Cost-effectiveness of pertussis immunization in pregnancy in Canada

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Declaration of Interests

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Abstract

Background: The Canadian National Advisory Committee on Immunization recommends universal immunization against pertussis in pregnancy. The cost-effectiveness of this strategy has not been studied. We assessed the cost-effectiveness of immunization in pregnancy with tetanus-diphtheria-acellular pertussis (Tdap) vaccine in Canada.

Methods: A cost-utility analysis comparing an immunization program to no program was conducted corresponding to recent Canadian guidelines for economic evaluation. Two hybrid models – part-decision tree, part-Markov model – were developed to estimate the long-term cost and quality adjusted life years (QALYs) for the pregnant woman and for the infant. Epidemiological data were obtained from the period 2006-2015, and costs and utility values were derived from credible sources. Results were reported in 2019$CAN. Expected values were obtained through probabilistic analysis with methodological and structural uncertainty assessed through scenario analyses. Analysis adopted acquisition price of $12.50 of Tdap vaccine with scenario analysis conducted to identify the threshold price for immunization to be cost-effective.

Results: In the base case scenario, immunization would lead to increased total costs of $12,987 with 0.3 greater total QALYs per 1,000 pregnant women immunized. This would lead to an incremental cost per QALY gained of $44,301. Based on a threshold of $50,000 per QALY, immunization would have been cost-effective in 6/10 years during 2006-2015 ($20,463-$100,348 per QALY). The threshold cost of Tdap vaccine to be cost-effective over the ten-year horizon was $14.03.

Interpretation: Based on a threshold of $50,000 per QALY, immunization against pertussis in pregnancy would be cost-effective if the acquisition cost per vaccine is <$14.03.

Introduction

Pertussis (whooping cough) is an endemic respiratory disease caused by the bacterium *Bordetella pertussis*. Globally, there are ~24 million cases and 160,000 deaths from pertussis in children age <5 years every year.[1] Canada introduced whole cell pertussis (wP) vaccine into the routine immunization schedule in 1943, and replaced it with acellular pertussis (aP) vaccine, which has a better safety profile, in 1997-1998. In Canada, pertussis vaccines are given to all children at ages 2, 4, 6 and 18 months, 4-6 years and 10-15 years (Quebec: 2, 4, 12 months, 4-6 years).[2] During 2012-2015, pertussis incidence markedly increased to 3.6-13.4/100,000/year[3] and frequent outbreaks continue to occur.[4-10] Young infants have the highest burden of pertussis in Canada.[11] Specifically, during 1999-2015, 76% of 1,402 children hospitalized with pertussis were infants aged ≤3 months. Infants aged <2 months had the highest annual incidence of hospitalization and intensive care unit (ICU) admission (116 and 33 per 100,000, respectively). Current infant immunization programs starting at age 2 months cannot protect these youngest, most vulnerable infants, therefore pertussis immunization in pregnancy is recommended.

In February 2018, The Canadian National Advisory Committee on Immunization (NACI) recommended that all pregnant women should receive pertussis vaccine (in the form of tetanus-diphtheria-acellular pertussis [Tdap] vaccine) in every pregnancy, ideally at 27-32 weeks gestation (WG).[12] Vaccination against pertussis in pregnancy has proved to be highly (nearly 90%) effective in preventing pertussis disease among infants aged <3 months in the UK and USA,[13-15] and decreasing the risk of hospitalization, ICU admission and hospital length of stay.[16] Assuming that vaccination against pertussis in pregnancy is 90% effective in the prevention of pertussis hospitalization among infants aged <3 months, approximately 825 cases of hospitalized pertussis cases admitted to tertiary care centers in Canada could have been prevented via maternal immunization during 1999-2015. However, the cost-effectiveness of this strategy is an important consideration and has never been evaluated in the Canadian context. The objective of this study was to assess the cost-effectiveness of pertussis immunization in pregnancy with Tdap vaccine in Canada.

Methods

Decision Problem

The decision problem or research question was whether vaccination against pertussis in pregnancy should be funded by the relevant public healthcare payer. To answer this question, a cost utility analysis was conducted which compared pertussis vaccination to no vaccination. A cost utility analysis over a lifetime horizon was conducted from a healthcare payer perspective (incorporating the lifetime costs and effects of the vaccination and subsequent events). Analysis corresponded with the most recent Canadian guidelines for economic evaluation.[17]

Model structure

Two hybrid models – part decision tree/part Markov model – were developed to estimate the long term cost and quality adjusted life years (QALYs) associated with vaccination *vs.* no vaccination for both infants and adults[18]. For infants the short term decision tree estimated the following outcomes: proportion of infants who by twelve months of age would have had no pertussis, mild pertussis (no hospitalization), pertussis requiring hospitalization (with and without encephalitis and chronic encephalitis) or death. For pregnant women, a decision tree estimated the following outcomes: proportion with no pertussis, mild pertussis, severe pertussis (cough illness with apnea, cyanosis, vomiting, or urinary incontinence), pneumonia without hospitalization, pneumonia with hospitalization or death. For both infants and adults, for each of the outcomes, a Markov model with a one year cycle and a lifetime horizon (up to age 110) was created with the states of alive and dead.

Model parameter values

Detailed literature reviews were conducted to identify the most pertinent recent data applicable to the Canadian context (Table 1). Data required to facilitate estimation of transition probabilities included the probability of pertussis in infants and adults, the severity of pertussis cases and the duration of symptoms, the effectiveness of vaccination, the incidence of vaccination related adverse events and their duration. In addition, costs and utility values for each potential outcome were required. Utility values and costs were obtained from the literature through a detailed systematic review and were selected based on their fitness for purpose (i.e., relevance to the decision problem), credibility and consistency. Fitness for purpose was assessed based on the contemporaneous nature of the data and the relevance to the specific outcomes. Credibility was assessed based on the appropriateness of the methodology adopted to derive the data estimates. Consistency was assessed by adopting parameter values from the literature using similar methods and approaches.

As pertussis is a cyclical disease, with peaks occurring every 3-4 years asynchronously across the country, epidemiological data relating to infant infection were obtained from a 10-year period between 2006 and 2015.

Analysis

Long-term outcomes were discounted at a rate of 1.5% per annum with costs expressed in 2019 Canadian dollars. In the base analysis, expected values of costs and QALYs were obtained through probabilistic analysis with values for all uncertain data obtained through random sampling from their probability distributions and in addition, for the epidemiological data, the year from which epidemiological data were taken also drawn randomly.

Methodological and structural uncertainty were assessed through scenario analyses. Analysis was conducted using different discount rates (0% and 3%) and time horizon (50 years). In addition, analysis was conducted using epidemiological data specific to each year (2006-2015).

As the acquisition cost of Tdap vaccine in this context was uncertain, analysis adopted a price of $12.50 with scenario analysis conducted to identify the threshold price for immunization to be cost-effective.

Results

Base Data

The model estimated 71 cases of pertussis disease per 100,000 in all infants under 1 year of age, with 68% of cases in infants aged <2 months and 18% of cases in infants aged 2-4 months.[19] This would translate to ~284 cases per year in all infants aged under 1 year (assuming an annual birth cohort of 400,000), including 192 cases in those aged <2 months and 52 cases in infants 2-4 months of age. High rates of hospitalization occur in this age group, with an estimated 87% in infants <2 months of age and 84% in those aged 2-4 months.[6] Amongst all hospitalized infants under 12 months of age, it was estimated that death would occur in 0.8%, and encephalitis in 0.5% with chronic encephalitis in 33% of those with acute encephalitis.[2,20]

In contrast, the model estimated only 0.6 cases per 100,000 adults per year, with pneumonia requiring hospitalization occurring in 1 in every 10 million adults. Overall, 31% of adult cases were assumed to be mild and 67% severe.[21] Symptom duration was estimated at 93 days for adults and 75 days in infants.[22]

Vaccine effectiveness was estimated at 91% against all pertussis cases (infant and adult) and 95% against pertussis deaths.[23] Adverse events following immunization (AEFIs) were divided into local and systemic AEFIs. Local AEFIs were modelled to occur at a prevalence of 15% and a time to full recovery of 7 days.[24,25] Systemic reactions were estimated to occur in 6% of cases, with a time to full recovery of 7 days.[24,25] Anaphylaxis was estimated to occur once per 200,000 doses, with a time to full recovery of 2 days.[25,26]

Cost Effectiveness Results

In the base case scenario, using data across the period from 2006-15, the Tdap vaccination program would cost an additional $17,000 per 1,000 pregnant women vaccinated ($17 per woman), but would reduce the costs of treatment for pertussis per 1,000 pregnant women vaccinated for both infants (by $12,987) and pregnant women (by $1). Tdap immunization in pregnancy would lead to gain of 0.3 QALYs per 1,000 pregnant women immunized occurring solely in infants. This leads to an incremental cost per QALY gained of $44,301 (Table 2).

At a threshold of $50,000 per QALY gained, the probability that vaccination is cost-effective is 52% (Figure 1). At a threshold of $100,000 per QALY gained the probability that it is cost-effective is 84%. At a willingness to pay of $50,000 per QALY gained, the threshold cost of Tdap vaccine was $14.03 (Figure 2).

Scenario Analysis

Analysis by each year of epidemiological data, illustrates the estimates are highly dependent on the annual disease burden, which fluctuates due to the natural cycling of disease (Table 3). During the ten years included in the model, immunization would be cost effective (based on a threshold of $50,000 per QALY gained) in six years out of ten (range $20,463 in the year with the highest disease burden to $100,348 in the year with the lowest disease burden) (Table 3). The probability that vaccination would be cost effective (assuming a threshold of $50,000) would range from a high of greater than 99% to a low of less than 1% (Figure 2).

Because most of the benefits from a Tdap maternal immunization program is expect to occur in the future a discount rate was applied resulting in incremental costs of $29,365 for a rate of 0% to $75,872 for a rate of 5%. Adopting a reduced time horizon of 50 years for estimating long-term costs and QALYs, led to an increase in the incremental cost per QALY to $54,378.

Interpretation

Our cost-effectiveness analysis demonstrates that immunization in pregnancy with Tdap vaccine would be cost-effective in Canada if the acquisition cost of the vaccine alone is no more than $14.03 per dose at a threshold of $50,000 per QALY. This is based on national data and disease burden estimates over a 10-year period that accounts for the natural, annual fluctuation in pertussis incidence. Our analysis highlights cost-effectiveness is somewhat dependent on annual disease incidence, with the $50,000 per QALY threshold being reached in six of the 10 years. This cost-effectiveness modelling is comprehensive as it considered the age-specific burden of disease, temporal changes in disease incidence, severe outcomes, vaccine effectiveness, adverse events following immunization (AEFIs) and costs of both the vaccine program and healthcare treatment costs related to pertussis.

This is the first Canadian cost-effectiveness analysis of pertussis immunization in pregnancy. Our results are similar to those found in the USA, Brazil and The Netherlands, although any comparisons with other settings should be carefully interpreted, as results of cost-effectiveness analyses are highly context dependent.[27-29] Based on our base case scenario, immunization with Tdap in pregnancy in Canada leads to an incremental cost of $44,301 per QALY gained and would have been cost- effective in 6 out of 10 years studied. Similarly the incidence of pertussis influenced cost-effectiveness estimates in England where the strategy of pertussis immunization in pregnancy was estimated to achieve an incremental cost of £16,856-£42,070 per QALY. Specifically, the highest gain was predicted to be achieved at £16,856 in the highest incidence year.[30]

In our analysis, underreporting of pertussis cases could have affected the estimation of the true incidence and burden of pertussis disease, especially in older adults, and thus might have underestimated the cost effectiveness of a maternal pertussis immunization program. However, the effect of this under reporting in our model is expected to be minimal as pertussis in early infancy leads to severe disease that is recognized and reported in young infants, who are the primary target of protection following Tdap immunization during pregnancy. The applicability of our results for current and future policy decisions will depend on the incidence of the pertussis disease, especially in infants <3 months of age, which is difficult to predict and can be province-specific.

The results of cost-effectiveness analyses are impacted by the cost per vaccination, which directly affects costs per QALY. Lower cost pertussis vaccines may be cost effective even in lower incidence rates years, if they can display similar efficacy. In our study, vaccination cost was at $17 with an incremental cost of $44,301 per QALY gained. Whereas in a different US study with a high vaccine cost (US$57.60/dose), the cost per QALY was much higher than in our study at US$414,523.[31] Other studies have estimated the cost of vaccination to be in the range of US$14.6 - US$57.6 (CAN$19.6 to $77.2),[27-33] with cost-effectiveness ranging depending on disease incidence.

Our study has several strengths. Pertussis is a notifiable disease in Canada, increasing the accuracy and completeness of the data used for the analysis. In addition, our pediatric morbidity and mortality data is based on detailed data captured by active surveillance system based in tertiary health care centers across Canada thus minimizing underreporting in these age groups [34]. The study is based on data over 10 years, which enabled capture of the natural disease cycle of pertussis. Finally, adverse events following immunization were also considered in the model, to further increase the accuracy of the assessment of the economic impact of the vaccination program.

Our study has several limitations. Although, the costs and benefits to pregnant women arising from a vaccination program from prevention of pertussis in the initial year were included, the direct protection of the mother against pertussis disease might last for several years and this might affect the cost-effectiveness of the program. It was shown that mothers played a central role in transmission of pertussis to infants and other household members.[35] Thus vaccination might prevent transmission within household contacts for several years after vaccination in pregnancy and potentially increase the cost-effectiveness of this strategy. Higher antibody levels transferred to the infant after maternal immunization may inhibit the response to subsequent infant immunization to pertussis vaccines and other vaccines.[36] Our model did not take into account the potential effect of this modulation of the infant's immune response, as the clinical significance of this is unclear. If modulation is found to be clinically significant, this effect should be modeled in future cost-effectiveness analyses as it may decrease the cost-effectiveness of a maternal immunization strategy if additional infant booster doses are required. Our model assumed that the average program costs would be $2.50. Should the costs be higher than this would have the incremental effect of reducing the threshold for the cost of the vaccine to be considered cost effective,

In conclusion, based on a threshold of $50,000 per QALY, pertussis immunization in pregnancy would be cost-effective if the acquisition cost per vaccine is less than $14.03.

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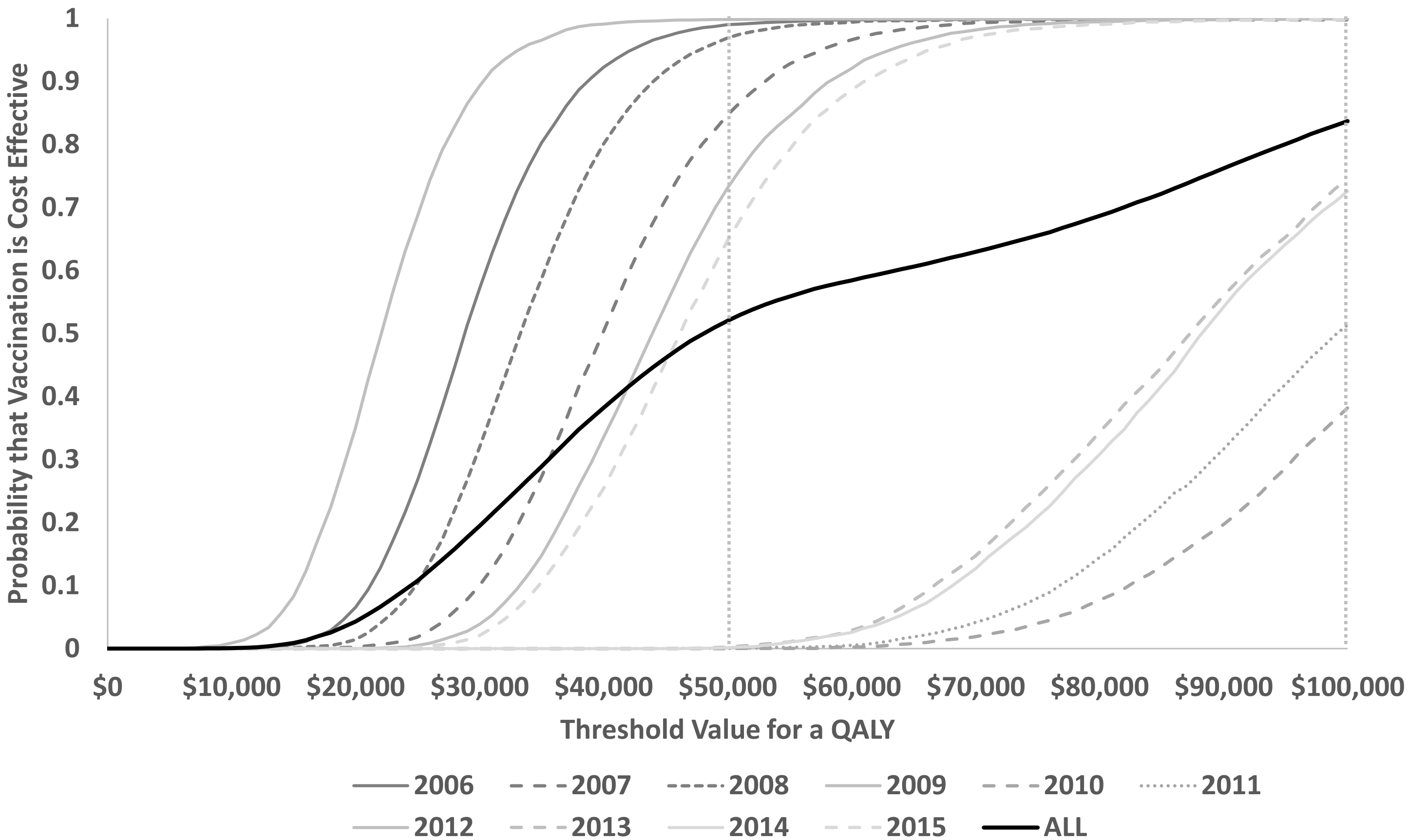
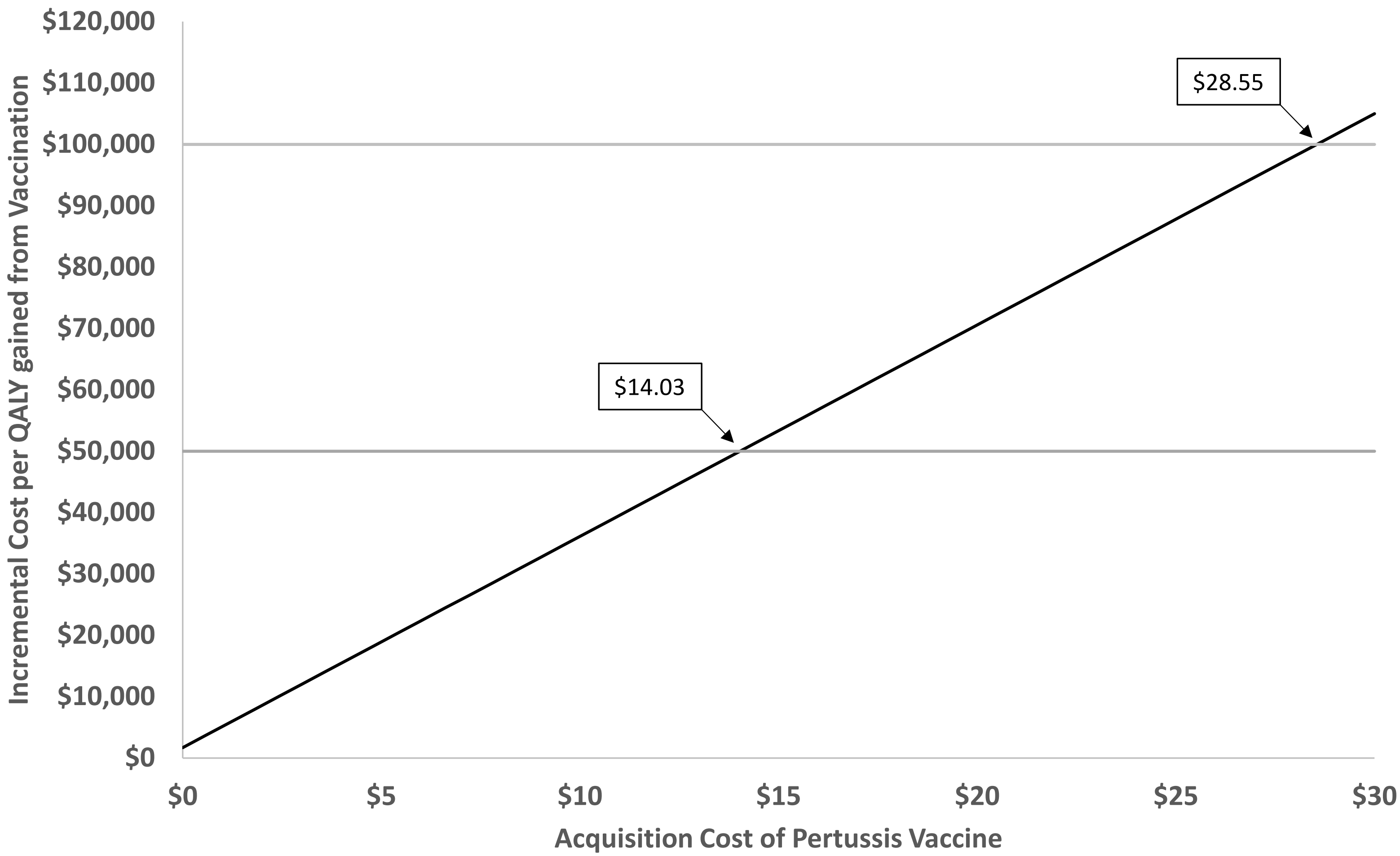
Figures and Tables

Figure 1: Cost-effectiveness acceptability curve for pertussis immunization during pregnancy in Canada



Abbreviation: QALY: quality adjusted life years.
All costs presented in 2019 Canadian dollars.

Figure 2. Estimated incremental cost per quality adjusted life years gained by acquisition cost of pertussis vaccine



Abbreviation: QALY: quality adjusted life years.
All costs presented in 2019 Canadian dollars.

Table 1. Data input, assumptions and epidemiological data used for the base case analysis of the cost-effectiveness analyses of maternal immunization against pertussis in Canada.

Variable	Point Estimate	Probability Distribution	Source
Probability of Pertussis infection in infant <1 year			[19]
2006	0.001027	Beta (359, 349219)	
2007	0.000812	Beta (292, 359377)	
2008	0.000934	Beta (348, 372095)	
2009	0.000752	Beta (284, 377192)	
2010	0.000368	Beta (139, 377542)	
2011	0.000393	Beta (148, 376007)	
2012	0.001201	Beta (453, 376594)	
2013	0.000442	Beta (169, 382448)	
2014	0.000433	Beta (167, 385526)	
2015	0.000734	Beta (285, 387978)	
Age of infection by year of data			[19]
2006			
< 2 months	0.675	Dirichlet(81,22,9,8)	
2-4 months	0.183		
4-6 months	0.075		
6-12 months	0.067		
2007			
< 2 months	0.68	Dirichlet (66, 22, 4, 5)	
2-4 months	0.227		
4-6 months	0.041		
6-12 months	0.052		
2008			
< 2 months	0.678	Dirichlet (82, 19, 10, 10)	
2-4 months	0.157		
4-6 months	0.083		
6-12 months	0.082		
2009			
< 2 months	0.73	Dirichlet (81, 23, 5, 2)	
2-4 months	0.207		
4-6 months	0.045		
6-12 months	0.018		
2010			
< 2 months	0.711	Dirichlet (86, 19, 9, 7)	
2-4 months	0.157		
4-6 months	0.074		
6-12 months	0.058		
2011			
< 2 months	0.638	Dirichlet (74, 26, 7, 9)	
2-4 months	0.224		
4-6 months	0.060		
6-12 months	0.079		
2012			

Variable	Point Estimate	Probability Distribution	Source
< 2 months	0.739	Dirichlet (147, 35, 7, 10)	
2-4 months	0.176		
4-6 months	0.035		
6-12 months	0.050		
2013			
< 2 months	0.596	Dirichlet (65, 25, 7, 12)	
2-4 months	0.229		
4-6 months	0.064		
6-12 months	0.110		
2014			
< 2 months	0.638	Dirichlet (83, 30, 9, 8)	
2-4 months	0.231		
4-6 months	0.069		
6-12 months	0.063		
2015			
< 2 months	0.637	Dirichlet (86, 33, 6, 10)	
2-4 months	0.244		
4-6 months	0.044		
6-12 months	0.075		
Probability of Pertussis case hospitalized			6
< 2 months	0.867	Beta (738, 113)	
2-4 months	0.843	Beta (214, 40)	
4-6 months	0.685	Beta (50, 23)	
6-12 months	0.617	Beta (50, 31)	
Probability of death from Pertussis in <1 year if hospitalized			2
Infants	0.00811	Beta (17, 2079)	
Probability of encephalitis from Pertussis in <1 year if hospitalized			2
Infants	0.0052	Beta (11, 2085)	
Probability of chronic encephalitis if developed encephalitis in hospital			20
Infants	0.33	Beta (3.33,6.67)	
Effectiveness of vaccination			23
Reduction in pertussis cases	0.91	1-Lognormal (-2.41, 0.69)	
Reduction in pertussis deaths	0.95	1-Lognormal (-3, 3.74)	
Probability of Pertussis in Adults	0.000006	Beta(2996, 499330337)	6
Distribution of Adult cases			21
Mild	0.31	Dirichlet (290, 627, 16,	

Variable	Point Estimate	Probability Distribution	Source
Severe	0.67	3)	
Pneumonia treated at home	0.017		
Pneumonia requiring hospitalization	0.003		
Duration of pertussis symptoms (days)			22
Adult	93	Gamma (7.11, 13.09)	
Infant	75	Gamma (41.15, 1.82)	
Utility Values			
Pertussis - child	0.27	Normal (0.27, 0.028)	25
Encephalitis	0.21	Normal (0.21, 0.024)	25
Health male aged 0-15	0.894	Normal (0.894, 0.004)	37
Health male aged 15-18	0.88	Normal (0.88, 0.004)	
Health male aged 18-20	0.89	Normal (0.89, 0.006)	
Health male aged 20-25	0.878	Normal (0.878, 0.004)	
Health male aged 25-30	0.888	Normal (0.888, 0.005)	
Health male aged 30-35	0.889	Normal (0.889, 0.005)	
Health male aged 35-40	0.89	Normal (0.89, 0.005)	
Health male aged 40-45	0.885	Normal (0.885, 0.005)	
Health male aged 45-50	0.859	Normal (0.859, 0.006)	
Health male aged 50-55	0.837	Normal (0.837, 0.005)	
Health male aged 55-60	0.837	Normal (0.837, 0.004)	
Health male aged 60-65	0.831	Normal (0.831, 0.004)	
Health male aged 65-70	0.849	Normal (0.849, 0.004)	
Health male aged 70-75	0.845	Normal (0.845, 0.005)	
Health male aged 75-80	0.808	Normal (0.808, 0.006)	
Health male aged 80+	0.734	Normal (0.734, 0.007)	
Health female aged 0-15	0.896	Normal (0.896, 0.004)	
Health female aged 15-18	0.867	Normal (0.867, 0.005)	
Health female aged 18-20	0.863	Normal (0.863, 0.007)	
Health female aged 20-25	0.878	Normal (0.878, 0.005)	
Health female aged 25-30	0.882	Normal (0.882, 0.004)	
Health female aged 30-35	0.892	Normal (0.892, 0.004)	
Health female aged 35-40	0.886	Normal (0.886, 0.004)	
Health female aged 40-45	0.875	Normal (0.875, 0.005)	
Health female aged 45-50	0.844	Normal (0.844, 0.006)	
Health female aged 50-55	0.825	Normal (0.825, 0.005)	
Health female aged 55-60	0.821	Normal (0.821, 0.004)	
Health female aged 60-65	0.831	Normal (0.831, 0.004)	
Health female aged 65-70	0.836	Normal (0.836, 0.004)	
Health female aged 70-75	0.824	Normal (0.824, 0.004)	
Health female aged 75-80	0.792	Normal (0.792, 0.005)	
Health female aged 80 +	0.712	Normal (0.712, 0.005)	
Disutility in adults			25
Mild pertussis	0.33	Normal (0.33, 0.045)	

Variable	Point Estimate	Probability Distribution	Source
Severe pertussis	0.42	Normal (0.42, 0.049)	
Pneumonia	0.38	Normal (0.38, 0.047)	
Disutility from adverse event			[25]
Local	0.09	Normal (0.09, 0.028)	
Systemic	0.17	Normal (0.17, 0.034)	
Anaphylaxis	0.4	Normal (0.4, 0.05)	
Time to full recovery (days)			[25]
Local reaction	7	Gamma (16, 0.4375)	
Systemic reaction	7	Gamma (16, 0.4375)	
Anaphylaxis	2	Gamma (16, 0.125)	
Prevalence of severe adverse events			[26]
Local reaction - pain	0.002	Beta (503,207160)	
Local reaction - rash	0.001	Beta (122,207700)	
Systemic reaction - fever	0.0006	Beta (129, 207692)	
Anaphylaxis	0.000005	Beta (1, 207850)	
Vaccine related costs			
Vaccine	12.50 CAD	Fixed	Assumed
Administration	4.50 CAD	Fixed	[38]
Cost Hospitalization			
Infant – pertussis	6911 CAD	Gamma (16, 431.9)	[39]
Infant – encephalitis	17445 CAD	Gamma (16, 1090.3)	[40]
Adult - pneumonia	12275 CAD	Gamma (16, 767.2)	[39]
Cost of chronic encephalitis			
Per annum	3457 CAD	Gamma (16, 216.1)	[40]
Cost of outpatient care for pertussis			[2,20,38,41-43]
Child	158.20 CAD	Derived^	
Adult – mild	169.91 CAD	Derived^	
Adult – severe	202.56 CAD	Derived^	

All costs presented in 2019 Canadian dollars.
^ Costs of outpatient care are combination of diagnostic costs, physician visits and drug treatment

Table 2. Cost Effectiveness Results per 1000 Pregnant Women

	Vaccine	No vaccine	Incremental
Costs			
Vaccine	$17,000	0	$17,000
Treatment of Pertussis - Infant	$404	$4416	-$4012
Treatment of Pertussis and Adverse Events - Woman	$0.1	$1	-$1
Total	$17,404	$4,417	$12,987
QALYs			
Infant	41,020.4	41,020.1	0.3
Woman	31,966.0	31,966.0	0
Total	73,016.4	73,016.1	0.3
Incremental Cost per QALY gained			$44,301

Abbreviation: QALY: quality adjusted life years.
All costs presented in 2019 Canadian dollars.

Table 3. Scenario Analyses relating to Year of Epidemiological Data, Discount Rates, Time Horizon

Year	Total Costs per 1000 Pregnant Women (2019$)		Total QALYs per 1000 Pregnant Women		Incremental Cost of maternal Tdap immunization program per QALY gained
	Tdap Vaccine	No vaccine	Tdap Vaccine	No vaccine	
Base Result	$17,404	$4,417	73,016.4	73,016.1	**$44,729**
Results by Individual Year					
2006	$17,579	$6,339	73,015.4	73,015.0	**$26,660**
2007	$17,464	$5,089	73,017.2	73,016.8	**$37,024**
2008	$17,525	$5,750	73,017.1	73,016.7	**$30,961**
2009	$17,437	$4,766	73,015.7	73,015.4	**$40,811**
2010	$17,210	$2,297	73,016.8	73,016.6	$100,348
2011	$17,224	$2,448	73,015.7	73,015.5	$93,145
2012	$17,691	$7,551	73,015.6	73,015.1	**$20,463**
2013	$17,248	$2,703	73,016.8	73,016.6	$82,554
2014	$17,244	$2,672	73,016.2	73,016.0	$83,076
2015	$17,415	$4,533	73,017.6	73,017.3	**$42,772**
Results by Discount rates					
0%	$17,413	$4,521	117,249.1	117,248.7	**$29,365**
3%	$17,397	$4,349	50,463.6	50,463.4	$59,594
5%	$17,394	$4,295	34,738.1	34,737.9	$75,872
Time Horizon					
50 years	$17,402	$4,395	60,992.1	60,991.9	$54,398

Abbreviation: QALY: quality adjusted life years. Tdap: tetanus-diphtheria-acellular-pertussis.
All costs presented in 2019 Canadian dollars.
Incremental costs per QALYs in bold represent scenarios under which maternal Tdap immunization is cost effective assuming a willingness to pay for a QALY of $50,000.

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