | | | |
| Family planning | | | | | | |
| Reduce unmet need 25% (66.5%) | 793 | 5.8% | 9.1% | 1 in 126 | 22,089,305 | 12,838,532 |
| Reduce unmet need 50% (69.0%) | 743 | 11.7% | 8.6% | 1 in 135 | 44,214,305 | 25,696,437 |
| Reduce unmet need 75% (71.5%) | 694 | 17.6% | 8.1% | 1 in 144 | 66,398,305 | 38,578,054 |
| Reduce unmet need 100% (74.0%) | 644 | 23.5% | 7.5% | 1 in 155 | 88,611,805 | 51,483,279 |
| Safe abortion | | | | | | |
| Increase safe abortion 50% | 822 | 2.4% | 9.4% | 1 in 122 | 11,351,305 | 9,742,159 |
| Increase safe abortion 75% | 788 | 6.4% | 9.1% | 1 in 127 | 30,821,305 | 26,413,778 |
| Increase safe abortion 95% | 758 | 9.9% | 8.7% | 1 in 133 | 50,438,805 | 36,823,443 |

See [87]. Reduction in direct causes of maternal mortality, including abortion-related complications, postpartum hemorrhage, hypertensive disorders, sepsis, and obstructed labor.

*Model-projected cost savings reflect net costs averted over a woman’s reproductive lifespan (ages 15–45 y) applied to the current population of 15 y olds in India stratified by rural (75%) and urban (25%) settings [87]. Future costs discounted 3% annually.

*Cost savings for a single representative year of a successfully implemented strategy were calculated using population-level data from India [87] stratified by rural (75%) and urban (25%) settings, for the current distribution of reproductive age women (ages 15–45 y).

*In rural India, model-projected TFR is 2.76, 2.56, 2.36, 2.14 with reductions in unmet need of 25%, 50%, 75%, 100%, respectively.

*In urban India, model-projected TFR is 1.94, 1.82, 1.71, 1.59 with reductions in unmet need of 25%, 50%, 75%, 100%, respectively.

doi:10.1371/journal.pmed.1000264.t004
integrated strategy ranged from cost saving to US$170 per YLS (Text S1).

Universal antenatal care by itself averted fewer than 2% of maternal deaths; however, if enhanced antenatal care increased the probability of either facility-based delivery or SBA-attended birth (linked with accurate referral and transport) from 31% to 60%, health benefits increased 5-fold (Text S1).

As a greater proportion of routine deliveries shifted from home to facilities, we assumed 70% would shift to birthing centers or health centers staffed by SBA and 30% to facilities with full EmOC capacity. Although the differential benefits of routine delivery in birthing/health centers versus bEmOC was dependent on expedient transfer from a center to referral EmOC if needed, provided this was assured, both approaches were cost-effective. In contrast, when we varied assumptions about the proportion of routine deliveries in cEmOC versus bEmOC, cost-effectiveness results changed drastically; as routine deliveries shifted to cEmOC, the incremental cost-effectiveness ratios became much less attractive, ranging from US$8,300 to US$27,000 per YLS.

Table 6 shows the potential incremental benefits and cost-effectiveness of adjunctive community-based SBA-administered misoprostol for births at home and birthing centers/health centers in rural India. For all four “upgrade” strategies, additional lives could be saved; depending on the phase of improvements in intrapartum care, an additional 7%–13% of maternal deaths were prevented. Cost-savings for a single birth cohort of 15-y-old girls (2010) expected to accrue over their reproductive lifespan (age 15–45 y) ranged from US$128 million to US$190 million.

Discussion

We have identified several strategic options that would cost-effectively reduce maternal mortality in both rural and urban India. Our principal findings are that early intensive efforts to improve family planning and provide safe abortion, accompanied by a systematic stepwise effort to scale up intrapartum and EmOC, could reduce maternal mortality by 75%. Despite the inherent uncertainty in data and assumptions used in the analysis, four critical themes emerge as robust.

First, increasing effective family planning is the most effective individual intervention to reduce pregnancy-related mortality. If the unmet need was met in rural and urban India by 2012, our results imply that the lives of 168,000 women would be saved by the end of 2015. The cost savings over that time period would exceed US$1 billion. Because strategies to increase contraceptive options for limiting and spacing do not require the same level of infrastructure as improving intrapartum care, targeting these strategies toward rural areas with high TFRs is a promising way to initiate equitable improvements in maternal health.

Second, two distinct—yet synergistic—approaches, family planning and safe abortion, can reduce deaths from unsafe abortion. Enhanced access to family planning by itself reduces demand for elective abortion and consequently reduces deaths attributable to unsafe abortion. In fact, reducing the unmet need for contraception can prevent one of every two abortion-related deaths. Furthermore, just a fraction of the cost savings from family planning would fully fund an intervention to provide safe abortion and postabortion care.

Third, despite the substantial health and economic benefits associated with family planning and safe abortion, there is a threshold above which further reductions in mortality are impossible. MDG 5 will therefore not be achievable without involving integrated interventions that ensure reliable access to high-quality intrapartum care.

While formidable effort and financial investment would be required to scale up maternal health services over time, we identified a number of phased approaches that would ultimately prevent four out of five maternal deaths. Coupled with stepwise improvements in family planning and safe abortion, these approaches incrementally shifted home births to birthing centers or facilities with EmOC, and improved both access to SBAs as well as accurate recognition of referral need, transport, and availability/quality of EmOC. Successful implementation of these
strategies would be expected to dramatically reduce the MMR, proportionate mortality ratio, and lifetime risk of maternal death.

Fourth, despite the possible variation in pace associated with scaling up maternal health services in India, systematic and consecutive phases will be cost-effective. Our results showed that—when coupled with family planning and safe abortion—both early initial strategies and late intensive strategies resulted in cost-effectiveness ratios that were just a fraction of India’s per capita GDP; these would unarguably be considered very cost-effective [95–98].

Table 5. Health and economic outcomes of integrated packages of services: intrapartum care, family planning, and safe abortion.

| Region          | Facility Birth (%) | Transport-Home (%) | Transport-Facility (%) | Quality of Care (%) | Family Planning (%) | Safe Abortion (%) | MMR (Deaths per 100,000 Live Births) | Maternal Deaths as Percent of Deaths Ages 15–45 y | Lifetime Risk of Maternal Death | Lifetime Costs (US$) | Cost-Effectivenessa (%) |
|-----------------|-------------------|--------------------|------------------------|---------------------|---------------------|-------------------|--------------------------------------|---------------------------------|----------------------------|------------------------|------------------------|
| Rural Indiaa    | 45 50 65 70 56.7 50 | 17.3 460 14.0 1 in 65 | 218.38                 | CS                  | C5                  |
| Upgrade 2       | 60 60 75 80 60.3 60 | 33.7 397 11.5 1 in 98 | 218.51 150 14        |
| Upgrade 3       | 75 70 85 90 64.0 75 | 53.4 302 8.3 1 in 139 | 226.18 160 15       |
| Upgrade 4       | 80 75 95 95 67.6 95 | 77.1 162 4.3 1 in 282 | 243.46 300 28       |
| Urban Indiaa    | 75 60 85 70 66.5 50 | 15.8 363 8.2 1 in 141 | 174.91 C5 CS        |
| Upgrade 2       | 80 75 90 80 69.0 60 | 33.3 305 6.6 1 in 178 | 178.30 150 14       |
| Upgrade 3       | 90 80 92.5 90 71.5 75 | 54.1 225 4.7 1 in 259 | 183.44 220 21       |
| Upgrade 4       | 95 85 95 95 74.0 95 | 78.5 113 2.3 1 in 553 | 194.97 350 33       |

Reduction in direct causes of maternal mortality, including abortion-related complications, postpartum hemorrhage, hypertensive disorders, sepsis, and obstructed labor.

- Transport encompasses the expedient availability of means of transport (e.g., vehicle, cart), fuel (if needed), driver, and interim attendant care. Facility transport represents a weighted average of transport availability from a health center or birthing center to an EmOC facility and from a bEmOC facility to a cEmOC if indicated. Accuracy of referral need recognition at home and in health center with SBA increase, on average, to 60%, 75%, 90%, and 95% (not shown) with upgrade 1, 2, 3, and 4 in both rural and urban India.
- Quality refers to the availability and quality of services at EmOC facilities, including adequate staffing and supplies, expedient attention (e.g., without delay to collect fees or requirement for family to bring supplies), and evidence-based clinical practices.
- Family planning refers to contraceptive use for limiting and spacing; shown are values representing the reduction in unmet need by 25%, 50%, 75%, and 100% with upgrade 1, 2, 3, and 4, respectively, for both rural and urban India.

Fourth, the incremental cost-effectiveness ratio (US$ per YLS) for each upgrade is calculated as the difference in lifetime costs relative to the difference in lifetime effects, compared with the preceding next best strategy. Cost-effectiveness ratios are also expressed as percent of the per capita GDP (US$1,068), shown in the farthest right column, as interventions with cost-effectiveness ratios of less than the per capita GDP are considered very cost-effective according to criteria proposed by the Commission on Macroeconomics and Health [98].

Status quo (rural India): 31.1% facility births; 11.6% SBA (home births); transport from home (20%), primary-level health center (40%); availability and quality of EmOC (67.5%); 64% family planning.

Status quo (urban India): 69.4% facility births; 19% SBA (home births); transport from home (44%); primary-level health center (69%); bEmOC (81%); recognition of referral need at home (20%); primary-level health center (40%); availability and quality of EmOC (67.5%); 64% family planning.

CS, cost saving; ICER, Incremental cost-effectiveness ratio.

doi:10.1371/journal.pmed.1000264.t005

Although our general findings are consistent with earlier suggestions that interventions to reduce maternal mortality are good public health investments [7,17], our analytic approach also allowed us to identify more and less efficient ways to achieve this. In this regard, we highlight four robust insights: (1) In settings with limited infrastructure, investing in “intermediate” facilities (e.g., birthing centers) is very cost-effective, provided there is reliable referral capacity and transport to an appropriate EmOC facility if necessary; (2) A strategy of routine hospital-based delivery (i.e., cEmOC) is not cost-effective; (3) A community-based strategy that includes SBA-administered oral misoprostol in homes and birthing centers is likely to be cost-effective. Although alone it cannot substitute for reliable intrapartum care and EmOC, if added to a long-term plan that increases facility-based intrapartum care, it will save additional lives and will reduce costs; (4) Because settings with the highest TFRs and worst maternal health indicators also tend to be those with the greatest need for enhanced health delivery infrastructure, early consistent commitments to provide family planning and safe abortion reduce the total resources required. To place the synergistic benefits of enhanced family planning and safe abortion in context, the magnitude of cost savings from eliminating unmet need and ensuring access to safe abortion is approximately 25% of the required 10-y investment estimated by Johns et al. for scaling up maternal services in India [30].

We may have underestimated both effectiveness and cost-effectiveness by excluding effects of certain indirect indicators and interventions. Although we purposely focused on maternal mortality, if we included neonatal health and survival, for example, most strategies would be even more cost-effective due...
### Mortality reduction with different strategies in rural Uttar Pradesh

| Strategy | Mortality Reduction (%) | Cost Saving | CE Ratio < $250 | CE Ratio < $500 | CE Ratio < $750 | CE Ratio = $800 |
|----------|-------------------------|-------------|-----------------|-----------------|-----------------|-----------------|
| FP 100% Unmet Need 100% Safe Abortion | 41.8% | 49.8% | 55.4% | 66.8% | 80.0% |
| FP 100% Unmet Need 75% Safe Abortion | 39.3% | 47.3% | 52.8% | 64.1% | 78.0% |
| FP 75% Unmet Need 60% Safe Abortion | 28.8% | 37.8% | 44.1% | 57.0% | 72.9% |
| FP 50% Unmet Need 50% Safe Abortion | 20.5% | 30.4% | 37.2% | 51.4% | 68.8% |
| FP 25% Unmet Need 15% Safe Abortion | 9.6% | 20.4% | 28.0% | 43.7% | 62.9% |
| Current Status | * | 11.8% | 20.1% | 37.0% | 58.0% |

**Integrated Strategy (Upgrade 1)**
- SBA (non-facility births): 6.3% (15-100%)
- Recognition referral need: 20.0% (25-100%)
- Transport to EmOC: 18.1% (25-100%)
- Quality EmOC: 31.5% (50-100%)

**Integrated Strategy (Upgrade 1)**
- SBA 40% (non-facility births)
- Recognition, 50% (home), 75% (birth. centre)
- Transport, 25% (home), 60% (birth. centre)
- Quality EmOC, 70%
Figure 4. Health and economic outcomes in rural Uttar Pradesh. Upper panel. Reduction in maternal deaths and cost-effectiveness with stepwise approaches to improve maternal health in rural Uttar Pradesh. The vertical axis (from bottom to top) shows outcomes associated with increased access to family planning and safe abortion. The horizontal axis (from left to right) displays outcomes associated with investments in high-quality health-center–based intrapartum care, which involved stepwise improvements in SBAs, recognition of referral need, and antenatal/postpartum care, incrementally shifted birth away from home, and improved transport, availability, and quality of EmOC. Each cell represents a unique strategy; the reduction in maternal deaths shown is relative to current conditions (far lower left corner). Shading reflects cost-effectiveness ratios, compared to status quo (pink, cost saving; blue, <US$250/YLS; green, <US$500/YLS; purple, <US$750/YLS; orange, US$890/YLS). See text for details. Lower panel. Sensitivity analysis depicting the impact of improving only one component of intrapartum care services in rural Uttar Pradesh. Base case and improvements for each component are shown in numbers below the component name (e.g., quality of EmOC is 31.5% in the base case, improvements of 50%–100% were assessed). In settings where most deliveries occur at home, linkage of services in multiple domains is a critical determinant of reduction in maternal deaths. Even large improvements in skilled birth attendants for nonfacility births (yellow bar), recognition of referral need (pink bar), transport (green bar), or quality of EmOC (purple bar) fail to reduce mortality more than 2%–5% if other interdependent components are not improved as well. In contrast, even modest improvements in all four components, as shown in upgrade 1 (blue bar), reduce mortality by 22%. Cost-effectiveness of the integrated strategy ranged from cost saving to US$170 per YLS compared with US$700 to US$4,900 per YLS for single unlinked improvements.

doi:10.1371/journal.pmed.1000264.g004

YLS for single unlinked improvements.

to associations between place of birth and presence of a skilled attendant, with neonatal and maternal deaths [99,100]. With the exception of anemia, we focused on direct causes of maternal mortality; a priority for future analyses is to include interventions to reduce the indirect causes of pregnancy-related mortality. The analysis would be strengthened by availability of indicators that reflect safe motherhood externalities including measures of enhanced household well-being, increased school attendance, decreased numbers of orphans, and reduced impoverishment resulting from catastrophic expenses [94,99].

Other limitations in our analysis stem from its inherent reliance on high-quality data about maternal mortality specifically. While our calibration of setting-specific models allows us to better represent within-country differences in baseline risk, coverage, and capacity than previous studies, high-quality empiric evidence for the effectiveness of comprehensive strategies to reduce maternal mortality and morbidity is often either lacking or inconsistent. More studies quantifying the benefits of community-level interventions on preventing maternal morbidity remain a priority [100]. The additional costs that we assumed would be required to scale up interventions and build infrastructure are, at best, gross estimates. That being said, our assumption of 2- to 3-fold increases in the per woman costs to reflect the additional resources required to improve capacity is consistent with those implied by recent analyses assessing global resource needs for maternal health [30,93].

Shiffman and Smith [101] have described the importance of framing priority public health issues in a manner that resonates with both the “internal” community and other “external” decision makers. With regard to the internal community, the

Table 6. Incremental benefits of community-based misoprostol in rural India.

| Rural India | Family Planning* (%) | Safe Abortion (%) | Facility Birth (%) | Transport-Homeb (%) | Transport-Facilityb (%) | Quality of Careb (%) | Incremental Benefits and Cost-Effectiveness of Community-Based Misoprostol* |
|-------------|----------------------|------------------|-------------------|---------------------|-----------------------|---------------------|----------------------------------------------------------|
|             |                      |                  |                   |                     |                       |                     | Decrease in Maternal Deaths | Lives Saved with Addition of Community-based Misoprostol* | Cost-Effectiveness |
| Upgrade 1   | 56.7                 | 50               | 45                | 50                  | 65                    | 70                  | —                         | —                         | —                      |
| Plus community interventiona | —                   | —                | —                 | —                   | —                     | —                   | 12.3%                     | 16,992                    | Cost saving* |
| Upgrade 2   | 60.3                 | 60               | 60                | 60                  | 75                    | 80                  | —                         | —                         | —                      |
| Plus community interventiona | —                   | —                | —                 | —                   | —                     | —                   | 13.0%                     | 17,612                    | Cost saving* |
| Upgrade 3   | 64.0                 | 75               | 75                | 70                  | 85                    | 90                  | —                         | —                         | —                      |
| Plus community interventiona | —                   | —                | —                 | —                   | —                     | —                   | 10.2%                     | 13,983                    | Cost saving* |
| Upgrade 4   | 67.6                 | 95               | 80                | 75                  | 95                    | 95                  | —                         | —                         | —                      |
| Plus community interventiona | —                   | —                | —                 | —                   | —                     | —                   | 6.9%                      | 9,470                     | Cost saving* |

*Family planning refers to contraceptive use for limiting and spacing; shown are values representing the reduction in unmet need by 25%, 50%, 75%, and 100% with upgrades 1, 2, 3, and 4, respectively.

†Transport encompasses the expedient availability of means of transport (e.g., vehicle, cart), fuel (if needed), driver, and interim attendant care.

‡Quality refers to the availability and quality of services at EmOC facilities, including adequate staffing and supplies, and evidence-based clinical practices.

§Community-based interventions assume SBA-administered misoprostol for births at home and birthing centers/health centers with a 50% (25%–60%) reduction in PPH [72].

¶Population-level incremental benefits (lives saved) associated with the community-based misoprostol intervention (compared to the same strategy without the community-based misoprostol intervention). These were calculated by applying model-projected outcomes to population-level data from rural India [87]. Cost-savings for a single birth cohort of 15-y-old girls (2010) expected to accrue over their reproductive lifespan (age 15–45) ranged from US$128 million to US$190 million.

doi:10.1371/journal.pmed.1000264.t006
strategies we identified as most effective support three crucial elements already recognized as essential to achieve MDG 5: family planning and control of fertility choices, provision of safe abortion, and, assurance that all women have access to intrapartum care and EmOC. Our results reinforce this message, and extend it by quantifying the cost savings of family planning and safe abortion, and identifying efficient and cost-effective approaches to scaling-up capacity for integrated maternal health services.

With regard to the external community, we have tried to provide a range of outcomes that can be used to create effective “take home” messages for different target audiences. For example, in only 5 y, more than 150,000 lives could be saved just from increasing contraception rates by a few percentage points; nearly US$1.5 billion could be saved by adding safe abortion to family planning efforts; and finally, with stepwise investments to provide facility-based intrapartum care, the majority of maternal deaths could be prevented. In the next decade, this accomplishment would save the lives of 1 million Indian women.

Finally, by placing and prioritizing safe motherhood in the context of other global health priorities [101,102], our results can also be effectively framed for policymakers who must allocate limited resources, by providing comparative and contextual information about the relative benefits and cost-effectiveness of investments in maternal health measured against other public health priorities. One of the robust findings of our analysis, for example, is that there are integrated strategies that involve improvements in family planning, safe abortion, and intrapartum care that are equally or more cost-effective or attractive than childhood immunization or treatment of malaria, tuberculosis, or HIV [95].

The Indian government has initiated several policies to improve maternal health [5], particularly in rural areas [27,103], and efforts to both implement and evaluate new strategies are ongoing [83,94,104–106]. Although our analysis is intended to catalyze actionable steps, we recognize that decisions in India about the choice of strategies and rate of stepwise investments to reduce maternal mortality will be a function not only of cost-effectiveness and affordability, but also of political will and local circumstances. Identifying approaches that can be tailored to local situations, but that rely on firm core principles and are cost-effective, holds considerable promise as a way to mobilize further political support and convince stakeholders that MDG 5 is within reach.

In particular, it is clear from our analysis that an initial focus on family planning, especially in rural poor areas, will significantly prevent pregnancy-related deaths, reduce deaths from unsafe abortion, and save resources. Providing universal access to safe abortion will further augment these benefits. The cost savings from these two strategies will partially offset the resources required to invest in the necessary infrastructure that would assure every woman access to high-quality intrapartum care and EmOC. While MDG 5 is unlikely to be met without assuring access to health-center-based intrapartum care, implementation of a phased stepwise approach, designed to reach this goal while reflecting the current realities and most feasible initial approaches in different settings, is absolutely within reach.

Supporting Information
Text S1 Supplemental material accompanying the article. Part I, overview of model; part II, overview of model parameterization, calibration, performance; part III, overview of costs and estimates; part IV, supplemental results; part V, references. Found at: doi:10.1371/journal.pmed.1000264.s001 (0.53 MB PDF)

Acknowledgments
We are appreciative of the administrative assistance from Meredith O’Shea, and constructive feedback on the model assumptions (Dan Grossman, Kelly Blanchard, Carol Levin).

Author Contributions
ICMJE criteria for authorship read and met: SG SS NC UCMN DH. Agree with the manuscript’s results and conclusions: SG SS NC UCMN DH. Designed the experiments/the study: SG SS NC DH. Analyzed the data: SG SS NC UCMN DH. Collected data/did experiments for the study: SG DH. Wrote the first draft of the paper: SG. Contributed to the writing of the paper: SG SS NC UCMN DH. Wrote first draft of Text S1: DH.

References
1. World Health Organization (WHO) (2007) Maternal mortality in 2005: estimates developed by WHO, UNICEF, UNFPA, and The World Bank. Available: http://www.who.int/whosis/mme_2005.pdf. Accessed 19 August 2009.
2. Hill K, Thomas K, AbuZahra C, Walker N, Say L, et al. (2007) Estimates of maternal mortality worldwide between 1990 and 2005: an assessment of available data. Lancet 370: 1311–1319.
3. United Nations (UN). Millennium Development Goals: Goal 5 (MDG 5): Improve maternal health. Available: http://www.un.org/millenniumgoals/maternaltheme.pdf. Accessed 31 July 2009.
4. World Health Organization (WHO) (2003) Millennium Development Goals and Health-India. Chapter III: Goal 5: improve maternal health. Geneva: WHO. Available: http://www.whoindia.org/LinkFiles/MDG_Chapter5.pdf. Accessed 31 July 2009.
5. Schiffman J, Ved R (2007) The state of political priority for safe motherhood in India. BJOG 114: 785–90.
6. Ronsmans C, Graham WJ (2006) Maternal and perinatal conditions. Jamison DT, Berman JG, Measham AR, Alleyne G, Clasen M, et al., eds. Disease control priorities in developing countries. 2nd edition. New York: Oxford University Press. pp 499–530. Available: http://www.dcp2.org/pubs/DCP/26/.
7. Campbell OM, Graham WJ (2006) Strategies for reducing maternal mortality: getting on with what works. Lancet 368: 1284–99.
8. Campbell OM, Graham WJ, Lancet Maternal Survival Series steering group (2006) Strategies for reducing maternal mortality: getting on with what works. Lancet 368: 1284–99.
9. Rosenfield A, Maine D, Freedman L (2006) Meeting MDG-5: an impossible dream? Lancet 368: 1133–1135.
10. Government of India (2005) Reproductive and Child Health Programme Document (RCH II–Document 2): the principles and evidence base for State RCH II Programme Implementation Plans (PIPs). New Delhi, India. Government of India. Available: http://www.whoindia.org/LinkFiles/Child_Health_in_India_PIP_Doc_Chapter02.pdf. Accessed 21 August 2009.
11. Government of India, Ministry of Health and Family Welfare, Department of Family Welfare (2005). National rural healthcare mission. New Delhi, India: Government of India. Available: http://www.mohfw.nic.in/nrchm/Documents/NRHMPMission%20Document.pdf. Accessed 21 August 2009.
12. Schiffman J (2007) Generating political priority for maternal mortality reduction in 5 developing countries. Am J Public Health 97: 796–803.
13. Costello A, Azad K, Barnett S (2006) An alternative strategy to reduce maternal mortality. Lancet 368: 1477–1479.
14. Mills S, Boe E, Lide E, Ramana GNV, Bhalotra R (2007) Obstetric care in poor settings in Ghana, India, and Kenya. Washington (D.C.): The World Bank Available: http://www-wds.worldbank.org/external/default/main?pagePK=64187510&methodPK=64187510&rqstPK=64187510&sk=0&titlPK=64187510&pgPK=64187510&tkPK=64187510&datePK=64187510&ltlang=0&rtlang=0&pgsrcPK=64187510&pgtsrPK=64187510&ucsrcPK=64187510&tsrcPK=64187510&lsrcPK=64187510&lvsrcPK=64187510&lcsrcPK=64187510. Accessed 27 July 2009.
15. Registrar General, India (2006) Maternal mortality in India: 1997–2003; trends, causes and risk factors. New Delhi, India. Available: http://www.mohfw.gov.in/health/Maternal_Mortality_in_India_1997-2003.pdf. Accessed 22 August 2009.
16. Goldie SJ, Goldhaber-Fiebert JD, Garnett GP (2006) Public health policy for cervical cancer prevention: role of decision science, economic evaluation, and mathematical modeling. Vaccine 24: S155–S163.
40. Shah I, Ahman E (2004) Age patterns of unsafe abortion in developing countries. BMJ 331: 1107.

41. Henshaw SK, Singh S, Haas T (1999) The incidence of abortion worldwide: worldwide incidence and trends. Available: http://www.guttmacher.org/pubs/PlannedParenthood.html. Accessed 19 August 2009.

42. Berer M (2004) National laws and unsafe abortion: the parameters of change. Reprod Health Matters 12: 1–8.

43. The Alan Guttmacher Institute (AGI) (2006) Preventing unsafe abortion and its consequences: priorities for research and action. New York: Alan Guttmacher Institute. Available: http://www.guttmacher.org/pubs/2006/07/10/PreventingUnsafeAbortion.pdf. Accessed 24 August 2009.

44. The Alan Guttmacher Institute (AGI) (2007) Facts on induced abortion worldwide: worldwide incidence and trends. Available: http://www.guttmacher.org/pubs/PDF/AGI_FactsOnInducedAbortion.pdf. Accessed 24 August 2009.

45. Hu D, Bertozzi SM, Gakidou E, Sweet S, Goldie SJ (2007) The costs, benefits, and cost-effectiveness of interventions to reduce maternal mortality and morbidity in Mexico. PLoS ONE 2: e730. doi:10.1371/journal.pone.0000730.

46. Johns B, Sigurbjornsdottir K, Fogstad H, Zupan J, et al. (2007) Estimated global resources needed to attain universal coverage of maternal and newborn health services. Bull World Health Organ 85: 256–263.

47. World Health Organization (WHO) (2004) National laws and unsafe abortion: the parameters of change. Geneva: World Health Organization. Available: http://www.who.int/healthinfo/global_burden_mortality_2001/en/index.html. Accessed 24 August 2009.

48. Singh S (2006) Hospital admissions resulting from unsafe abortion: estimates from 13 developing countries. Lancet 368: 1087–1091.

49. Hofmeyr GJ, Kulier R (2000) Planned Caesarean section for term breech delivery. Cochrane Database Syst Rev 2: CD000166.

50. Ahman E, Shah I (2007) Unsafe abortion: global and regional estimates of unsafe abortion and associated mortality in 2003 (4th edn). Geneva: World Health Organization. Available: http://www.who.int/reproductivehealth/publications/unsafe_abortion/9241562706/en/index.html. Accessed 24 August 2009.

51. Ahman E, Shah I Unsafe abortion: global and regional estimates of unsafe abortion and associated mortality in 2000 (4th edn). Geneva: World Health Organization. Available: http://www.who.int/reproductivehealth/publications/unsafe_abortion/9241591803/en/index.html. Accessed 24 August 2009.

52. Grimes DA (2005) Risks of mifepristone abortion in context. Contraception 71: 551–556.

53. Hofmeyr GJ, Hannah ME (2003) Planned Caesarean section for term breech delivery. Cochrane Database Syst Rev 2: CD000166.

54. Hofmeyr GJ, Hannah ME (2003) Planned Caesarean section for term breech delivery. Cochrane Database Syst Rev 3: CD001060.

55. Hofmeyr GJ, Hannah ME (2003) Planned Caesarean section for term breech delivery. Cochrane Database Syst Rev 2: CD000093.

56. Crowther C, Hillier J, Doyle I (2002) Magnesium sulphate for preventing preterm birth in threatened preterm labour. Cochrane Database Syst Rev 4: CD001060.

57. French LM (2003) Prevention and treatment of postpartum endometritis. Curr Women's Health Rep 4: 274–279.

58. French LM, Small FM (2004) Antibiotic regimens for endometritis after delivery. Cochrane Database Syst Rev 4: CD001067.

59. Koomen LM, Smith JC, Ramich M (1995) Abortion surveillance—United States, 1990. MMWR CDC Surveill Summ 42: 29–57.

60. Institute of Medicine (IOM) (1975) Legalized abortion and the public health; report of a study by a committee of the Institute of Medicine. Washington (D.C.): National Academy of Sciences.

61. Grimes DA (2005) Risks of mifepristone abortion in context. Contraception 71: 161.

62. World Bank (2002) India’s transport sector: the challenges ahead. Vol 1. South Asia Region. Washington (D.C.): National Academy of Sciences.

63. French LM, Small FM (2004) Antibiotic regimens for endometritis after delivery. Cochrane Database Syst Rev 4: CD001067.

64. French LM, Small FM (2004) Antibiotic regimens for endometritis after delivery. Cochrane Database Syst Rev 4: CD001067.

65. World Bank (2002) India’s transport sector: the challenges ahead. 1. South Asia Region. Washington (D.C.): National Academy of Sciences.
69. Harlap S, Shinoe PH, Ramcharan S (1980) A life table of spontaneous abortions and the effects of age, parity and other variables. Porter IH, Hook EB, eds. Human embryonic and fetal death. New York: Academic Press, pp 145–158.
70. Menken J, Rahman MO (2006) Chapter 3: Reproductive health. Merson MH, Black RE, Mills AJ, eds. International public health: diseases, programs, systems, and policies, 2nd ed. Sudbury (Massachusetts): Jones and Bartlett Publishers. pp 71–125.
71. Brahmbhatt BJ, Hakimi M, Pelletier D (2001) An analysis of anemia and pregnancy-related maternal mortality. J Nutr 131: 640S–648S.
72. Holmeyr GJ, Gulmezoglu AM (2008) Misoprostol for the prevention and treatment of postpartum hemorrhage. Best Pract & Research Clinical Obstet and Gynaecol 22: 1025–1041.
73. Cahuana-Hurtado I, Sooa-Rahi S, Bertozzi S (2004) The application of the mother baby package reproductive health costing spreadsheet in Morelos: National Institute of Public Health, Division of Health Economics and Policy, Mexico.
74. Thaddeus S, Maine D (1994) Too far to walk: maternal mortality in context. Soc Sci Med 38: 1091–1110.
75. International Institute for Population Sciences (IIPS) and ORC Macro (2007) National Family Health Survey (NFHS-3), 2005–06: India, maternal health Chapter 8. Mumbai: IIPS. 191–222 Available: http://www.nfisindia.org/NFHS-3%20Data/VOL-1/india-volume_I_chapter_8_corrected_for_website_17oct08.pdf. Accessed 23 August 2009.
76. International Institute for Population Sciences (IIPS) (2006) Reproductive and Child Health Project. District Level Household Survey. DLHS-2. 2002–2004. Available: http://www.rchiips.org/pdfs/rch2/National_Report_RCH-II.pdf. Accessed 1 September 2009.
77. International Institute for Population Sciences (IIPS) (2007) Fact sheet: Uttar Pradesh. Reproductive and Child Health Project. District Level Household and Facility Survey. DLHS-3. Available: http://www.rchiips.org/pdfs/rch3/state/Uttar-Pradesh.pdf. Accessed 1 September 2009.
78. International Institute for Population Sciences (IIPS) (2007) Fact sheet: Rajasthan. Reproductive and Child Health Project. District Level Household and Facility Survey. DLHS-3. Available: http://www.rchiips.org/pdfs/rch3/state/Rajasthan.pdf. Accessed 1 September 2009.
79. Vora KS, Mavalankar DV, Ramani KV, Upadhyaya M, Sharma B, et al. (2009) Maternal health situation in India: a case study. J Health Popul Nutr 27: 104–107.
80. Iyeran GD, Iyengar K, Gupta V (2009) Maternal health: a case study of Rajasthan. J Health Popul Nutr 27: 271–292.
81. Iyengar K, Iyengar K, Sahalka V, Agarwal K (2009) Comparison of domiciliary and institutional delivery-care practices in Rural Rajasthan, India. J Health Popul Nutr 27: 303–312.
82. Iyengar K, Iyengar K, Sahalka V, Dashora K (2009) Pregnancy-related deaths in rural Rajasthan, India: exploring causes, context, and care-seeking through verbal autopsy. J Health Popul Nutr 27: 293–302.
83. Mavalankar DV, Vora KS, Ramani KV, Raman P, Sharma B, et al. (2009) Maternal health in Gujarat, India: a case study. J Health Popul Nutr 27: 235–248.
84. AMDD Working Group on Indicators (2002) Program note: using UN process indicators to assess needs in emergency obstetric services: Bhusan, Cameroon and Rajasthan, India. Int J Gynaecol Obstet 77: 277–284.
85. World Health Organization (WHO) (2006) World Health Report: working together for health. Geneva: World Health Organization. Available: http://www.who.int/whr/2006/en/index.html. Accessed 23 August 2009.
86. UNICEF, WHO, UNFPA (2007) Maternal mortality declining in middle-income countries; women still die in pregnancy and childbirth in low-income countries. UNICEF, WHO, UNFPA Joint Press Release. Available: http://www.unicef.org/media/media_41208.html. Accessed 27 July 2009.
87. United Nations (UN), Department of Economic and Social Affairs, Population Division (2007) World Population Prospects: the 2006 revision. CD-ROM edition - extended dataset in Excel and ASCII formats. New York: United Nations.
88. UNFPA (2007) Reproductive Health Costing Tools Model. New York: UNFPA. Available: http://www.who.int/pmnch/topics/economics/costing_tools/en/index15.html. Accessed 27 July 2009.
89. International Labour Organization (ILO) Labortisa database. Available: http://labortisa.ilo.org/. Accessed 27 July 2009.
90. UNICEF Supply Division. Available: http://wwwsupply.unicef.de/catalogue/. Accessed 27 July 2009.
91. Management Sciences for Health (MSH). International Drug Price Indicator Guide (IDPfG). Available: http://erc.msh.org/mainpage.cfm/file = 1.0. html& &k = 1& tempi tle = Introduction& module = DMP& language = English. Accessed 27 July 2009.
92. Duggal R (2004) The political economy of abortion in India: cost and expenditure patterns. Reprod Health Matters 12: S130–S137.
93. Borghi J, Ensor T, Somanathan A, Lissner C, Mills A, on behalf of The Lancet Maternal Survival Series steering group (2006) Mobilising financial resources for maternal health. Lancet 368: 1457–1465.
94. Bhat R, Mavalankar DV, Singh PV, Singh N (2009) Maternal healthcare financing: Gujarat’s Chiranjeevi Scheme and its beneficiaries. J Health Popul Nutr 27: 249–258.
95. Jamison DT, Berman JG, Measham AR, Alleyne G, Claeson M, et al. (2006) Disease control priorities in developing countries. 2nd edition. Washington (D.C.): The International Bank for Reconstruction and Development/ The World Bank. Available: http://www.dcp2.org. Accessed 4 May 2009.
96. Laxminarayan R, Chow J, Shahid-Salles SA (2006) Intervention cost-effectiveness: overview of main messages. Disease control priorities in developing countries. 2nd edition. 35–86. New York: Oxford University Press. Available: http://www.dcp2.org/pubs/DCP2/FullText. Accessed 4 May 2009.
97. Breenz L, Volson IJ, Foc-Rushby J, Miller M, Halsey NA (2006) Vaccine-preventable diseases. Disease control priorities in developing countries. 2nd edition. 309–412. New York: Oxford University Press. Available: http://www. dcp2.org/pubs/DCP2/FullText. Accessed 4 May 2009.
98. World Health Organization (WHO) (2001) Macroeconomics and health: investing in health for economic development: report of the Commission on Macroeconomics and Health. Geneva: World Health Organization.
99. Ekstrom B, Pathmanathan I, Liljestrand J (2008) Integrating health interventions for women, newborns, and children: a framework for action. Lancet 372: 990–1000.
100. Bang RA, Bang AT, Reddy MH, Desshmukh MD, Baitule SB, et al. (2004) Maternal morbidity during labour and the puerperium in rural homes and the need for medical attention: A prospective observational study in Gadchiroli, India. BJOG 111: 231–238.
101. Shiffman J, Smith S (2007) Generation of political priority for global health initiatives: a framework and case study of maternal mortality. Lancet 370: 1370–1379.
102. Filippi V, Rommans C, Campbell OM, Graham WJ, Mills A, et al. (2006) Maternal health in poor countries: the broader context and a call for action. Lancet 368: 1537–1541.
103. National Rural Health Mission (2005–2012) Mission document. Available: http://india.gov.in/outerwin.php?id = http://mohfw.nic.in/NRHM/NRHM%20National%20Rural%20Health%20Mission%29.htm. Accessed 1 September 2009.
104. Padmanaban P, Ramon PS, Mavalankar DV (2009) Innovations and challenges in reducing maternal mortality in Tamil Nadu, India. J Health Popul Nutr 27: 202–219.
105. Prakasam M (2009) Maternal mortality-reduction programme in Andhra Pradesh, J Health Popul Nutr 27: 229–234.
106. McPake B, Kohlinsky M (2009) Improving maternal survival in South Asia: what can we learn from case studies? J Health Popul Nutr 27: 93–107.
Editors’ Summary

Background. Every year, more than half a million women—most of them living in developing countries—die from pregnancy- or childbirth-related complications. About a quarter of these “maternal” deaths occur in India. In 2005, a woman’s lifetime risk of maternal death in India was 1 in 70; in the UK, it was only one in 8,200. Similarly, the maternal mortality ratio (MMR; number of maternal deaths per 100,000 live births) in India was 450, whereas in the UK it was eight. Faced with the enormous maternal death toll in India and other developing countries, in September 2000, the United Nations pledged, as its fifth Millennium Development Goal (MDG 5), that the global MMR would be reduced to a quarter of its 1990 level by 2015. Currently, it seems unlikely that this target will be met. Between 1990 and 2005, global maternal deaths decreased by only 1% per annum instead of the 5% needed to reach MDG 5; in India, the decrease in maternal deaths between 1990 and 2005 was about 1.8% per annum.

Why Was This Study Done? Most maternal deaths in developing countries are caused by severe bleeding after childbirth, infections soon after delivery, blood pressure disorders during pregnancy, and obstructed (difficult) labors. Consequently, experts agree that universal access to high-quality routine care during labor (“obstetric” care) and to emergency obstetrical care is needed to reduce maternal deaths. However, there is less agreement about how to adapt these “ideal recommendations” to specific situations. In developing countries with weak health systems and predominantly rural populations, it is unlikely that all women will have access to emergency obstetric care in the near future—so would beginning with improved access to family planning and to safe abortions (unsafe abortion is another major cause of maternal death) be a more achievable, more cost-effective way of reducing maternal deaths? How would family planning and safe abortion be coupled efficiently and cost-effectively with improved access to intrapartum care? In this study, the researchers investigate these questions by estimating the health and economic outcomes of various strategies to reduce maternal mortality in India.

What Did the Researchers Do and Find? The researchers used a computer-based model that simulates women through pregnancy and childbirth to estimate the effect of different strategies (for example, increased family planning or increased access to obstetric care) on clinical outcomes (pregnancies, live births, or deaths), costs, and cost-effectiveness (the cost of saving one year of life) in India. Increased family planning was the most effective single intervention for the reduction of pregnancy-related mortality. If the current unmet need for family planning in India could be fulfilled over the next 5 years, more than 150,000 maternal deaths would be prevented, more than US$1 billion saved, and at least half of abortion-related deaths averted. However, increased family planning alone would reduce maternal deaths by 35% at most, so the researchers also used their model to test the effect of combinations of strategies on maternal death. They found that an integrated and stepwise approach (increased family planning and safe abortion combined with consecutively increased skilled birth attendants, improved care before and after birth, reduced home births, and improved emergency obstetric care) could eventually prevent nearly 80% of maternal deaths. All the steps in this strategy either saved money or involved an additional cost per year of life saved of less than US$500; given one suggested threshold for cost-effectiveness in India of the per capita GDP (US$1,068) per year of life saved, these strategies would be considered very cost-effective.

What Do These Findings Mean? The accuracy of these findings depends on the assumptions used to build the model and the quality of the data fed into it. Nevertheless, these findings suggest that early intensive efforts to improve family planning and to provide safe abortion accompanied by a systematic, stepwise effort to improve integrated maternal health services could reduce maternal deaths in India by more than 75% in less than a decade. Furthermore, such a strategy would be cost-effective. Indeed, note the researchers, the cost savings from an initial focus on family planning and safe abortion provision would partly offset the resources needed to assure that every woman had access to high quality routine and emergency obstetric care. Thus, overall, these findings suggest that MDG 5 may be within reach in India, a conclusion that should help to mobilize political support for this worthy goal.

Additional Information. Please access these Web sites via the online version of this summary at http://dx.doi.org/10.1371/journal.pmed.1000264.

- UNICEF (the United Nations Children’s Fund) provides information on maternal mortality, including the WHO/UNICEF/UNFPA/The World Bank 2005 country estimates of maternal mortality
- The World Health Organization also provides information on maternal health and about MDG 5 (in several languages)
- The United Nations Millennium Development Goals Web site provides detailed information about the Millennium Declaration, the MDGs, their targets and their indicators, and about MDG 5
- The Millennium Development Goals Report 2009 and its progress chart provide an up-to-date assessment of progress toward all the MDGs
- Computer simulation modeling as applied to health is further discussed at the Center for Health Decision Science at Harvard University