The Application of Game Theory in Analyzing Public Health Issues

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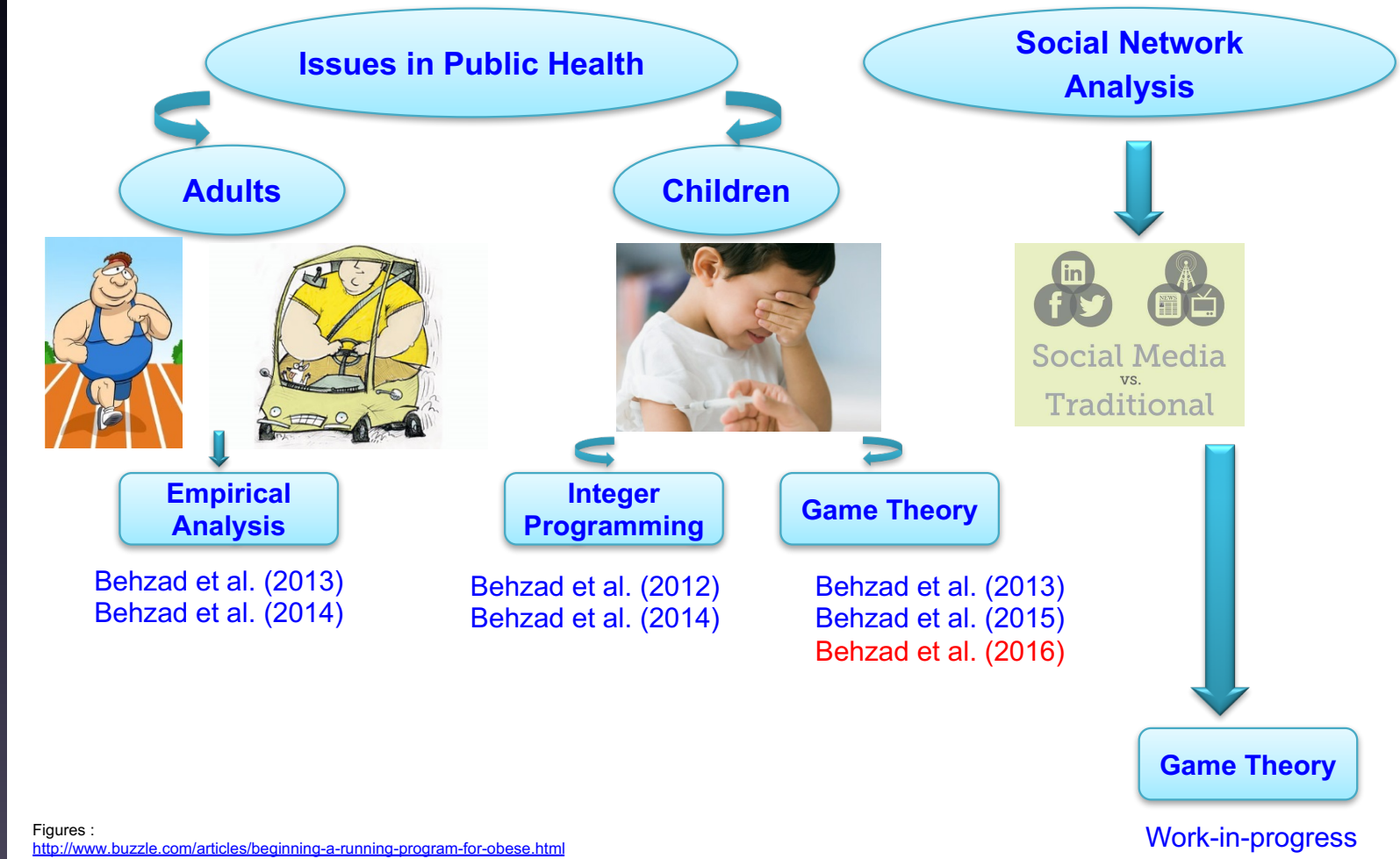
Research Summary



Figures :
http://www.buzzle.com/articles/beginning-a-running-program-for-obese.html
http://www.mcavoy.com/a_ts_obesity.html
http://www.freewebs.com/mercurybabies

What is Game Theory?

- The branch of mathematics concerned with
  - the analysis of strategies for dealing with competitive situations
  - where the outcome of a participant's choice of action depends critically on the actions of other participants.
- What economists call game theory psychologists call the theory of social situations.

Immunization

- Immunization against infectious diseases: single factor that has had the greatest impact on world health (Plotkin and Orenstein, 2004)
- Much work remains to be done.
  - In 1998, over 20% of worldwide deaths were attributable to infectious diseases.
  - Measles accounted for 8% of these deaths.
  - Emergence of new infectious diseases creates new challenges.

Centers for Disease Control and Prevention (CDC)

- Primary public health organization in the United States
- Responsible for management of the Recommended Childhood Immunization Schedule (RCIS) (Source: CDC)

Vaccine	Birth	1 mo	2 mos	4 mos	6 mos	9 mos	12 mos	15 mos
Hepatitis B[1] (HepB)	1st dose	←2nd dose→			←3rd dose→			
Rotavirus[2] (RV) RV1 (2-dose series); RV5 (3-dose series)			1st dose	2nd dose	See footnote 2			
Diphtheria, tetanus, & acellular pertussis[3] (DTaP: <7 yrs)			1st dose	2nd dose	3rd dose			←4th dose→
Haemophilus influenzae type b[4] (Hib)			1st dose	2nd dose	See footnote 4		←3rd or 4th dose, See footnote 4→	
Pneumococcal conjugate[5] (PCV13)			1st dose	2nd dose	3rd dose		←4th dose→	
Inactivated poliovirus[6] (IPV:<18 yrs)			1st dose	2nd dose	←3rd dose→			

The Problem

CDC
CENTERS FOR DISEASE CONTROL AND PREVENTION

- **Infanrix®(DTaP)**
- **ENGERIX®(HepB)**
- **Hiberix®(Hib)**
- **Pediarix®(DTaP-HepB-IPV)**

- **RECOMBIVAX HB®(HepB)**
- **PedvaxHIB®(Hib)**

- **Tripedia®(DTaP)**
- **ActHIB®(Hib)**
- **Pentacel®(DTaP-IPV-Hib)**

Public Sector

Series of negotiations between the CDC and the vaccine manufacturers:

- State and local public health departments
- Public sector: 57% of the total pediatric purchases by volume in the United States (Vaccines for Children (VFC) Program)
- Limited profits and high research and development costs for manufacturers
- Six vaccine manufacturers in 2010 vs. 35 in 1970

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The Role of CDC

- Negotiate the vaccine prices with vaccine manufacturers
- Provide financial incentives for vaccine manufacturers to stay in the market

Motivation

A small number of pharmaceutical companies:

- Manufacturing vaccines which are competing with each other
- Seeking higher profits

CDC:

- Seeks awareness on vaccine prices when preparing for series of negotiations

Question

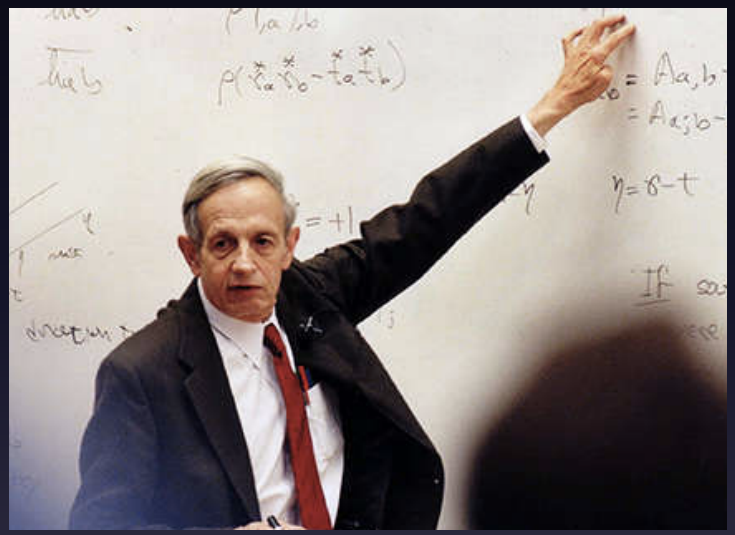
Can game theory be used to better understand pediatric vaccine pricing in the United States?

Objectives

- Determine the equilibrium price of each vaccine in the public sector.
- Gain awareness about vaccine equilibrium prices in future years.

Nash Equilibrium

A stable state of a system involving the interaction of different players, in which no player can gain by a unilateral change of strategy if the strategies of the others remain unchanged.



Pure and Mixed Strategy Nash Equilibrium

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- Mixed strategy Nash equilibrium: is an assignment of a probability to each pure strategy.

Bertrand Framework

- A pricing game
- Nash equilibrium occurs when each firm selects a price level which maximizes their profits, given the price level chosen by the other firms.

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Main Assumptions:

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- Firms' products are interchangeable.
  - No product differentiation

Is there a better model?

Bertrand-Edgeworth and Bertrand-Edgeworth-Chamberlin Competitions

Bertrand-Edgeworth Competition:

- Capacity-constrained firms compete on price.
  - The first assumption of the Bertrand framework is relaxed.

Bertrand-Edgeworth-Chamberlin Competition:

- Capacity-constrained firms compete on price over the sale of differentiated products.

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Main Focus

Bertrand-Edgeworth-Chamberlin competition in which the price competition among asymmetric capacity-constrained sellers is studied.

- Asymmetric capacity-constrained sellers: sellers with unequal production capacity
- Nash equilibrium is the solution concept applied to study the formulated game.

Game Formulation

Inverse and Direct Demands

$$P_i(\mathbf{q}) = \alpha - q_i - \gamma \sum_{j \neq i} q_j, \quad i = 1, 2, \cdots, n,$$

$$P_i^{-1}(\mathbf{q}) = a - bp_i + c \sum_{j \neq i} p_j \equiv D_i(\mathbf{p}), \quad i = 1, 2, \cdots, n$$

where $a = \alpha/(1 + (n-1)\gamma)$,
$b = (1 + (n-2)\gamma)/(1 + (n-1)\gamma)(1-\gamma)$,
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γ

The degree of product differentiation, ranging from zero for independent products to one for perfect substitutes.

Manufacturer i is capacity-constrained with production capacity k_i, $i = 1, 2, \cdots, n$, where $k_1 \geq k_2 \geq \cdots \geq k_n$, with the total production capacity of all manufacturers given by $K \equiv k_1 + k_2 + \cdots + k_n$.

Main Results

Result 1

The pure strategy equilibrium exists if the production capacity of a manufacturer is at their extreme.

Result 2

For the capacity regions where no pure strategy equilibrium exists, there exists a mixed strategy equilibrium (characterized).

United States Pediatric Vaccine Market

- Pharmaceutical companies
  - Merck (MRK)
  - GlaxoSmithKline (GSK)
  - Sanofi Pasteur (SP)
- Focus of the study: Competitive vaccines:
  - DTaP
  - HepB
  - Hib
  - Pediarix and Pentacel

Analysis of Equilibria

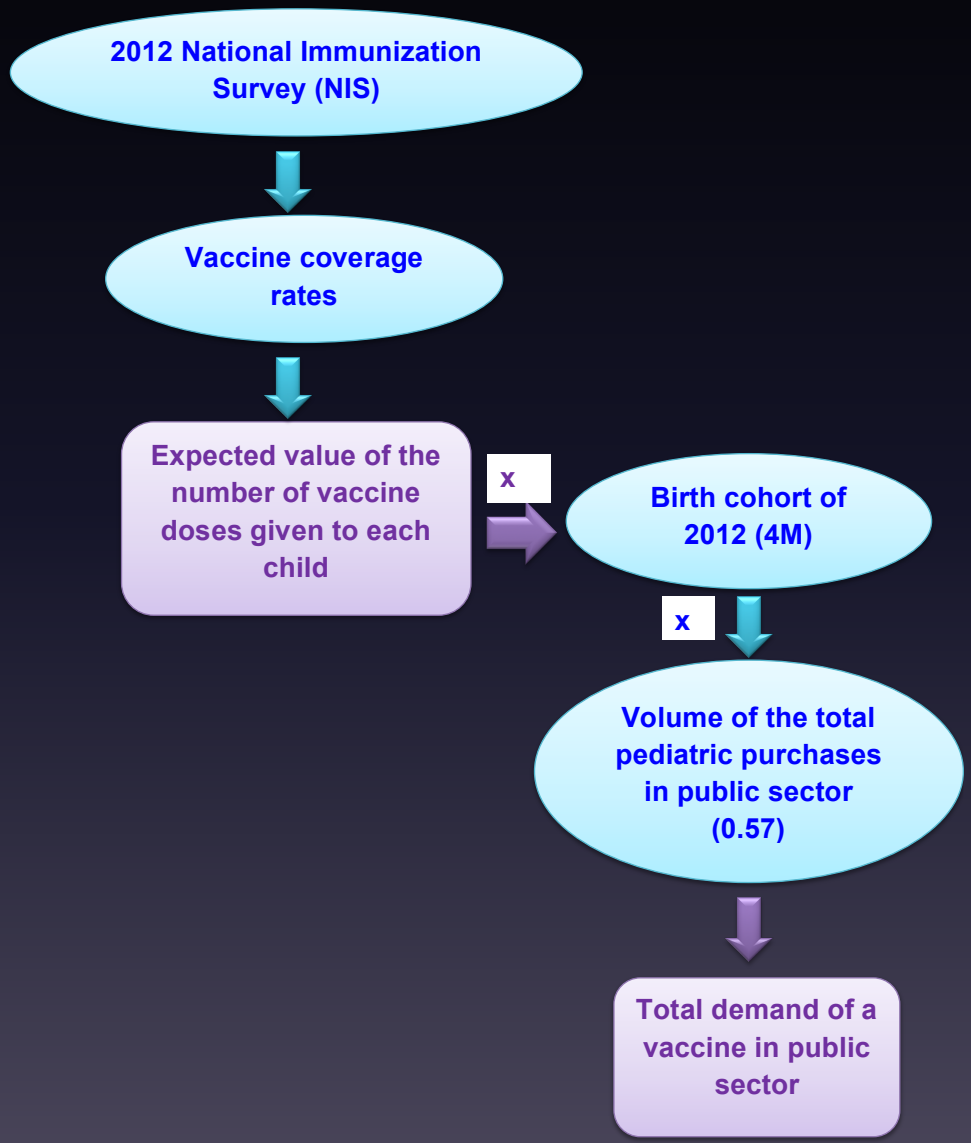
Equilibrium Prices

Equilibrium prices are sough for the vaccines in the United States pediatric vaccine market based on the 2012 federal contract.

Four games:

- DTaP monovalent vaccines
- HepB monovalent vaccines
- Hib monovalent vaccines
- Pediarix and Pentacel combination vaccines

Demand of a Vaccine

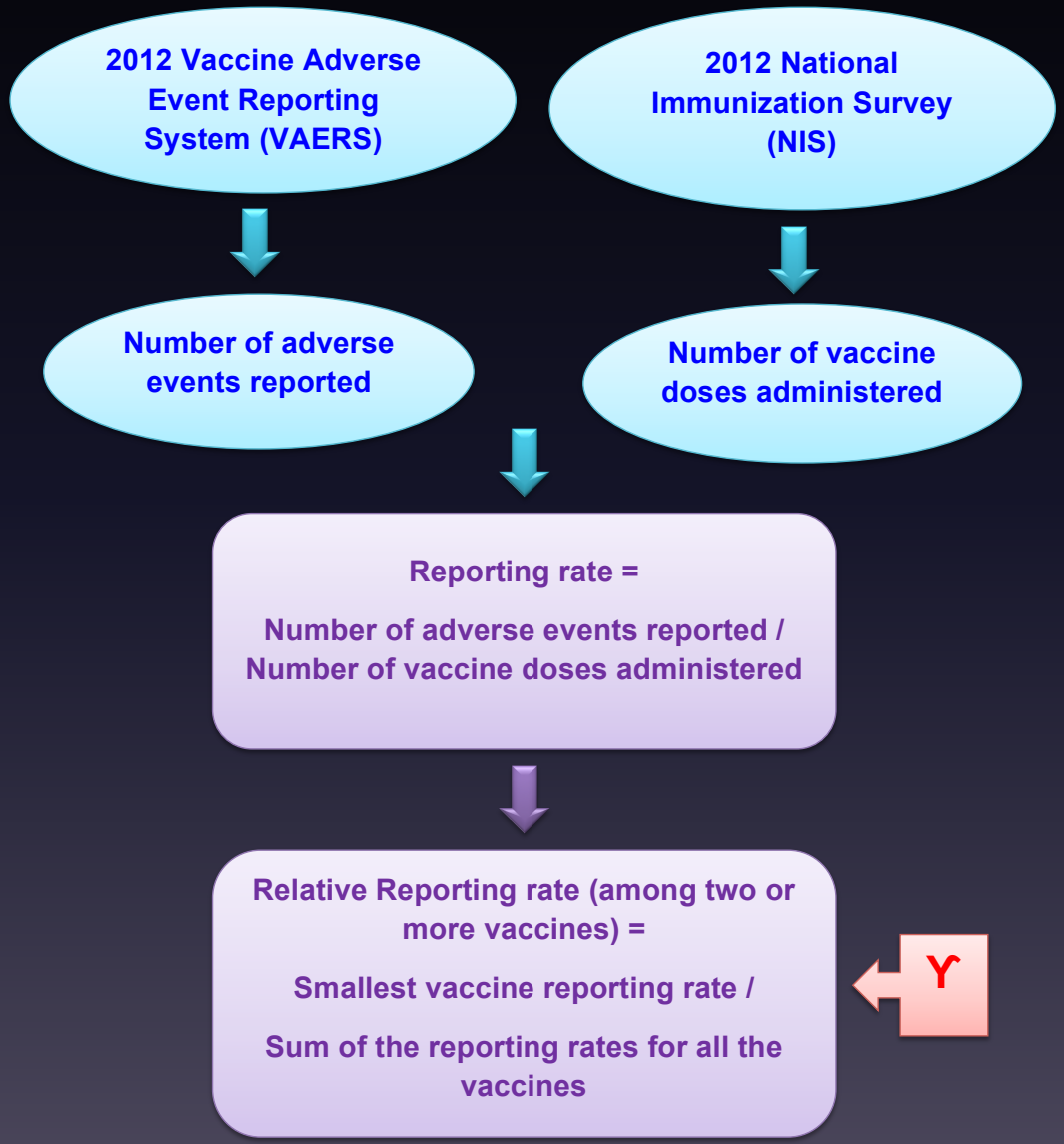


Demand Provided by the Public Sector

Table: Demand provided by the public sector

Vaccine	Demand (public sector)
DTaP monovalents	2.3M
HepB monovalents	5.1M
Hib monovalents	3.3M
DTaP-IPV-HIB (Pediarix)	4.5M
DTaP-HepB-IPV (Pentacel)	1.5M

Degree of Product Differentiation



Model Parameters

Vaccine	Manufacturer	Total number of adverse events	Percentage of total vaccine doses administered	γ	Adjusted γ
		Γ_{DTaP}			
DTaP (Infanrix)	GlaxoSmithKline	310			
DTaP (Daptacel)	Sanofi Pasteur	573			
			(Infanrix, Daptacel)		
			(90%,10%)	0.06	-
			(80%,20%)	0.13	-
			(70%,30%)	0.23	-
		Γ_{HepB}			
HepB (Engerix B)	GlaxoSmithKline	488			
HepB (Recombivax HB)	Merck	635			
			(Engerix B, Recombivax HB)		
			(50%,50%)	0.76	-
		Γ_{Hib}			
Hib (ActHIB)	Sanofi Pasteur	419			
Hib (PedvaxHIB)	Merck	298			
			(ActHIB, PedvaxHIB)		
			(70%,30%)	0.60	
					0.50
					0.40
					0.30
					0.20
					0.10
		$\Gamma_{Ped-Pent}$			
DTaP-HepB-IPV (Pediarix)	GlaxoSmithKline	400			
DTaP-IPV/HIB (Pentacel)	Sanofi Pasteur	744			
			(Pediarix, Pentacel)		
			(74%,26%)	0.18	
					0.08

Capacity

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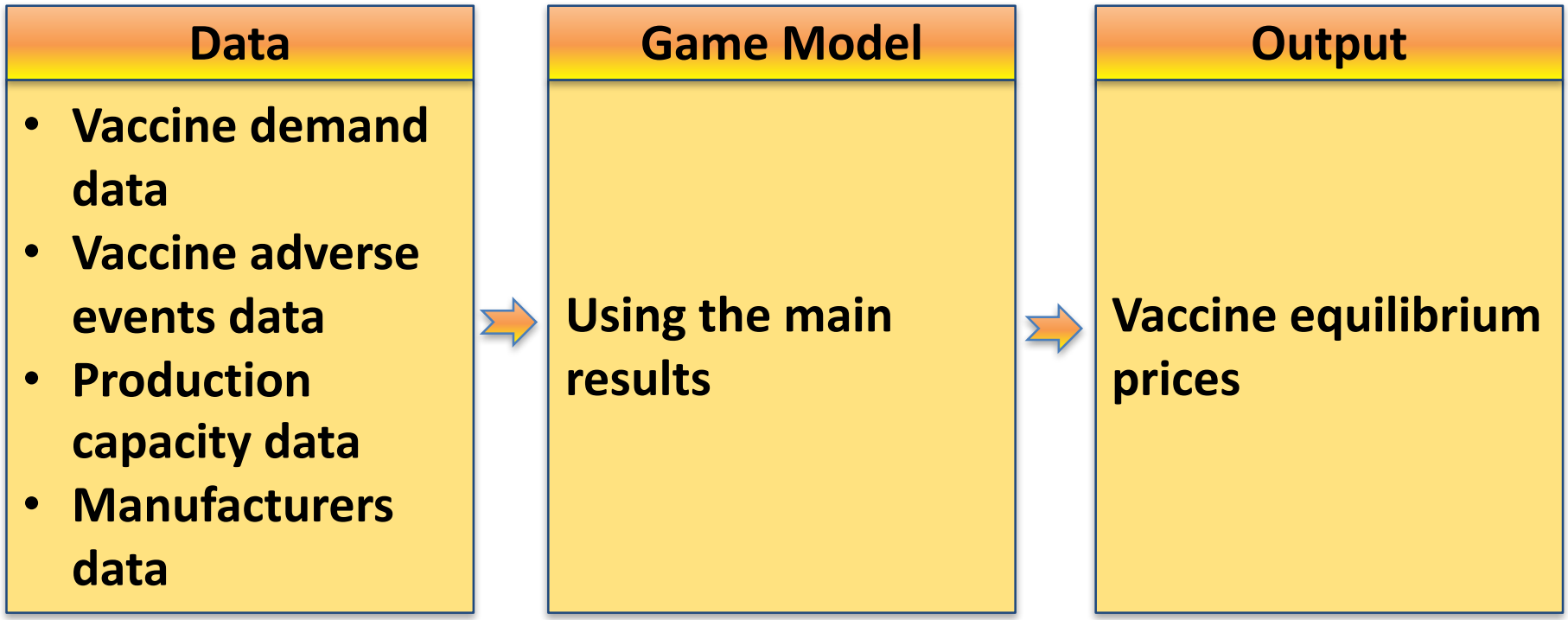
Assumption

Total production capacity of the vaccines in one instance of Gamma is 10% higher than the total market demand for those vaccines (Jacobson et al., 2006).

- The percentages for the number of vaccine doses administered multiplied by 1.1 of the total market demand then give the production capacity of each vaccine manufacturer.

The Analysis



Equilibrium prices

Γ_{DTaP}						
Degree of product differentiation	Infanrix			Daptacel		
γ	Capacity	Equilibrium price	Type of equilibrium	Capacity	Equilibrium price	Type of equilibrium
0.06	0.90D(p)	\$5.90	Bertrand-Chamberlin equilibrium	0.10D(p)	\$8.28	Competitive equilibrium
0.13	0.80D(p)	\$6.04	Bertrand-Chamberlin equilibrium	0.20D(p)	\$5.30	Competitive equilibrium
0.23	0.70D(p)	\$6.15	Bertrand-Chamberlin equilibrium	0.30D(p)	\$6.15	Bertrand-Chamberlin equilibrium
Γ_{HepB}						
Degree of product differentiation	Engerix B			Recombivax HB		
γ	Capacity	Equilibrium price	Type of equilibrium	Capacity	Equilibrium price	Type of equilibrium
0.76	0.50D(p)	\$8.72	Bertrand-Chamberlin equilibrium	0.50D(p)	\$8.72	Bertrand-Chamberlin equilibrium

Equilibrium prices

Γ_{Hib}						
Degree of product differentiation	ActHIB			PedvaxHIB		
Adjusted γ	Capacity	Equilibrium price	Type of equilibrium	Capacity	Equilibrium price	Type of equilibrium
0.50	0.70D(p)	\$8.21	Bertrand-Chamberlin equilibrium	0.30D(p)	[\$4.61,\$9.50]	Mixed strategy equilibrium
0.40	0.70D(p)	\$8.62	Bertrand-Chamberlin equilibrium	0.30D(p)	\$8.62	Bertrand-Chamberlin equilibrium
0.30	0.70D(p)	\$8.79	Bertrand-Chamberlin equilibrium	0.30D(p)	\$8.79	Bertrand-Chamberlin equilibrium
0.20	0.70D(p)	\$8.76	Bertrand-Chamberlin equilibrium	0.30D(p)	\$8.76	Bertrand-Chamberlin equilibrium
0.10	0.70D(p)	\$8.56	Bertrand-Chamberlin equilibrium	0.30D(p)	\$8.56	Bertrand-Chamberlin equilibrium
$\Gamma_{Ped-Pent}$						
Degree of product differentiation	Pediarix			Pentacel		
Adjusted γ	Capacity	Equilibrium price	Type of equilibrium	Capacity	Equilibrium price	Type of equilibrium
0.08	0.74D(p)	\$46.61	Bertrand-Chamberlin equilibrium	0.26D(p)	\$46.61	Bertrand-Chamberlin equilibrium

2012 Vaccine Prices

Table: Competitive vaccines analyzed using the model (2012)

(I) Vaccine	(II) Trademark name	(III) Vaccine manufacturer	(IV) 2012 public sector price
DTaP	Infanrix®	GlaxoSmithKline	$15.35
DTaP	Daptacel®	Sanofi Pasteur	$15.00
HepB	Engerix B®	GlaxoSmithKline	$10.73
HepB	Recombivax HB®	Merck	$10.75
Hib	ActHIB®	Sanofi Pasteur	$9.20
Hib	PedvaxHIB®	Merck	$11.97
DTaP-IPV-HIB	Pentacel®	Sanofi Pasteur	$54.50
DTaP-Hep B-IPV	Pediarix®	GlaxoSmithKline	$52.10

Comparison

Result

The equilibrium prices are lower than the 2012 federal contract prices.

Why?

- Vaccine prices: affected by several factors
- The two main roles of the CDC: negotiating lower prices for the vaccines and maintaining public health goals
- The prices of the licensed vaccines are required to be negotiated to account for the research and development costs of the vaccines that are not licensed.

Conclusions

- Competition between asymmetric manufacturers with limited production capacities and linear demand, producing differentiated products.
- Pure strategy equilibrium exists if the production capacity of a manufacturers is at their extreme.
- In a duopoly setting, the distribution functions of the mixed strategy equilibrium for both manufacturers are provided.

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Thank You

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