

Cost-effectiveness of an Evidence-Based Childhood Asthma Intervention in Real-World Primary Care Settings

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Abstract: We present an incremental cost-effectiveness analysis of an evidence-based childhood asthma intervention (Community Healthcare for Asthma Management and Prevention of Symptoms [CHAMPS]) to usual management of childhood asthma in community health centers. Data used in the analysis include household surveys, Medicaid insurance claims, and community health center expenditure reports. We combined our incremental cost-effectiveness analysis with a difference-in-differences multivariate regression framework. We found that CHAMPS reduced symptom days by 29.75 days per child-year and was cost-effective (incremental cost-effectiveness ratio: \$28.76 per symptom-free days). Most of the benefits were due to reductions in direct medical costs. Indirect benefits from increased household productivity were relatively small. **Key words:** *asthma, childhood asthma, cost-effectiveness analysis*

ASTHMA is one of the leading chronic diseases among children in the United States. In 2013, the prevalence of childhood

asthma was 10.3% (Centers for Disease Control and Prevention, 2015), or 1 in 10 children aged 5 to 14 years. In addition to being a health concern for children, asthma imposes a considerable economic burden. According to the National Center for Environmental Health (2010), in 2008, asthma caused 10.5 million missed days of school and 14.2 million missed

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days of work. In 2007, the estimated total cost of asthma was \$56 billion of which \$50.1 billion was direct medical costs (Centers for Disease Control and Prevention, 2014).

Although there is no known cure for asthma, many of its symptoms can be controlled or prevented by adopting certain health behaviors and by using a variety of medications. Several home-based, multitriggers, multicomponent environmental intervention programs aimed at managing asthma symptoms in children have been proposed, implemented, evaluated in the literature, and found to be clinically efficacious (Nurmagambetov et al., 2011; Community Preventative Task Force, 2010). The majority of these programs were conducted in the home, outside the primary care practice setting, thus overlooking the role of the primary care facilities and providers from whom children receive most of their asthma care. In this study, we evaluate a recent intervention known as Community Healthcare for Asthma Management and Prevention of Symptoms (CHAMPS), which uniquely combines both the home and the primary care setting of community health centers (CHCs) while adapting, translating, and implementing a hybrid of previous childhood asthma evidence-based interventions (Kennedy et al., 2017).

In addition to systematically reviewing the clinical efficacy of previous home-based asthma interventions, Nurmagambetov et al. (2011) systematically reviewed their economic value. They found cost-effectiveness analysis was seldom used in the economic analysis of these projects. Thus, scholars and policymakers have limited information to compare interventions. Moreover, even when other studies report costs, they do not take into account the intervention's impact on the productivity of the children and their parents, possibly understating the program's benefits. Our cost-effectiveness study extends past literature by taking into account both implementation costs and direct medical expenditures associated with the program and its participants.

Nationally, CHCs comprise the largest network of primary care providers, with about

1375 centers serving 24.3 million underserved patients across every state and territory in the United States (Rosenbaum et al., 2017). Health centers also served 1 in 6 Medicaid patients, and most of their pediatric patients are covered by Medicaid. Often situated in areas with high asthma concentrations, CHCs have been historically involved in asthma quality improvement initiatives, yet to date little has been known about the feasibility and effectiveness of implementing interventions that extend from CHCs into the home. In this analysis, we attempt to shed light on this issue and fill the gap in the literature.

THE CHAMPS INTERVENTION

The study was undertaken in 2 states, Arizona and Michigan, and in 1 US territory, Puerto Rico. Enrollment into CHAMPS was initiated in April 2012, with post-intervention data collection ending in February 2015. Focusing on children aged 5 to 12 years, it combined elements from 2 precursor projects, namely the National Cooperative Inner-City Asthma Study (NCICAS) (Evans et al., 1999; Sullivan et al., 2002) and the Inner-City Asthma Study (ICAS) (Kattan et al., 2005; Morgan et al., 2004). While CHAMPS builds on decades of evidence-based interventions, it was designed to test a complex evidenced-based intervention, using intervention sites and comparison sites that share similar organizational traits but operate in different policy environments.

In each location, 1 CHC was selected for the intervention, paired with a matched comparison CHC. Intervention sites were selected for participation in the CHAMPS study through a structured application process, publicized through state primary care associations and the National Association of Community Health Centers. Intervention sites were selected from the applicant pool to represent different levels of capacity (high, medium, and low) to conduct the intervention as assessed through scored self-assessments and in-person site visits. Key areas included each center's experience with electronic health records, asthma counseling, allergen testing, home

visits, and spirometry. Once the intervention sites were selected, the CHAMPS study design team identified comparison centers in Arizona, Michigan, and Puerto Rico, matched on the basis of geographic location and the organizational characteristics listed earlier.

In addition to having a similar policy and regulatory environment and comparable levels of organizational capacity, comparison sites serve a similar population as the intervention sites. The study population comprised children ages 5 to 12 years with moderate-to-severe asthma, as defined by the national guidelines for asthma symptoms and asthma-related health care utilization of each participant. All institutions participating in this study are designated as Federally Qualified Health Centers, and thus all care for a traditionally underserved, low-income population, comparable in terms of income, education, and household composition. The comparison sites met the same basic data collection requirements as intervention sites, and the research team paid for data collection under the grant we received. These are considered research costs, which are not included as program delivery costs in our cost-effectiveness analyses. Sites were required to enroll participants over a 12-month period* with the intervention occurring in the 6-month period after informed consent and baseline clinic information were obtained. A follow-up survey was conducted for every participant 12 months after the intervention was initiated. Overall, 92.9% participants completed the 12-month outcome survey. We include a side-by-side table comparing intervention and control populations (see Supplemental Digital Appendix Table A1, available at: <http://links.lww.com/JACM/A82>).

This study provides an incremental cost-effectiveness analysis (ICEA) of the CHAMPS

intervention. We first describe the multiple data sources involved in the analysis. Next, we describe how data elements were incorporated in the analysis and methodology. We then present the results of an ICEA of the overall sample and subgroups. We conclude with a discussion comparing our results with previous studies and some potential limitations.

METHODS

Our study methods follow 3 computational stages. First, we derived program delivery costs at the site level using expenditure reports. Second, we performed a cost-benefit analysis, namely a comparison of the above costs with the (1) monetized value of averted medical utilization and (2) the monetized value of averted medical utilization and productivity gains, using the CHAMPS survey and matched claims data. Third, we supplemented the program cost and benefit information with a basic effectiveness measure commonly used in studies of asthma interventions, namely number of symptom-free days (SFDs), and obtained the incremental cost-effectiveness ratio for CHAMPS. Figure 1 describes the decision-making process in the cost-effectiveness analysis. All cost estimates are reported in 2012 dollars. The data sources used in the analysis include site expenditure reports, household surveys, and the claims data (see Supplemental Digital Appendix A, available at: <http://links.lww.com/JACM/A82>). All data collection and analysis protocols for this study were reviewed and approved by the George

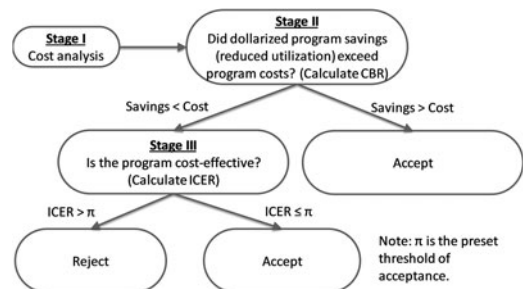


Figure 1. Cost-effectiveness analysis conceptual framework.

*However, enrollment patterns varied by the site. Michigan and Puerto Rico sites were able to complete enrollment of participants within a shorter period. In underlying multivariate models, we accounted for this using quarterly dummy variables and state-fixed effects (see Supplemental Digital Appendix Table A2, available at: <http://links.lww.com/JACM/A82>).

Washington University Institutional Review Board.

Stage I: Program costs

In stage I, we analyzed the expenditure reports and calculated the average per-person program delivery costs in CHAMPS. All research costs were excluded, while capital and equipment costs were depreciated over a 5-year period. Labor costs were adjusted for the project period and enrollment patterns. Accordingly, the average program delivery cost overall was \$1251 per participant per year.

Stage II: Cost-benefit analysis

In the cost-benefit analysis, we compared program delivery costs with dollarized program benefits (ie, program savings). The latter includes averted medical services utilization (ie, hospitalization and urgent care visits[†]), medication use[‡], and productivity loss. For survey items such as hospitalization, urgent visits, and medication use, we used corresponding expenditures from the claims data previously described to obtain weights. Furthermore, note that we use the average dollar values for all users in each state to generate the weights.

To gauge caretaker productivity loss, we associated the number of school-loss days with time diverted from economic activity. Following Wang et al. (2005), we estimated the value of productivity loss using wage data. If the caretaker was employed, we used her reported hourly wage and hours worked per week. If she was not employed, we assumed that the market value of her time was given by 20 hours per week at the federal minimum wage, a relatively conservative assumption (eg, Levy et al., 2011; Wang et al., 2005).

The cost-benefit ratio (CBR) is summarized as follows:

$$\text{CBR} = \frac{\text{Program Delivery Costs}}{\text{Averted Medical Service Costs} + \text{Averted Drug Costs} + \text{Averted Productivity Loss}} \quad (1)$$

Program costs were provided for the project years. As in most household surveys, questions regarding medical utilization and work or school days lost were based on 4-week look-back periods. For purposes of calculating the CBR, these values were annualized to match costs.

To estimate averted medical services, prescription drug use, and productivity loss associated with the intervention, we employed the difference-in-differences (DID) framework (Angrist & Pischke, 2008; Hansen, 2016). This framework allowed us to estimate the policy effect from individual-level regressions for participants in our survey data as follows:

$$y_i = \beta_0 + \beta_1 \text{Intervention} + \beta_2 \text{Post} + \beta_3 \text{Intervention} \times \text{Post} + \gamma X_i + e_i \quad (2)$$

where y_i is the outcome of interest (eg, utilization, school absences, and SFD), intervention is a dummy variable of intervention sites, post is the dummy variable of postintervention period,[§] and X_i is a vector of covariates, including patient characteristics, caretaker characteristics, and household characteristics (see Table 1). β and γ are coefficients of corresponding variables. β_3 is the policy impact parameter of interest and it represents the pure effect of CHAMPS that is independent of time trend (β_2) and site differences (β_1).[¶] Estimates were generated by the

[†]In the source data, urgent care visits are defined as unscheduled medical visits.

[‡]The CHAMPS surveys included a module for appropriate medication use. Enrollees were encouraged to take long-acting controller medicine as opposed to short-acting drugs in ongoing use. However, long-acting controller drugs are generally much more expensive than short-acting drugs. Moreover, Medicaid in Puerto Rico might not have covered the more expensive long-acting drugs.

[§]Postintervention period is defined as a 12-month period following enrollment in intervention for both intervention and comparison sites.

[¶]In all household interventions, there is the concern that individuals modify an aspect of their behavior due to their awareness of being observed. This is referred to as the "observer effect" or the Hawthorne effect. The underlying DID model addresses this by differencing out the effect in the treatment and comparison arms of the study.

Table 1. Descriptive Statistics at Baseline

Variables Outcomes	Intervention Mean (SD)	Comparison Mean (SD)	2-Tailed <i>t</i> Test Difference (SE)
Symptom-free days	18.607 (7.274)	17.316 (8.166)	− 1.291 ^a (0.650)
Overnight hospital stays, n	0.359 (0.893)	0.563 (1.552)	0.203 (0.107)
Urgent care visits, n	6.097 (6.696)	4.136 (3.029)	− 1.961 ^b (0.429)
Short-acting drug user	0.949 (0.221)	0.859 (0.349)	0.089 ^b (0.024)
Long-acting drug user	0.640 (0.481)	0.725 (0.447)	− 0.085 ^a (0.039)
School absence days	1.523 (2.487)	2.463 (3.652)	0.940 ^b (0.264)

Abbreviations: SD, standard deviation; SE, standard error.

^a*P* < .05.

^b*P* < .001.

Generalized Methods of Moments (GMM; see Wilde, 2008). The policy impact parameters are reported in Table 2. The underlying DID methods are discussed in greater detail in Supplemental Digital Appendix B (available at: <http://links.lww.com/JACM/A82>).

The following equations illustrate how we estimate the averted costs (loss):

Averted Medical Service Cost

$$= \Delta \text{ Medical Services} \times \text{Per Unit Cost} \quad (3a)$$

Averted Drug Cost = Δ Drug Utilization

$$\times \text{Per Year Cost} \quad (3b)$$

Averted Productivity Loss

$$= \Delta \text{ School Absence Days}$$

$$\times \text{Caretaker's Daily Wage} \quad (3c)$$

where Δ represents the change between values in the 12-month postenrollment survey

and the baseline survey administered at the point of enrollment. These changes were obtained from the DID regression models described earlier.

The benefits and costs integrated into the ICEA described earlier are borne by different parties. For example, averted drug and medical costs primarily benefit insurance companies (in this case, Medicaid-managed care organizations), whereas averted productivity loss primarily benefits patients and families. Thus, depending on the audience for this economic analysis, a case can be made both for the inclusion and exclusion of productivity measures. In order to account for both the societal and insurer's perspectives, we report results for both types of analysis.

For medical services, we analyzed 2 categories of services: urgent care services (including emergency department visits) and

Table 2. Subgroup Analysis^a

Subgroup	ICER (95% CI)
Baseline: all sites (n = 570)	\$28.76 (\$15.51-\$91.03)
All sites: high users (n = 455)	\$30.19 (\$13.59-\$103.05)
≥2 urgent care visits in 12 mo before baseline	
All sites: high risk (n = 314)	\$24.18 (\$10.57-\$122.90)
<18 SFD in past 4 wk before baseline	
All sites: low risk (n = 215)	\$29.53 (\$15.88-\$88.89)
≥18 SFD in past 4 wk before baseline	
Continental US sites only (n = 328)	\$11.60 (\$6.14-\$34.41)

Abbreviations: CI, confidence interval; ICER, incremental cost-effectiveness ratio; SFD, symptom-free day.

^aThe ICER indicates the cost per additional SFD—based on middle range cost estimates.

Table 3. Changes in Outcomes From Baseline to the Postintervention Period (Unadjusted)^a

Variables	All Sites Mean (SE)	Intervention Sites Mean (SE)	Comparison Sites Mean (SE)
Symptom-free days	5.676 ^b (0.427)	6.139 ^b (0.547)	5.174 ^b (0.654)
Overnight hospital stays, n	− 0.295 ^b (0.061)	− 0.305 ^b (0.056)	− 0.286 ^c (0.112)
Urgent care visits, n	− 0.319 ^b (0.023)	− 0.405 ^b (0.034)	− 0.225 ^b (0.031)
Short-acting drug user	− 0.340 ^b (0.025)	− 0.428 ^b (0.036)	− 0.245 ^b (0.031)
Long-acting drug user	− 0.0736 ^c (0.029)	0.0143 (0.037)	− 0.169 ^b (0.043)
School absence days	− 1.210 ^b (0.152)	− 0.973 ^b (0.175)	− 1.471 ^b (0.251)

Abbreviation: SE, standard error.

^a12-month intervals.^b $P < .001$.^c $P < .05$.

inpatient hospital stays. For medications, following the American Academy of Allergy, Asthma and Immunology guidance (American Academy of Allergy, Asthma and Immunology, 2016), we categorized asthma-related drugs into 2 categories: short-acting drugs and long-acting drugs.

Stage III: Cost-effectiveness analysis

Because dollarized program benefits (or cost savings) turned out to be less than program delivery costs, we proceeded to the cost-effectiveness phase of the analysis, which incorporated information from cost-benefit analysis but took into account health-related outcomes. Cost-effectiveness analysis assesses the incremental cost of the intervention for a given unit increase of outcome. The main outcome variable in the CHAMPS data was SFDs. We use the following formula to calculate the incremental cost-effectiveness ratio (ICER) (Polsky et al., 1997):

$$\text{ICER} = \frac{\text{Program Cost}_{\text{intervention}} - \text{Program Savings}_{\text{intervention}}}{\Delta \text{SFD}_{\text{intervention}} - \Delta \text{SFD}_{\text{comparison}}} \quad (4)$$

Given that program delivery costs are effectively zero in comparison sites, we needed to consider program costs in the intervention sites only. Program savings are the dollarized values of the program benefits

previously obtained from the cost-benefit analysis. The reduction in SFDs is also estimated using the DID model described in the Supplemental Digital Appendix (available at: <http://links.lww.com/JACM/A82>). Following Gomes et al. (2012), we used the bootstrap technique to obtain the confidence interval around the cost-effectiveness ratio.

Summary statistics for the full samples are shown in Tables 1 and 3. Table 4 reports the weights (mean expenditures) that were used to convert utilization into dollar amounts. Results from the cost-benefit and cost-effectiveness analyses are reported in Tables 5 and 6. Subgroup analyses are reported in Table 2. Additional comparisons between continental US sites and Puerto Rico sites are exhibited in Table 7. Note that all our estimates were adjusted using the covariates shown in Table 1.

RESULTS

Table 1 provides preintervention descriptive statistics of outcomes and key characteristics of intervention and comparison groups,

Table 4. Summary of Dollar Weights Used in Cost-effective Analysis

Outcomes	Dollar Weights
Hospitalization (per day)	\$961.92
Urgent care visits (per visit)	\$125.81
Short-acting drugs (per person per year)	\$113.68
Long-acting drugs (per person per year)	\$455.22
Productivity loss (per day)	\$46.54

along with results from a 2-sample *t* test. Many covariates are not balanced in the preintervention period. Thus, it was necessary to adjust for covariates in the regression models that generated cost-effectiveness analysis (Willan et al., 2004). In total, 292 children enrolled in intervention sites and 278 children enrolled in comparison sites. The attrition rate was 7.2%. The combined preintervention and postintervention samples had a total 1099 observations.^{||} Table 3 reports the pre-/postcomparisons in outcome statistics. We generally found a larger improvement in outcomes in the intervention sites, prior to adjustments.

Per-person average costs are reported in Table 4. These were used as the dollar weights for utilization counts in the cost-benefit and cost-effectiveness analyses.**

Table 5 summarizes the average policy effects of the intervention on health services utilization, medication use, and productivity loss per child over the 12-month follow-up period. The intervention reduced utilization

Table 5. CHAMPS Intervention Effects on Health Services Utilization and Productivity Loss

Measure	Policy Effect (SE)
Overnight hospital stay days, n	− 0.157 ^a (0.043)
Urgent care visits, n	− 2.542 ^a (0.216)
Short-acting medication user	− 0.182 ^a (0.047)
Long-acting medication user	0.192 ^a (0.048)
School absence days	0.015 (0.237)

Abbreviation: SE, standard error.

^a*P* < .01.

dramatically, including urgent care visits (by 2.5 visits, a 41.7% reduction relative to the baseline at intervention sites), and hospitalization visits (by 0.16 visit, equivalent to a 43.7% reduction). For asthma medications, we find a difference in the responses to the intervention between short-acting and long-term medications: the probability of being a short-acting asthma medication user fell by 18.1 percentage points (a 19.1% reduction), whereas the probability of being a long-acting asthma medication user increased by 19.2% percentage points (a 30.0% increase). School absence days due to asthma did not change significantly over the 12-month follow-up period.

Table 6 provides adjusted reduction in medical services costs, medication costs, productivity loss, and SFDs per child over the 12-month period. All costs are in constant 2012 dollars. The adjusted estimates are the policy parameters from the DID analysis. For the adjusted estimates, children in the treatment group save \$471.50 in medical services use. The treatment group incurs \$66.87 more in medication costs and \$9.19 more (though insignificantly) in productivity loss than the comparison group. The adjusted net program cost is \$861.60 per child. The intervention led to a 29.75-day increase in symptom-free days over the 12-month follow-up period. The ICER for CHAMPS is thus estimated to be \$28.76 per SFD gained from the societal perspective and \$28.45 per SFD gained from the insurer's perspective (productivity gains excluded). In

^{||} Although an exact census of moderate-severe, persistent asthma patients (those targeted by the intervention) was not available, participating sites did provide an estimate of the total number of pediatric asthma patients served at their respective health centers. Estimates for intervention health centers were as follows: 4850, 1800, and 700 children with asthma in Arizona, Michigan, and Puerto Rico sites, respectively.

**By design equal weights are assigned to intervention and comparison sites.

Table 6. 12-Month Cost and Outcome Differences and Incremental Cost-effectiveness Analysis^a

	Difference (Intervention – Control)	
	Insurer Perspective	Societal Perspective
Cost (saving) items		
Program delivery	\$1251	\$1251
Medical services utilization	\$–471.45	\$–471.45
Medication use	\$66.87	\$66.87
Productivity loss	–	\$9.19
Net program cost	\$846.42	\$855.61
Effectiveness		
Additional SFD	29.75	29.75
Cost-benefit analysis		
Benefit-cost ratio	0.32	0.31
Cost-effectiveness		
Point estimate of ICER (95% CI)	\$28.45 per SFD (\$18.71-\$71.20)	\$28.76 per SFD (\$14.59-\$84.72)

Abbreviations: CI, confidence interval; ICER, incremental cost-effectiveness ratio; SFD, symptom-free day.

^aThe ICER provides the cost per additional SFD per child over the 12-month follow-up period.

practice, the 2 methods yielded very close estimates of incremental cost-effectiveness ratios. Moreover, removing the productivity gains from the estimate led to a better statis-

tical fit and smaller confidence interval (95% confidence interval: \$18.71- \$71.20 from the insurer's perspective vs \$14.59-\$84.72 from the societal perspective, see Figure 2).

Table 7. Differences Between Continental US and Puerto Rico Intervention Sites (Preintervention)

Variables	Continental US Mean (SD)	Puerto Rico Mean (SD)	2-Tailed <i>t</i> Test	
			Difference	<i>P</i> Value
Outcomes				
SFD	17.627 (8.170)	20.410 (4.775)	2.783 ^a	.750
Overnight hospital stay, n	0.161 (0.604)	0.724 (1.181)	0.563 ^a	.123
Urgent care visits, n	4.016 (4.460)	9.924 (8.276)	5.908 ^a	.869
Short-acting drug user	0.850 (0.358)	0.876 (0.331)	0.026	.041
Long-acting drug user	0.746 (0.436)	0.686 (0.466)	– 0.060	.055
School absence days	2.078 (2.669)	0.505 (1.699)	– 1.573 ^a	.254
Patient characteristics				
Age	8.237 (2.123)	8.201 (2.183)	– 0.036	.262
Male	0.617 (0.487)	0.552 (0.500)	– 0.064	.060
Race—white non-Hispanic	0.083 (0.276)	0.000 (0.000)	– 0.083 ^a	.020
Race—black non-Hispanic	0.145 (0.353)	0.000 (0.000)	– 0.145 ^a	.025
Race—Hispanic	0.746 (0.436)	1.000 (0.000)	0.254 ^a	.031
Race—other	0.026 (0.159)	0.000 (0.000)	– 0.026 ^b	.011
N	193	105		

Abbreviations: SD, standard deviation; SFD, symptom-free day.

^a*P* < .001; ^b*P* < .05.

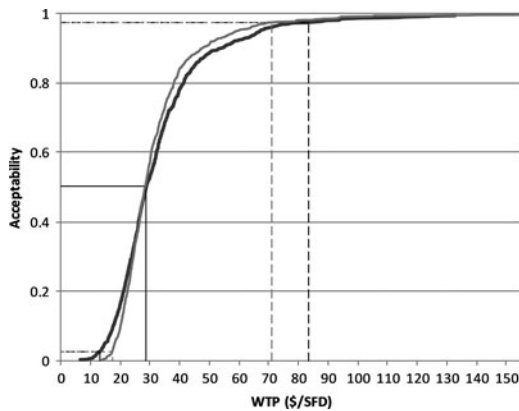


Figure 2. Cost-effectiveness acceptability curve (black curve represents societal perspective and gray curve represents insurer's perspective).

Figure 2 exhibits the cost-effectiveness acceptability curves, which shows the portion of bootstrapped ICER results under certain willingness-to-pay thresholds. The black curve represents the societal perspective and the gray curve represents the insurer's perspective. From the societal perspective, a society that is willing to pay \$54.73 per SFD per child can be 90% confident that CHAMPS is cost-effective.^{††} From the insurer's perspective, a payer that is willing to pay \$48.91 per SFD per child can be 90% confident that CHAMPS is cost-effective.

It has been suggested that targeting high-risk or high-use populations may further improve the cost-effectiveness of asthma interventions (Sullivan et al., 2002). To probe this, we performed analyses of subgroups using the following criteria: (1) whether the participant required more than 2 urgent care visits in the 12 months prior to the baseline visit (high users)^{‡‡} and (2) whether

the participant's SFDs in the 4 weeks prior to baseline are less than 18 days (higher risk). Table 2 presents results of subgroup analyses. The ICER of high users (ie, baseline urgent visit number ≥ 2) and that of low-risk participants (ie, baseline SFDs ≥ 18 days) were slightly higher than the ICER for the full sample. Higher-risk participants (baseline SFD < 18) had the lower ICER per SFD gained. Thus, targeting high-risk children could help make the program even more cost-effective.

Difference between continental US sites and Puerto Rico sites

Another subanalysis in Table 7 separates out the US sites from Puerto Rico. Limiting the analysis to the United States only results in a large drop in the ICER. While this suggests that benefits relative to costs are particularly low in Puerto Rico, we opted not to conduct the more detailed analyses for the territory, as the smaller sample size impacted statistical significance. We note however that the benefits in Puerto Rico may have been understated due to underlying clinical and cultural differences. A more in-depth analysis of these qualitative observations is discussed elsewhere (publication forthcoming).

Table 7 exhibits the difference between the intervention sites in continental US and Puerto Rico sites in the preintervention period. While higher acute utilization indicators (urgent care and overnight hospital stays) were worse (higher) in Puerto Rico, main symptom indicators (SFD and school absence days) were better (lower) in Puerto Rico than in the US sites. At first glance, this appears counterintuitive—children in Puerto Rico were expected to have worse health indicators and should benefit more from asthma interventions. However, qualitative interviews with health center staff and leadership suggest that initially lower awareness of asthma among parents and caretakers may have led to underreporting of symptoms at baseline, while higher awareness associated with the intervention led to increased utilization of urgent care, and parents keeping their children at home rather than sending them to school with symptoms, in the follow-up period. This could also

^{††}Cost-effectiveness acceptability curves were obtained by bootstrapping the ICER results with 1000 replications. The 95% confidence interval around each point estimate is given by the bootstrapped estimates around the 2.5 and 97.5 percentiles on the curve.

^{‡‡}We did not perform subgroup analyses for hospitalizations, given that these were rare events, with too few observations available for the underlying regression analysis.

be attributable to the fact that 98% of CHAMPS patients in Puerto Rico were prescribed oral steroids at baseline, which may have ameliorated their symptoms at the expense of improper asthma care. These would have contributed to the seemingly high cost-effectiveness ratio for Puerto Rico sites, which could be justified as some costs are devoted to raising awareness about proper management of asthma symptoms. In addition, there is potentially a downward bias in reporting of symptoms days in the baseline clinical survey, because caretakers did not pay enough attention to track their children's symptoms in the pretreatment period. With this preface, we note that the confidence intervals of the full-sample and mainland-only ICERs overlap.

DISCUSSION

Although the underlying study design of CHAMPS and related analytical methods make direct comparisons with earlier interventions difficult, with some standardization it appears that CHAMPS offers a clear improvement: on an annualized basis, CHAMPS yielded an additional 29.75 SFDs per patient compared with 18.9 SFDs in ICAS (Kattan et al, 2005).^{§§} Excluding productivity loss to account for the insurer's perspective does not change our results significantly. Trending data forward to 2012 to adjust for medical inflation, the ICER estimate for CHAMPS (\$28.76) is lower than that of ICAS (\$40.45). Similarly, the ICER estimate of US sites in CHAMPS (\$11.60) was well below the inflation-adjusted NCICAS estimate.^{¶¶}

Moreover, our estimates should be taken as conservative, for several reasons. First, unlike some previous work, our study collected the full costs of administering the intervention (net of research costs). Second, by design, CHAMPS was compressed into a shorter follow-up period, possibly underestimating longer-term benefits from the intervention. Third, unlike previous studies, our estimates incorporate the costs of expensive long-acting medications; we observed that utilization of these medications increased after the program initiation, indicating that patients are receiving a better standard of care in accordance with nationally published guidelines. The benefits of these long-acting medications are likely to accrue over the long run, and thus could not be taken into account in the shorter follow-up period observable in CHAMPS (Wang et al., 2005).

Including Puerto Rico with mainland U.S. states in the underlying intervention also influenced the CHAMPS cost-benefit ratios in the upward direction. We speculated that these may be an artifact of raised awareness of asthma and asthma symptoms gained by Puerto Rico participants in the area of the island where CHAMPS was being implemented. Excluding Puerto Rico from the analysis yielded a substantially lower ICER for the mainland sub-sample (\$11.60). Together, these results lend confidence to concluding that programs that extend implementation from CHCs to the home can provide substantial benefits at reasonable costs to children with asthma.

In addition to shedding light on the CHAMPS program itself, our analysis makes contributions to the program evaluation literature more broadly. First, by explicitly employing a 3-stage conceptual framework, we first attempt to justify the intervention by using only dollarized tangible benefits (e.g. reduction in utilization of medical services) and, if failed, we move to show the cost-effectiveness of the program in terms of more intangible non-monetized effectiveness outcomes. The results from this step-wise cost-effectiveness

^{§§}The original additional SFDs reported were 26.59 (NCICAS) and 37.8 (ICAS). However both NCICAS and ICAS tracked patients over a 2-year period, whereas CHAMPS had a more conservative 1-year follow-up period.

^{¶¶}The ICER reported here are trended forward to 2012 dollars using the medical component of CPI. Kattan et al. (2005) reported an ICER of 27.57 for ICAS in 2001 dollars and Sullivan et al. (2002) reported a much lower (9.20 in 1995 dollars) ICER for NCICAS. In 2012 dollars, ICER of ICAS was \$40.45 per SFD and that of NCICAS was \$17.31 per SFD.

analysis provide information for decision makers who may want to adopt this program. It allows decision makers to consider how much they are willing to pay for an additional SFD as opposed to how much they are able to save from implementation of the program. Second, by combining actually incurred claims data from health plans with utilization information for program participants, we estimate the costs of medical utilization directly. Other studies rely on national expenditure data that serve as approximations but may not accurately reflect actual costs incurred by the target population and its insurers. While our cost information is more complete, additional research on the extent of switching from short-acting to long-acting drugs would further in-

form program comparisons. This remains a limitation.

As noted in a recent policy review from the Brookings Institution (Farmer et al., 2015), targeting high-risk children for intervention in order to improve cost-effectiveness is an important issue, often overlooked in program design. While CHAMPS was not designed specifically to address this gap, in sensitivity analyses we observed lower cost-effectiveness ratios among higher-risk children relative to their lower-risk counterparts. Additional research is needed in which risk-targeting is explicitly included as part of the study design. More broadly, by focusing on an actual practice setting, our study contributes to translational research in asthma.

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