An Economic Evaluation of PulseNet

A Network for Foodborne Disease Surveillance

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The PulseNet surveillance system is a molecular subtyping network of public health and food regulatory agency laboratories designed to identify and facilitate investigation of foodborne illness outbreaks. This study estimates health and economic impacts associated with PulseNet. The staggered adoption of PulseNet across the states offers a natural experiment to evaluate its effectiveness, which is measured as reduction of reported illnesses due to improved information, enhanced industry accountability, and more-rapid recalls. Economic impacts attributable to PulseNet include medical costs and productivity losses averted due to reduced illness. Program costs are also reported. Better information and accountability from enhanced surveillance is associated with large reductions of reported illnesses. Data collected between 1994 and 2009 were assembled and analyzed between 2010 and 2015. Conservatively, accounting for underreporting and underdiagnosis, 266,522 illnesses from *Salmonella*, 9,489 illnesses from *Escherichia coli (E. coli)*, and 56 illnesses due to *Listeria monocytogenes* are avoided annually. This reduces medical and productivity costs by $507 million. Additionally, direct effects from improved recalls reduce illnesses from *E. coli* by 2,819 and *Salmonella* by 16,994, leading to $37 million in costs averted. Annual costs to public health agencies are $7.3 million. The PulseNet system makes possible the identification of food safety risks by detecting widespread or non-focal outbreaks. This gives stakeholders information for informed decision making and provides a powerful incentive for industry. Furthermore, PulseNet enhances the focus of regulatory agencies and limits the impact of outbreaks. The health and economic benefits from PulseNet and the foodborne disease surveillance system are substantial.

(Am J Prev Med 2016;50(5S1):S66–S73)

Introduction

Foodborne illness continues to be an important source of morbidity and mortality in the U.S. Annually, approximately 48 million illnesses resulting in 128,000 hospitalizations and 3,000 deaths are caused by contaminated food.[1,2] In response to this problem, the Centers for Disease Control and Prevention (CDC) created PulseNet: a molecular subtyping network of federal, state, and local public health laboratories designed to facilitate the identification of and response to outbreaks caused by bacterial foodborne pathogens. The development of a national database of molecular "fingerprints" for clinical isolates of foodborne pathogens utilizing uniform standards and protocols has allowed for seemingly sporadic cases of foodborne illness to be linked to previously unidentifiable outbreaks. The specific objectives of PulseNet are to detect foodborne disease case clusters through comparison of pulsed field gel electrophoresis (PFGE) patterns; to allow for real-time communication between federal, state, and local health departments; to facilitate early identification of common source outbreaks; and to help food regulatory agencies identify areas where implementation of new measures is likely to improve the safety of the food supply.[3]

The goals of this study were to estimate illness reduction attributable to PulseNet and assess the costs and benefits associated with the PulseNet program. The study focuses on program effectiveness for *Salmonella,* shiga toxin–producing *Escherichia coli* (STEC) and *Listeria monocytogenes*— a subset of important pathogens that have been a part of PulseNet for an amount of time sufficient to allow

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This article is part of the supplement issue titled The Use of Economics in Informing U.S. Public Health Policy.

0749-3797/$36.00

http://dx.doi.org/10.1016/j.amepre.2015.09.018

for empirical analysis. Results from this analysis will help public health officials, policymakers, and the public assess the health and economic returns from maintaining, and potentially even expanding, the PulseNet program.

Methods

Two approaches were used to assess the number of illnesses averted due to PulseNet. First, a "Recall" model was developed to assess the direct effects of faster identification of outbreaks on consumption of contaminated product and the resultant illness reduction. Second, a "Process Change" model was designed to capture the indirect effects from enhanced outbreak identification on illnesses averted due to new incentives and information used by industry and government. A comprehensive Monte Carlo analysis using @Risk, version 5.7.1, was performed to account for uncertainty in both the illness and economic models. Credible intervals are reported for terminal values across alternative models. A conservative cost of illness analysis is then used to produce summary measures for burden of illness averted. Data for this study were assembled and analyzed between 2010 and 2015. An enhanced description of the methodology is available in the Appendix (available online).

The Recall Model

The primary direct effect from PulseNet is earlier identification and recall of contaminated foods, leading to a reduced number of illnesses associated with the contaminated product. Specifically, contaminated food products in interstate commerce may cause illnesses across multiple states. Aggregation of cases by PulseNet reduces the time until the outbreak is recognized and increases the likelihood of preventing additional exposures. To measure this, two Monte Carlo (probabilistic) models were built to estimate the number of cases prevented through recalling contaminated ground beef products associated with *E. coli* O157:H7 and multistate *Salmonella* outbreaks detected by the PulseNet system for the period 2007–2008, which were the most current years with data available at the start of the project. Separate models were developed for *E. coli* O157:H7 and *Salmonella* outbreaks owing to differences in the data available from which to build the models. The *E. coli* O157 model specifically looked at ground beef because it was implicated in 19 of 29 (66%) *E. coli* O157 outbreaks with a confirmed food vehicle and because the second most common vehicle was leafy greens (eight outbreaks), which are not typically identified early enough to prevent cases by recalls.[4]

For the first model, U.S. Department of Agriculture Food Safety and Inspection Service recall records were reviewed to identify recalls related to *E. coli* O157:H7 outbreaks in which ground beef products were implicated as a vehicle.[5,6] For each recall, the number of pounds of consumed ground beef was calculated by subtracting the amount of product recovered from the amount of recalled product, reduced by 32% to account for product loss at the consumer level.[7] The number of outbreak-associated cases was determined by reviewing published outbreak summaries, the CDC Foodborne Outbreak Response and Surveillance database, and the PulseNet database to identify isolates with PFGE patterns matching the outbreak strain. This allowed for the determination of the number of cases that were reported, confirmed, and subtyped by PFGE for each outbreak. The rate of *E. coli* O157:H7 outbreak–associated cases per 1,000 pounds of product consumed was calculated, and this rate was multiplied by the amount of product recovered to determine the number of *E. coli* O157:H7 cases averted in each outbreak. Although each outbreak-specific attack rate was treated as a constant over the course of the outbreak, because the value is derived from outbreak-specific parameters, it functionally averages variability in attack rate differences that would have occurred over the course of the outbreak. Beta distributions were fit to each of the input variables for which uncertainty existed: pounds of distributed product, pounds of recovered product, fraction of consumed product, and the number of reported outbreak cases. Ninety percent ranges for the number of cases averted per outbreak were determined by Monte Carlo simulation with 10,000 iterations per outbreak using @Risk, version 5.7.1.

In contrast to Food Safety and Inspection Service recalls, the U.S. Food and Drug Administration does not routinely collect or report information that would allow an estimation of the amount of distributed or consumed product. Therefore, the number of *Salmonella* cases was calculated by modeling the difference between observed and expected cases reported following initiation of the product recall. The analysis of U.S. Food and Drug Administration–recorded recalls was limited to those in which the recalled food item was identified as a result of an outbreak investigation.

To estimate the number of cases expected to occur, the number of reported cases was counted during each week of the outbreak. The duration of the outbreak was determined on the basis of the number of weeks between onset of the first and last outbreak-associated cases. Outbreak-specific negative binomial distribution parameters were used to generate an expected range of cases per week for the remainder of the outbreak period, with the ranges bounded by zero and the highest weekly count of reported cases.[1] *Salmonella* cases averted in each outbreak were calculated as $\sum$ (expected cases, week i – reported cases, week i) for all weeks from initiation of the recall to the end of the outbreak.

Ninety percent ranges for the number of cases averted in each outbreak were determined by Monte Carlo simulation with 10,000 iterations per outbreak using @Risk, version 5.7.1.

The Process Change Model

The process change model was developed to capture indirect effects of the PulseNet system on incidence of illness. Specifically, better identification of the source of outbreaks provides information to regulators and industry, while creating an enhanced incentive for industry members to implement practices that reduce the risks associated with their foods. The fact that PulseNet was adopted by states to different degrees in different years creates ideal conditions for evaluating PulseNet as a natural experiment. The result of this process change is expected to be fewer foodborne illnesses experienced and reported.

The following three specifications were used to test the effect of PulseNet on reported illnesses:

$$\text{Illnesses}_{ist} = \beta_1 \text{Pulse}_{ist} + \beta_2 \text{Iso}_{ist} + \beta_3 \text{Iso}_{ist-1} + \delta \mathbf{X}_{st} + \varepsilon_i$$

$$\text{Illnesses}_{ist} = \alpha_{ist} + \beta_1 \text{Pulse}_{ist} + \beta_2 \text{Iso}_{ist} + \beta_3 \text{Iso}_{ist-1} + \delta \mathbf{X}_{st} + \varepsilon_{ist}$$

$$\text{Prob}(\text{Illnesses} = \text{Illnesses}_{ist}) = \frac{\exp(-\lambda_{ist})(\lambda_{ist})^{\text{illnesses}_{ist}}}{\text{illnesses}_{ist}!}, y = 1, 2, \ldots;$$

$$\text{where } \log \lambda_{ist} = \beta_1 \text{Pulse}_{ist} + \beta_2 \text{Iso}_{ist} + \beta_3 \text{Iso}_{ist-1} + \delta \mathbf{X}_{st} + \varepsilon_i \quad (1)$$

In equation 1, $Illnesses_{ist}$ = number of illnesses recorded by National Notifiable Diseases Surveillance System (NNDSS) by pathogen i in state s at time t, Iso_{ist} = number of isolates tested in the state lab at time t, Iso_{ist-1} = number of isolates tested in the state lab at time t − 1, $Pulse_{ist}$ = PulseNet implemented for pathogen i in state s at time t × population, and X_{st} = a set of potentially confounding variables (Table 1).

Reported illnesses are a function of the existence of PulseNet, the number of tested isolates, both past and present, and a set of variables which may impact adoption and effectiveness of changes in food handling and production.[8,9] In the first equation, no intercept is specified because it was assumed that the pre-PulseNet number of illnesses in a state was essentially independent of population size. The second equation includes an intercept, allowing for baseline (pre-PulseNet) differences in number of cases. The third equation is a maximum likelihood Poisson model, designed for estimating count data models (such as the number of illnesses in a given state at a given time). An alternative (spillover effects) specification of this model includes a variable, Iso_{-ist}, to measure the reduction of pathogen i owing to process changes resulting from identification of other pathogens –i. Essentially, this model asserts that efforts aimed at reducing one pathogen will also reduce risks from other pathogens. For example, a facility's improved sanitation measures in response to a highly publicized *Listeria* outbreak will also reduce the risk in that facility from *Salmonella* and *E. Coli*.

Table 1. Descriptive Statistics of Sample Used

Variable	Description	Mean	SD
Illnesses Reported to NNDSS			
Salmonella illnesses	*Salmonella* illnesses at time t in state s	869.292	1,034.520
E. coli illnesses[a]	*E. coli* O157 illnesses at time t in state s	64.207	75.240
Listeria illnesess[b]	*Listeria* illnesses at time t in state s	15.329	21.934
Tests Reported by Labs			
Salmonella isolates	*Salmonella* isolates at time t in state s	304.538	488.820
STEC isolates[a]	STEC isolates at time t in state s	31.137	55.840
Listeria isolates[b]	*Listeria* isolates at time t in state s	10.445	20.641
State Participation in PulseNet			
	0–1 dummy variable equals 1 if state has implemented PulseNet at time t	0.631	0.483
Controls			
State Population	Population at time t in state s	5,570,499	6,206,105
Year (t)	(Calendar year − 1993)	8.500	4.613
PCI	State per capita personal income at time t	36,149	6,331
Regions			
New England	(0–1 dummy variable)	0.118	0.322
Middle Atlantic	(0–1 dummy variable)	0.059	0.235
East North Central	(0–1 dummy variable)	0.098	0.298
West North Central	(0–1 dummy variable)	0.137	0.344
South Atlantic	(0–1 dummy variable)	0.157	0.364
East South Central	(0–1 dummy variable)	0.078	0.269
West South Central	(0–1 dummy variable)	0.078	0.269
Mountain	(0–1 dummy variable)	0.157	0.364
Pacific	(0–1 dummy variable)	0.098	0.298
Number of Observations = 816			

[a] *E. coli* O157:H7 estimates based on 561 observations (1994–2005).
[b] Listeriosis estimates based on 501 observations (2000–2009).
STEC, shiga toxin–producing *Escherichia coli*; PCI, per capita income; NNDSS, National Notifiable Diseases Surveillance System.

The PulseNet system currently collects data for six pathogens (*Salmonella*, STEC, *Listeria*, *Campylobacter, Shigella, and Yersinia).* This study focused, however, on *Salmonella*, STEC, and *Listeria* because these pathogens were the first to be adopted by PulseNet states and, as a result, have a sufficient number of observations to allow for empirical analysis.

To populate the model, data were collected from a number of sources for the period 1994–2009. The number of reported illnesses from each pathogen in each state was obtained from the NNDSS.[10,11] *Salmonella* data were available for each state for all years of surveillance (1994–2009). *E. coli* O157 data for the years 1994–2005 were used in the analysis. In 2006, *E. coli* O157 was replaced in the NNDSS by STEC, which could not be used because it is a broader category of pathogens. Reports for illnesses caused by *Listeria* were available for most states from 2000 to 2009. Isolates tested and reported to PulseNet from 1993 to 2009 for each pathogen were obtained through personal correspondence (P. Gerner-Smidt, CDC, written communication, 2010). For each of these variables, a "lagged isolate" variable was created. The number of usable observations ranged from 501 (for *Listeria*) to 816 (for *Salmonella*). The three models detailed in Equation 1 were estimated using LIMDEP, version 9.0 econometric software.

National illness reduction was calculated as "PulseNet Implemented" × 51 (the marginal effect of PulseNet implementation for the average state times the number of states in which PulseNet has been implemented) + "Lagged Isolates Tested" × number of illnesses for pathogen i reported in the U.S. in 2009. For the spillover model, this calculation included the marginal effects of lagged isolate testing for each of the three pathogens.

For each pathogen, the number of reported illnesses is an underestimate of the true number of experienced illnesses. Alternative benefits estimates that are adjusted to account for underreporting and underdiagnosis are provided. A multiplier for reported cases is taken from Scallan et al. (29.3 for *Salmonella*, 26.1 for *E. coli* O157, and 2.1 for *Listeria*).[6]

Economic Impacts of PulseNet: Program Costs and Costs Averted Due to Reduced Foodborne Illnesses

Program costs associated with implementing PulseNet are generated as a result of laboratory setup, isolate testing, and outbreak response, borne both by government and industry. Costs averted due to PulseNet include medical costs and productivity losses associated with reduced mortality and morbidity from foodborne illnesses. These direct and indirect costs averted for each illness are reported in 2010 dollars.[12,13] A complete explanation of the methodology used to estimate these costs is found in the Appendix (available online).

Results

The Recall Model

The recall model demonstrated that more-rapid outbreak response led to significant reductions in reported illnesses associated with *Salmonella* and *E. Coli* O157:H7 outbreaks.

During 2007–2008, 15 recalls of Food Safety and Inspection Service–regulated ground beef products were initiated owing to foodborne illness outbreaks of *E. coli* O157:H7 (Appendix Table A1, available online). The percentage of recalled meat recovered ranged from 0% to 66%, with a median of 5%. Thus, for most outbreak-associated recalls, only a small percentage of the recalled meat was recovered. Other outbreak-associated parameters were similarly skewed toward the low end of distributions observed across the 15 recalls. The number of outbreak-associated cases ranged from 0 to 49 with a median of 11. The estimated rate of illness per 1,000 pounds of consumed meat ranged from 0 to 7.1 with a median of 0.054. The estimated number of prevented cases ranged from 0 to 49 with a median of 1.2. For the 15 outbreak-associated recalls, the final estimate for the number of reported prevented cases was 108, with a 90% credible interval (CI) from 95 to 266 cases (Table 2). Based on the CDC multiplier for underdiagnosis of 26.1 cases occurring for each reported case, the estimated total number of prevented cases was 2,819, with a 90% CI from 2,480 to 6,943.[1]

During 2007–2008, five major multistate *Salmonella* outbreaks of foodborne illness that led to recalls of food products were investigated. For these outbreaks, the numbers of prevented cases ranged from 0 to 345, with an estimated total of 580 and a 90% CI of 128 to 1,127 (Table 2). Based on the CDC multiplier for underdiagnosis of 29.3 cases occurring for each reported case, the estimated total number of prevented cases was 16,994 with a 90% CI from 3,750 to 33,021.[1]

The Process Change Model

The process change empirical model tested the effect of PulseNet implementation and testing intensity on reported illnesses, finding that both implementation and intensity were negatively related to illness reporting.

The descriptive statistics for the variables used in the process change model are illustrated in Table 1. Over the studied periods, states reported an average of 869 *Salmonella* illnesses, 64 *E. coli* O157 illnesses, and 15 *Listeria* illnesses. Over the respective time periods for which NNDSS illnesses were recorded, states tested an average of 305 *Salmonella* isolates, 31 STEC isolates, and ten *Listeria* isolates.

The effect of PulseNet isolate testing on reported illnesses is illustrated in Table 3. In the upper panel, the marginal effects from the base model, as specified in Equation 1, are presented for each pathogen and each model type. For *Salmonella,* there was a strong negative effect on illnesses from both the existence of PulseNet and the intensity of testing within each state. For other pathogens, only intensity of testing is significant. The

Table 2. Estimated Numbers of Cases Prevented by Outbreak-Associated Recalls of *E. coli* O157:H7 and *Salmonella* Infections, 2007–2008

Agent	Vehicle	No. outbreaks	No. outbreak cases reported[a]	No. reportable cases prevented[b]	Cases prevented, 90% credible interval[c]
E. coli O157:H7	Ground beef	15	276	108	95, 266
Salmonella outbreaks					
Wandsworth, Typhimurium	Veggie Booty	1	87	49	32, 67
I 4,[5],12:i:-	Pot pies	1	401	72	19, 132
Litchfield	Cantaloupe	1	51	0	0
St. Paul	Jalapeno and serrano peppers	1	1,500	345	50, 714
Typhimurium	Peanut butter and peanut-containing products	1	714	114	27, 214
Total *Salmonella*	Multiple	5	2,753	580	128, 1,127

[a]Total number of outbreak-associated cases reported.
[b]Reportable cases prevented based on expected number of reported cases minus actual number of reported cases for *Salmonella*, and the estimated attack rate of cases per 1,000 pounds consumed times the pounds of product recovered for *E. coli* O157:H7.
[c]90% credible intervals based on Monte Carlo simulations (10,000 iterations) with distributions of possible values substituted for specific values.

intensity variable (lagged isolate testing) measures the effect of past isolate testing on current illnesses reported. This was negative and significant for all specifications except the random effects *E. coli* model and Poisson *Listeria* model. Given that more testing leads to better identification and traceback of outbreaks, this is consistent with a reduction in future illness due to enhanced industry accountability. The models' predictive power (as demonstrated by R^2 values) was weakest for *E. coli*, which makes sense given that the dependent variable measures *E. coli* O157 whereas isolates were recorded for the more general category, STEC.

The lower panel of Table 3 presents the predicted illness reduction associated with PulseNet for each pathogen. The inclusion of spillover effects led to larger declines in *Salmonella* and *E. coli* cases, but not in *Listeria* cases. The reduction in *Salmonella* illnesses associated with PulseNet ranged from 9,096 (90% CI=8,504, 9,686) in the Poisson base model to 25,181 (90% CI=20,747, 29,595) in the fixed effects spillover model. For *E. coli*, illness reduction ranged from 310 (90% CI= −99, 717) to 2,673 (90% CI=1,718, 3,627). For *Listeria*, reported illnesses declined by 27 (90% CI= −38, 92) to 151 (90% CI=46, 256).

Adjusted for underdiagnosis and underreporting (in italics in Table 3), mean estimates of 266,522–737,845 *Salmonella* illnesses, 8,096–69,755 *E. coli* illnesses, and 56–316 *Listeria* illnesses were predicted to be avoided as a result of PulseNet in 2009.

Economic Impacts of PulseNet

The economic impact of PulseNet was calculated as the product of the expected cost per illness for each pathogen and the number of averted illnesses, as estimated above.

The cost per illness was estimated to be $1,792 (90% CI=$1,461, $2,295) for *Salmonella*, $2,154 (90% CI=$1,464, $3,435) for *E. coli* O157, and $156,019 (90% CI=$81,003, $254,934) for *Listeria*, based on data from Scharff[14] and Grosse and colleagues.[15] The total program costs and healthcare costs averted from PulseNet are presented in Table 4. Results from the Poisson model, which generally yielded the most conservative illness reduction estimates, are illustrated. Estimates are presented for both the reported NNDSS number of illnesses and the number of illnesses adjusted with the underdiagnosis and underreporting multiplier.

The economic returns from PulseNet were substantial. For the process change models using reported illnesses, total median costs averted ranged from $21 to $33 million, depending on the model used. When estimates were adjusted for underreporting and underdiagnosis factors, the range became $491–$654 million. The direct effect of removing tainted product from the market (because of faster recalls) added $1–$37 million.

The measurable PulseNet costs borne by public health agencies were approximately $7.3 million. These costs included $1.3 million for the amortized annual laboratory setup costs associated with the three PulseNet

Table 3. Effect of PulseNet on Reported Foodborne Illnesses: Process Change Model

Independent variables[a]	*Salmonella*			*E. Coli*			*Listeria*		
	A	B	C	A	B	C	A	B	C
N	809	809	809	561	561	561	501	501	501
PulseNet implemented	**−22.647****	**−37.294****	**−13.573****	−0.199	**2.894***	0.008	0.197	0.146	0.013
Isolate tests	**0.227****	**0.160****	**0.053****	**0.461****	**0.150****	**0.057****	**0.288****	**0.301****	**0.102****
Lagged isolate tests	**−0.292****	**−0.321****	**−0.166****	−0.068	**−0.231****	**−0.092****	**−0.118****	**−0.109****	−0. 023
Adjusted R-squared	0.859	0.948	0.966	0.484	0.676	0.809	0.905	0.935	0.798
Predicted reduction in reported illnesses									
Base model									
Illnesses	**15,784****	**19,758****	**9,096****	310	**489***	**364****	**113****	**113***	27
90% CI	11,948, 19,623	15,871, 23,662	8,504, 9,686	−95, 717	**48, 939**	**274, 453**	**39, 187**	**31, 195**	−38, 92
Adjusted	*462,487*	*578,947*	*266,522*	*8,096*	*12,750*	*9,489*	*238*	*237*	*56*
Hospitalizations	297	372	171	11	17	12	104	103	25
90% CI	140, 516	180, 636	86, 286	−3, 29	1, 39	5, 23	33, 190	26, 197	−34, 88
Deaths	6	7	3	<1	<1	<1	18	18	4
90% CI	0, 16	0, 19	0, 9	0, 1	0, 1	0, 1	0, 55	0, 55	−6, 21
Spillover effects model									
Illnesses	**21,249****	**25,181****	**11,291****	**2,673****	**1,597****	**670****	**151****	75	73
90% CI	16,863, 25,632	20,747, 29,595	5,628, 16,948	1,718, 3,627	609, 2,589	451, 889	46, 256	−46, 196	−26, 172
Adjusted	*622,614*	*737,845*	*330,840*	*69,755*	*41,684*	*17,475*	*316*	*157*	*153*
Hospitalizations	400	474	212	90	54	23	138	68	67
90% CI	192, 687	231, 805	77, 407	31, 173	13, 114	8, 43	38, 259	−39, 189	−22, 167
Deaths	8	9	4	1	1	<1	24	12	12
90% CI	0, 21	0, 25	0, 12	0, 5	0, 3	0, 1	0, 74	−6, 48	−3, 43

Note: A = Random effects model; B = Fixed effects model; C = Poisson model. Boldface indicates statistical significance (*$p<0.05$; **$p<0.01$).
[a]Variables not reported, are: for the random effects models: population, year, PCI, and eight census division dummy variables; for the fixed effects models (state and year being the fixed effects): population and PCI; for the Poisson models: population, PCI, 15 year dummy variables, and 50 state dummy variables.

Table 4. Means and Medians. Economic Impact of PulseNet (in Millions, 2010 U.S.$)

Model	Costs averted, Mean, Median CI (5%–95%)	Program costs for public health agencies, Mean, Median CI (5%–95%)	Net cost averted, Mean, Median CI (5%–95%)	Net cost averted per public health $ invested, Mean, Median CI (5%–95%)
Simple lag (Process change model)				
Reported	21.3, 20.7 (11–34)	7.3, 7.3 (7.1–7.6)	14.0, 13.5 (3–26)	2.9. 2.9 (1–5)
Adjusted[a]	506.8, 491.3 (410–646)	7.3, 7.3 (7.1–7.6)	499.5, 484.0 (402–639)	69.7, 67.6 (56–89)
Spillover effects (Process change model)				
Reported	33.1, 32.0 (14–55)	7.3, 7.3 (7.1–7.6)	25.8, 24.7 (7–48)	4.6, 4.4 (2–8)
Adjusted[a]	654.4, 638.5 (340–1,002)	7.3, 7.3 (7.1–7.6)	647.1, 631.2 (333–995)	90.0, 87.7 (47–138)
Recall model				
Reported	1.3, 1.2 (0.5–2)	7.3, 7.3 (7.1–7.6)	−6.0, −6.1 (−7– −5)	0.2, 0.2 (0.1–0.3)
Adjusted[a]	36.5, 35.1 (13–65)	7.3, 7.3 (7.1–7.6)	29.2, 27.8 (6–58)	5.0, 4.8 (2–9)

[a]Adjusted for underreporting and underdiagnosis, based on estimates from Scallan et al.[1]

pathogens examined in this study, $4.3 million in costs for testing samples and investigating clusters, and $1.65 million for CDC's internal cost of running the program.

Annually, averted illnesses attributable to improved industry processes resulted in $14–$647 million in median reduced direct and indirect costs, yielding a societal return of $3–$90 for every $1 invested by public health agencies. The direct effects from improved recalls yielded up to $29 million, with a societal return of up to $5 for every $1 invested by public health agencies.

Discussion

This evaluation of PulseNet demonstrated significant economic and public health benefits from the system. These benefits are driven by improvements in outbreak detection, which provide industry and government with valuable information, while exposing food producers to increased threat from litigation and reputation losses. This ultimately leads to adjustments in processes that reduce foodborne illness. The measurable costs of the program, in contrast, are very modest.

Limitations

One limitation of this study is that it does not include all economic costs. Welfare losses from premature death and reduced quality of life due to illness are not monetized here, but could be potentially large. Also missing are indirect costs from PulseNet, including costs to other government entities, administrative costs of litigation, costs associated with recalls, and costs of implementing and managing process changes. The largest of these costs, however—the industry cost of implementing and managing process changes—is primarily driven by the expression of consumer preferences in the marketplace (the avoidance of lost sales owing to outbreaks). As such, this cost essentially represents actions to correct a market failure, thereby restricting process changes to be efficiency-enhancing.

Another potential limitation is that, for *Salmonella*, the predicted illness reduction numbers are high relative to the baseline number of illnesses and are not apparent in NNDSS or FoodNet trend data (www.cdc.gov/foodnet/index.html), which have shown relatively stable incidence rates over the past decade. Nevertheless, Appendix Figure A1 (available online) makes it clear that the numbers estimated in this study are plausible. Although *Salmonella* cases increased more than 20% in states that had a low ratio of tests to reported illnesses (bottom ten adopters), the states that analyzed samples from the highest proportion of reported illnesses experienced a reduction in illnesses of almost 10% (top ten adopters). Thus, PulseNet may well have helped prevent a substantial national increase in the occurrence of *Salmonella* over the past decade.

Also complicating the analysis is the fact that outbreak identification and the media attention surrounding it leads to enhanced illness reporting by the public. Theoretically, this will affect the analysis in two ways. First, because reported illnesses are used as a dependent variable in one part of the analysis, enhanced reporting without a control for media effects introduces omitted variable bias into the model. Properly controlled, the process model would likely yield larger reductions in foodborne illness than it currently predicts. Second, enhanced reporting will affect the degree to which illnesses are underreported and underdiagnosed. As a result, in the adjusted model only, the effects of PulseNet may be overstated. The net effects of these biases are unclear, but do not undermine the principal conclusion.

Conclusions

The PulseNet system exposes food safety risks to the public, thereby giving consumers, industry, and the government valuable information that can be used to reduce foodborne illness. The reduction in healthcare costs and other economic benefits from the resulting actions are substantial. Improving public health surveillance for foodborne disease is a prerequisite for improving food safety in the U.S.

Publication of this article was supported by the Centers for Disease Control and Prevention (CDC), Office of the Associate Director for Policy. The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of CDC.

Many people outside of the core group of authors made important contributions to this paper. In particular, we would like to thank Kakoli Roy and Martin Meltzer at CDC and Tanya Roberts at the U.S. Department of Agriculture (USDA) Economic Research Service for their guidance along the way. We would also like to thank Emilio Esteban and his team at USDA for detailed comments on an early version of the paper that helped us substantially improve the paper. Finally, we thank other members of the PulseNet Cost Benefit Study Work Group, Hugh Maguire, Bela Matyas, David Zorn, Shari Shea, Heather Green, Lauren Rosenberg, Kara Watarida and Richard Skibicki. This Work Group was organized by Kristy Kubota and other staff at the Association of Public Health Laboratories (APHL) under the auspices of the Council to Improve Foodborne Outbreak Response (CIFOR).

This study was supported by the Association of Public Health Laboratories and CDC under Cooperative Agreement U60/CD303019.

No financial disclosures were reported by the authors of this paper.

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Appendix

Supplementary data

Supplementary data associated with this article can be found at http://dx.doi.org/10.1016/j.amepre.2015.09.018.