

ABSTRACT

BRIGHT, JUSTIN MICHAEL. The Vaccine Externality and its Impact on a Pharmaceutical Company. (Under the direction of Stephen Margolis).

Over the past twenty years, health costs in the United States have been rapidly increasing as a percentage of Gross Domestic Product (GDP). Many people have proposed solutions but one of the more promising solutions is investing in health promotion and disease prevention. Traditionally, some pharmaceutical companies have invested in vaccines as their source of health promotion and disease prevention as vaccines have been proven to be a cost-effective medical intervention in the prevention of disease. However, to date, there are only 75 vaccines that have been approved by the Food and Drug Administration (FDA) while over 110 new drugs were approved by the FDA in the five-year period from 2006 to 2010. This raises the question, given that the benefits of a vaccine often can exceed those of a drug, is there some structural reason that would make a vaccine less profitable than an equally costly and equally effective curative drug?

One structural reason that has not been thoroughly examined in the economic and public health literature is the externality problem associated with vaccines. The externality implies that an individual's decision to vaccinate not only improves his or her well being but it provides benefits to the community in which the individual lives through herd immunity (indirect benefits of vaccination). As a result, fewer individuals are vaccinated than what is socially optimal due to these indirect benefits. Thus, there is an impact on the quantity of a vaccine that a

pharmaceutical company can sell. This thesis uses the Heal and Kunreuther (2005) framework to analyze the externality, the individual's vaccination decision, and how both impact the pharmaceutical company's production decision. I find that the externality problem prohibits the pharmaceutical company from value pricing for a vaccine where it can value price for an equivalent drug. Thus, the pharmaceutical company earns less revenue from the vaccine than an equivalent drug. In order to incorporate one influence that would tend to offset the pricing disadvantage of vaccines, I extend the Heal and Kunreuther model to consider risk aversion. I also determine the effects of implementing a subsidy in the vaccine market with the goal of eliminating the externality.

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The Vaccine Externality and its Impact on a Pharmaceutical Company

by
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DEDICATION

I dedicate this thesis to my family for all of their support during my college career.

BIOGRAPHY

Justin was born in Charleston, South Carolina to Mike and Jill Bright on July 6, 1987. After graduating from the Academic Magnet High School in 2005, he pursued his Bachelor's degree in Economics and Finance at the University of South Carolina (USC) in Columbia, South Carolina. During his time at USC, Justin was very active in Student Government, the Supplemental Instruction program, and the business school. Upon graduation from USC, Justin enrolled in the Masters of Economics Program at North Carolina State University in Raleigh, North Carolina to further his passion for economics. While enrolled at NC State, he interned at the Institute for Emerging Issues where he supported the efforts and programs of the policy and communications team.

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TABLE OF CONTENTS

List of Tables.....	vi
List of Figures.....	vii
Forward.....	1
Introduction.....	2
Review of Literature.....	7
Regulatory Issues from the FDA.....	7
Product Liability.....	9
Industry Mergers.....	11
Size of the Market for Vaccines.....	12
Externality Problem Associated with Vaccines.....	13
The Model and Analysis.....	23
The Two-Individual Case.....	24
The N-Individual Case.....	27
The Social Optimum.....	29
Implications of the Results.....	31
Risk Aversion and the Market for Vaccines.....	36
Public Policy and the Market for Vaccines.....	42
Discussion.....	47

LIST OF TABLES

Table 1.1: Rates of Disease Reduction by Vaccines.....	3
Table 1.2: Pharmaceutical Company Expenditures on Drugs.....	4
Table 3.1: Payoff Matrix from the Vaccination Game.....	24

LIST OF FIGURES

Figure 3.1: Possible Dominant Strategy Equilibria.....	26
Figure 3.2: Graph of Heal and Kunreuther Vaccination Proposition.....	28
Figure 3.3: The Market for Vaccines.....	30
Figure 3.4: The Social Surplus Created by Vaccines.....	34
Figure 3.5: Utility of Income Model.....	39
Figure 3.6: The Market for Vaccines Under Risk Aversion.....	41
Figure 3.7: The Market for Vaccines Pre- and Post-Subsidy.....	44
Figure 3.8: Company Revenue Pre- and Post-Subsidy.....	45

Forward

During my time at the Institute for Emerging Issues, I had the opportunity to attend the Emerging Issues Forum on Healthcare Innovations. This event focused on innovations across North Carolina promising to reduce health costs and to improve the economy. The forum featured many nationally known speakers including Clayton Christensen of Harvard Business School, Indra Nooyi, CEO of Pepsi, as well as Dr. Sanjay Gupta, neurologist and journalist for CNN.

Following Dr. Gupta's presentation on health and the media, I asked him "what is one major economic issue facing the healthcare industry?" I didn't expect an answer; much less a well crafted answer. He responded, "health costs have skyrocketed due to the misalignment of the healthcare incentive structure. You have pharmaceutical companies earning record profits from drug sales, but they don't have clear incentives to care about preventing the diseases from occurring in the first place. That is a national tragedy."

After this conversation, I began to think about, and do some preliminary research on his assertion. It became clear to me that pharmaceutical companies did have something they could invest in to prevent diseases: vaccines. Even though the answer is clear, there has to be a barrier preventing these investments from occurring, as many of the world's most prevalent diseases have drug treatments and not vaccines. The inspiration for this thesis came from my conversation with Dr. Gupta and this thesis seeks to provide a solution to the problem that he identified.

1. Introduction

Over the past twenty years, health costs have increased threefold from \$714 billion in 1990 to \$2.3 trillion in 2008 accounting for 16% of the US Gross Domestic Product (Kaiser 2009). Many people have proposed solutions to this problem, including national healthcare reform, investing in new technology, and improving quality and efficiency. However, one of the most promising solutions is investing in health promotion and disease prevention (Rappuoli et al. 2002). The purpose of health promotion and disease prevention is to undertake activities, such as changing your diet, exercising, or getting vaccinated to reduce the prevalence of disease and to lower lifetime health costs. Individuals clearly have incentives to care about their own health, but what do others in the health industry stand to gain?

Traditionally, some pharmaceutical companies have invested in vaccines as their source of health promotion and disease prevention. Vaccines have been proven to be a cost-effective medical intervention in the prevention of disease (Rappuoli et al. 2002). The rates at which vaccines have been successful in eradicating and reducing the occurrence of some of the most prevalent diseases in the United States are shown in the table on the following page (Armstrong 2007).

Table 1.1: Rates of Disease Reduction by Vaccines

Disease	Number of Cases (Year)	Number of Cases in 2001	Reduction
Smallpox	48,164 (1900)	0	100%
Diphtheria	206,939 (1921)	2	99.99%
Measles	894,134 (1941)	96	99.99%
Rubella	152,209 (1968)	216	99.86%
Mumps	20,000 (1992)	51	99.75%

The reduction in the occurrence of the most prevalent diseases due to vaccines has contributed to the reduction of health costs. In the 1970s, the World Health Organization launched a campaign and committed funds to eradicate smallpox through mass-producing the vaccine. By the end of the decade, the disease was officially eradicated. Armstrong (2007) estimates that direct savings in health costs due to the eradication of smallpox exceed \$300 million per year. Armstrong (2007) also estimates that for every dollar spent on the measles-mumps-rubella vaccine, more than \$21 dollars is saved in direct health costs.

As the previous examples show, vaccines appear to be a mechanism that can be effective in reducing the prevalence of diseases and reducing health costs. Given that their positive benefits go beyond disease prevention for an individual, all else equal, vaccines should be prevalent in pharmaceutical markets. However, studies have shown that when given the choice between drugs and vaccines, pharmaceutical companies choose to invest in drugs. To date, there have been 75

vaccines that have received approval by the Food and Drug Administration (FDA). In the five-year period from 2006 to 2010, over 110 new drugs received FDA approval (FDA 2011). So, in five years, pharmaceutical companies produced more new drugs than the total number of vaccines available in the market.

Producing a vaccine requires approximately 12 to 15 years of research and has an average cost between \$500 million and \$1 billion (Prifti 2010). Drugs also require 12 to 15 years of research however they cost significantly more to produce. The following table shows the average per drug development expenditures for major pharmaceutical companies in the United States. Per drug development expenditures is calculated by dividing the pharmaceutical company's total research and development budget by their average number of drugs approved. It also shows the total expenditures from 1997 to 2011 of the major pharmaceutical companies (Herper 2012).

Table 1.2: Pharmaceutical Company Expenditures on Drugs

Company	Number of Drugs Approved	R&D Spending per Drug (\$Mil)	Total R&D Spending 1997-2011 (\$Mil)
AstraZeneca	5	11,790.93	58,955
GlaxoSmithKline	10	8,170.81	81,708
Pfizer	14	7,727.03	108,178
Johnson & Johnson	15	5,885.65	88,285
Merck	16	4,209.99	67,360

Even though vaccine development costs significantly less than drug development, all else equal, pharmaceutical companies are choosing to invest approximately five times the amount of money in drug development. Vaccines provide benefits not only to the individuals who consume them but also to individuals who do not consume them through herd immunity. However, drugs only provide benefits to individuals who consume them. So, it can be argued that a vaccine provides more benefit to society than a drug, yet pharmaceutical companies are choosing not to produce vaccines. This vaccine paradox raises the question: is there some structural reason that would make a vaccine less profitable than an equally costly and equally effective drug? This paper seeks to identify structural reasons why a vaccine is less profitable than an equally costly and effective drug and propose a solution to reduce these structural barriers.

This is an important question to investigate as it could pose a solution to the growing health costs problem. Eradicating diseases through vaccination has proven, in the case of small pox, to reduce health costs significantly each year. If there were vaccines for the world's most prevalent diseases, all else equal, there would be a decrease in health costs. These reductions in direct and indirect health costs include the costs associated with hospitalization or the value of an individual's missed time at work or school among others. The reduction in health costs could also have a major impact on the economy. For these reasons, this is a very important subject to study.

The next section of this paper reviews the relevant public health and economic literature that focuses on vaccines. There is an in-depth analysis of the traditional barriers to vaccine development: regulatory issues from the Food and Drug Administration (FDA), product liability, industry mergers, and the size of the market for vaccines. I also propose a new barrier to vaccine development that has not been thoroughly developed in the literature. This new barrier is the externality problem associated with vaccines. The third section of the paper presents a model that is used to analyze the externality problem and how it impacts a pharmaceutical company's production decision. It also looks at the impact of changing the individual's risk tolerance assumption in the model on the pharmaceutical company's implied ability to appropriately price the vaccine. Finally, it examines a public policy intervention in the market. The fourth section draws conclusions based on the model and provides a discussion of the results.

2. Review of Literature

Research about vaccines has traditionally been a topic of public health scholars and not a topic that economists have been interested in. Within the past ten years, pharmacoeconomics has become a field of study that focuses on the costs and benefits of pharmaceutical products. Pharmacoeconomic economists also focus their research on a pharmaceutical company's decision to produce a vaccine or a drug (Bootman et al 2009). These economists and public health scholars have identified traditional barriers as to why pharmaceutical companies choose to develop drugs instead of vaccines. The traditional barriers include regulatory issues from the Food and Drug Administration (FDA), product liability, industry mergers, and the size of the market for vaccines. I consider each of these barriers below.

Regulatory Issues from the FDA

In order for a new vaccine to be administered in the United States, it has to be approved by the FDA. The standards for FDA approval of vaccines are higher than the standards for drugs because products given to healthy people must be safer than products given to sick people (Offit 2005). The National Childhood Vaccine Injury Act (NCVIA) of 1986 requires that the FDA mandate higher standards of safety for vaccines than drugs. NCVIA specifies the standards of safety during the clinical trials phase and the post-approval phase. During the clinical trials, FDA scientists and doctors are responsible for monitoring product safety among human participants. Following vaccine approval, under FDA mandate 21 CFR, Subpart D,

pharmaceutical companies are required to report adverse events associated with vaccines through the Vaccine Adverse Event Reporting System (VAERS) (FDA 2012).

The following example shows the impact of the higher standards of safety for vaccines. In 1998, the FDA approved a vaccine for rotavirus, a disease that affects children. After one year on the market, the Centers for Disease Control (CDC) determined the vaccine caused a rare adverse side effect. About one of every 10,000 children that were vaccinated developed a blockage in their intestines. Following this discovery, the vaccine was removed from the market. Upon investigation, the FDA found that the sample size was too small during the clinical trials phase as only 11,000 children were vaccinated. As a result of this incident, the standards of safety for vaccines have been raised since the initial NCVIA mandate (Offit 2005).

The FDA also requires that drugs meet high standards of safety but not as high as vaccines. The Prescription Drug Marketing Act (PDMA) of 1987 charged the FDA with monitoring the safety and effectiveness of drugs. While the PDMA puts a small focus on monitoring safety of drugs during the clinical trials phase, its main focus is on diminishing the prevalence of counterfeit, adulterated, misbranded, or expired drugs (FDA 2012). Even though vaccines and drugs are inherently risky given that they are chemical or biological in nature, the higher standards of safety for vaccines increase their costs of production. Pharmaceutical companies are

required to disprove rare adverse effects prior to FDA approval and monitor and report adverse effects once the vaccine is available in the market.

Product Liability

Product liability is another major deterrent for pharmaceutical companies investing in vaccines. Since products given to healthy people must be safer than products given to sick people (Offit 2005), the risk associated with the threat of litigation for adverse effects is larger. During the 1980s, vaccines were held to a costly compensation liability rule where the vaccine-producing firm was responsible for compensating parties for any adverse effects (Boffey 1984). Since then, the National Vaccine Injury Compensation Program (NVICP) has been passed and has reduced the vaccine-producing firm's liability for the vaccines recommended for children. However, the NVICP does not cover all vaccines available in the market and for those vaccines, the vaccine-producing firm is still held to a costly compensation rule (HRSA 2001).

Manning (1994) looks at the effects of product liability in the market for childhood vaccines. The model begins with a hypothetical situation where the vaccine-producing firm does not assume any liability for the vaccine's adverse effects. He begins with this rule as a point of reference to determine how the vaccine's price and cost respond to changes in the liability rule. Then, he changes the liability rule to a costly compensating rule where the vaccine-producing firm is responsible for any adverse effect of the vaccine. Manning finds that the increase in

the price due to the changed liability rule exceeds the expected damage per dose by an amount related to the magnitude of compensation costs.

This notion is supported by his empirical work. The data shows that liability and litigation costs have caused major increases in vaccine prices (Manning 1994). For example, the wholesale price of the diphtheria, pertussis, and tetanus (DPT) vaccine has increased by more than 2,000% due to litigation. Approximately 96% of the DPT vaccine price increase goes toward paying litigation costs (Manning 1994). Manning assumes that the vaccine-producing firm must spend $(1+\alpha)$ dollars to transfer one dollar of compensation to the parties experiencing the adverse effects. The α term accounts for the transactions cost of moving the case through the court system. He estimates that α takes on a value between \$5 and \$7, which shows that there is significant transactions costs associated with vaccines (Manning 1994).

The liability rule for drugs is different from the rule for vaccines. In practice, drugs are held to a failure-to-warn liability rule and not a costly compensation rule. Failure-to-warn defects arise in products that carry inherent nonobvious dangers, which could be mitigated through adequate warnings to the user. Drugs are immune from side effect liability since they inherently involve risks and could not be designed any safer. While pharmaceutical companies are theoretically liable for drugs, they are rarely sued for side effects as they provide clear warnings for possible adverse effects (Helland et. al 2011). A vaccine being held to a costly

compensation liability rule contributes to increased transactions costs due to litigation. These transaction costs are a major disincentive of developing vaccines.

Industry Mergers

During the past fifty years, the pharmaceutical industry has undergone a transformation. Pharmaceutical companies, such as Praxis, that were solely focused on developing and manufacturing vaccines have since been acquired by other companies (Offit 2005). Grabowski and Kyle (2008) discuss the major economic incentives for mergers in the pharmaceutical industry. The motivations can be described in two major categories: defensive motives and proactive motives (Grabowski & Kyle 2008). In the late 1980s, the economic environment and the breakdown in the pharmaceutical pipeline posed major challenges for the industry. At this time, many affected pharmaceutical companies used their excess capital to acquire other companies' products and pipelines as a defense mechanism. Higgins and Rodriguez (2006) found in a study of 160 pharmaceutical mergers from 1994 to 2001, firms with lower scores in the strength of their pipeline had a greater probability to merge with other firms.

Proactive motives for mergers focus on economies of scale. Cockburn and Henderson (2001) look at economies of scale in pharmaceutical research and development. They conclude that projects initiated in a more diverse development effort are significantly more likely to result in approval by the FDA than ones initiated in a more narrow development effort. This result is attributed to the ability

of a larger pharmaceutical company to spread the fixed costs of research over a larger sales base and the advantages that large pharmaceutical companies have over smaller ones in financial markets. The financial market advantages include favorable borrowing rates to fund projects and easier access to the markets (Cockburn & Henderson 2001). There is a strong incentive for companies to merge and broaden their scope of research and development. Pharmaceutical companies that solely develop vaccines have a very narrow scope of research and development, which make them strong candidates for mergers with larger firms (Offit 2005).

As a result of the mergers, the number of companies solely producing vaccines has declined from twenty-six in 1967 to five in 2004 (Offit 2005). Before the mergers, in companies solely producing vaccines, one vaccine would compete with another for resources. However, following the mergers, vaccine research would compete with drug research for resources and would often lose. When determining projects to invest in, pharmaceutical companies evaluate their return on investment. Offit (2005) asserts that out of the four largest pharmaceutical companies producing both vaccines and drugs today, none have revenues from vaccines greater than ten percent of their total revenue.

Size of the Market for Vaccines

The size of the vaccine market is another reason why pharmaceutical companies choose to invest in drugs instead of vaccines. Vaccines, by design, are used several times during an individual's lifetime while drugs, in most cases, are

used at least once a day to cure a disease. This result impacts the quantity of vaccines and drugs sold and the revenue earned from each. For example, Fluvirin, a seasonal flu vaccine patented to Novartis, was priced at \$12.10 per dose and had annual revenues of \$400 million in 2010. Tamiflu, a drug used to treat the seasonal flu, had an average price of \$86.50 and had annual revenues of \$840 million in 2010 (Evaluate Pharma 2012)¹. Even though these two products eliminate the flu, this shows that there is a greater financial incentive to produce drugs. This also provides an explanation for why pharmaceutical companies compete to make similar drugs but not similar vaccines. Of the twelve off patent vaccines that are recommended for children, seven are made by one company and only one is made by made by multiple companies (Offit 2005).

Externality Problem Associated with Vaccines

While there has been significant research on the traditional barriers to vaccine development, the externality problem associated with vaccines and how it impacts an individual's decision to vaccinate and the pharmaceutical company's production decision has not been thoroughly examined. If people face the possibility of contracting a disease and have the option to receive a perfectly effective vaccine, will they choose to be vaccinated? If they do, how many people will choose to be vaccinated and will their decision affect others' decisions to be vaccinated? These are the sorts of questions that a small group of health

¹ The H1N1 flu scare occurred in 2009 and does not contribute to the difference in the numbers in 2010.

economists are currently examining. If fewer people than what is socially optimal are vaccinated, then there is an impact on the quantity of a vaccine that a pharmaceutical company can sell. Thus, there also is an influence on the revenue the pharmaceutical company can earn from vaccines (Stiglitz et al. 2011).

An externality can be defined as a spill over effect associated with production or consumption that extends to a third party outside of the market. In other words, an externality generates costs or benefits to a third party who does not participate in the market. Free riding emerges with externalities. Cullity (1995) defines a free rider as:

“an individual who, in successfully optimizing his own interests, does not contribute to the production of a good that is in joint supply to a certain group, in conditions where it would be collectively self-interestedly suboptimal for the group not to cooperate toward its production (p. 5)”.

More generally, a free rider is an individual who fails to pay for a good that he or she consumes, although it is worth paying for. When applying this definition to vaccines, the individual who vaccinates benefits but other individuals in the population also benefit regardless of whether or not they are vaccinated.

How does an individual decide to vaccinate? To make the decision to vaccinate, individuals weigh their own costs and benefits of vaccinating. There are two kinds of benefits of vaccination: direct and indirect. Direct benefits of vaccination are unique to every individual as they can vary over time and are often

difficult to measure. An individual's direct benefits of vaccination may depend on factors such as the probability of being exposed to a disease, the risk of developing a disease, or access to quality medical care. For example, in the United States, rotavirus is a disease that has a high clinical attack rate among children and is more common among children living in poverty. Therefore, the direct benefits of a child vaccinating may be greater for a child living in poverty than for other children (Coffin & Nelson 2005).

There are indirect benefits of being vaccinated as well. For diseases that are transmitted from individual to individual, increased vaccination rates reduce the prevalence of the disease. For example, for children born into families with older siblings vaccinated for pertussis, there is increased protection for the newborn child (Coffin & Nelson 2005). Vaccines can also benefit entire communities through herd immunity. Herd immunity is a form of immunity that occurs when vaccination of a significant portion of the population provides a measure of protection for individuals who have not developed immunity. Fine and Clarkson (1986) find that due to herd immunity, the benefits of vaccination may shift from the individual who is vaccinated to the community in which he or she lives. In areas where vaccination rates are high and where the incidence of preventable diseases is low, vaccines are a mechanism for disease control. Thus, a highly vaccinated population acts as an umbrella to protect the vulnerable, unvaccinated people (Coffin & Nelson 2005).

There are two types of costs that are associated with vaccination: the cost of the vaccine and the costs of the potential side effects. The cost of a vaccine is the price that the individual pays when he or she is vaccinated². In the United States, the price per dose of a vaccine ranges from \$10.00 for the tetanus vaccine to \$161.50 for the Zoster Vaccine (CDC 2012). Vaccines are not always perfectly effective, which gives rise to additional costs associated with vaccination. The main type of additional cost is the costs of side effects from the vaccine. Some of these costs include having to go to the doctor to treat the side effects or the value of lost time at work. The individual considers all of these costs in their decision to vaccinate (Coffin & Nelson 2005).

Hershey et al. (1992) concludes an individual will vaccinate if it is in their best interest after weighing the costs and direct benefits. An individual has the clear incentive to vaccinate to improve his or her well being. But, the externality problem distorts the decision to be vaccinated as an individual considers only his or her own costs and direct benefits. The individual will ignore any indirect benefits that his or her consumption may confer on others. As a result, the number of individuals that decide to be vaccinated may be suboptimal. They find that widening vaccine use decreases each individual's direct benefit from being vaccinated but does not change the risk from the vaccine itself. For this reason, individuals may perceive the

² This ignores the possibility for insurance. I am assuming that the individual pays the full cost of the vaccine.

indirect benefits of herd immunity as a strong enough incentive to not be vaccinated and not accept the personal risks associated with vaccination (Hershey et al. 1992).

The effect of the actions of others on the individual's decision to vaccinate has not been the subject of major research in economics. The majority of the research on this topic has been centered on disease transmission across populations and has been published in public health journals. In these articles, mathematical epidemiologists model the process of disease transmission from individual to individual or from non-human host to individual. The classic book in this field is Anderson and May (1991). They take a public health approach to study infectious diseases and their dynamics of interaction with host populations. They use an analytical framework combined with epidemiological data to evaluate public health strategies for controlling and eradicating particular diseases. While this book does not consider vaccinations and an individual's decision to vaccinate, it provides insight into the costs associated with diseases.

The small literature on vaccination in economics journals has focused on the implications of the individual's vaccination decision for public policy. For example, Brito et al. (1991) shows that when vaccines are perfectly effective, the competitive equilibrium is less efficient than a mandatory vaccination program. Therefore, fewer individuals voluntarily vaccinate themselves than the socially optimal level. This result emerges because vaccines, in their model, are not perfectly effective and the free riding alternative is not as attractive to an individual as it would be for a

perfectly effective vaccine. However, Francis (1997) concludes that in a particular dynamic environment where the transmission of disease is stochastic, the number of people that decide to voluntarily vaccinate is the same as the socially optimal decision. This result is derived from the proof in their paper that there is not an externality associated with vaccination. Other articles on the topic include Gersovitz and Hammer (2004), Geoffrard and Philipson (1997), and Barrett (2003).

There are two influential economic papers that present explicit models that address the individual's choice to vaccinate and the factors that affect that choice. Bauch and Earn (2004) base the individual's decision to be vaccinated on the proportion of the population that is vaccinated. Heal and Kunreuther (2005) base the individual's decision to be vaccinated on his or her own costs and benefits and the characteristics of the disease. Bauch and Earn (2004) is the more frequently cited model for considering what proportion of the population is vaccinated for a disease and studying epidemics.

Bauch's and Earn's (2004) game theoretic model analyzes how the population behaves under voluntary vaccination policies for childhood diseases. Their framework is focused on quantifying how risk perception influences vaccinations and the role that external factors play in that decision. They theorize that the parent's decision to vaccinate their child depends on the risk of morbidity from the vaccine, the probability that the child will become infected absent the vaccine, and the risk of morbidity from the disease.

Bauch and Earn (2004) find that if a sufficient proportion of the population is already immune to a disease, then the slightest risk associated with vaccination will outweigh the risk from the disease and a child will not be vaccinated. They also find that if the vaccine is perceived to be sufficiently risky, then the Nash Equilibrium of the game is to never vaccinate. However, if the risk is sufficiently small, then the Nash Equilibrium is to vaccinate with probability P , where P is the proportion of the newborn population that gets vaccinated ($0 < P < 1$). Therefore, they find that the optimal number of children vaccinated is not one hundred percent.

Another major implication of the risk of the vaccine and vaccination decision trade off presented above is that individual self-interest may prevent complete eradication of a vaccine-preventable disease. Bauch and Earn present and prove this claim in their paper based on the result that less than one hundred percent of the population is vaccinated in the equilibrium of their model. While this claim is true in their framework, data supports the opposite. Smallpox is a disease that was eradicated around the world in the 1970s through voluntary vaccination. With knowledge of perceived risk associated with the vaccine, the Bauch and Earn framework can predict vaccine coverage levels under voluntary policies. However, the perceived risk associated with the vaccine is a dynamic concept and can change drastically due to vaccine scares and media coverage. Under normal circumstances, the perceived risk is very low but during a vaccine scare, the perceived risk is higher leading to fewer people getting vaccinated (Bauch & Earn 2004).

Heal and Kunreuther (2005) develop a static game theory model where individuals choose whether to be vaccinated based on their economic costs and benefits, given their assumptions about the disease characteristics. In the model, vaccination is modeled as a risk management decision on the part of the individuals who are susceptible to contracting the disease. The framework determines the proportion of the population that is vaccinated and not vaccinated but does not consider who specifically is vaccinated. Unlike the conclusion of Bauch and Earn (2004), the framework specifies conditions under which voluntary vaccination can lead to disease eradication.

Heal and Kunreuther (2005) determine that if the vaccine is completely effective in preventing the disease, the decision to vaccinate is a function of four variables: the cost of vaccination, the monetary loss due to the disease, the probability of contracting the disease from a non-human host, and the probability of infecting another individual. These variables determine the proportion of the population that is vaccinated. In the case of two individuals, the dominant strategy equilibrium of the vaccination game differs from the social optimum due to the presence of the positive externality associated with vaccines. The socially optimal level of vaccination may be less than 100 percent since the marginal social benefits of vaccination decline as the number of individuals being vaccinated increases. The result of the two-individual case generalizes to the case where there are N individuals in the population.

The two models differ in their approach to the externality problem associated with vaccines. The Heal and Kunreuther (2005) framework uses the individual's preferences as a point of reference, while the Bauch and Earn (2004) framework looks at the environment in which the individual lives. The two frameworks also differ on the view that voluntary vaccination can eradicate diseases. Bauch and Earn conclude that voluntary vaccination cannot lead to eradication of a vaccine-preventable disease while Heal and Kunreuther conclude the opposite. Heal and Kunreuther (2005) provide a preferable framework for analyzing vaccination and is used in this paper because it is a model in which an individual decides to vaccinate based on his or her own self interests (see Hershey et al. (1992) for a consistent approach). Heal and Kunreuther also consider welfare losses, if any, resulting from an individual's choice to be vaccinated.

Previous research has identified traditional barriers to vaccine development as: regulatory issues from the FDA, product liability, industry mergers, and the size of the market for vaccines. Given that, I believe there is another barrier that has not been thoroughly examined in the literature. That is the externality problem associated with vaccines. While public health writings and economic modeling provide a basis for understanding an individual's vaccination decision, those models have not specifically addressed the question of whether the externality problem is a barrier to vaccine development. Using the framework introduced by Heal and Kunreuther (2005), in the next section, I examine the how the individual's

vaccination decision affects a pharmaceutical company's decision to produce a vaccine.

3. The Model and Analysis

Following Heal and Kunreuther (2005), let c_i be the cost for individual i to be vaccinated. This cost is not limited to the consumer's expenditure on the vaccine, but also includes psychological costs, inconvenience and possible side effects – in brief, all of the costs borne directly by the individual. If individual i contracts the disease, he or she experiences a loss, L_i , in dollar terms. Heal and Kunreuther initially assume that a non-human host introduces the disease into the framework. This assumption is necessary so that it is possible for an individual to initially contract the disease. This assumption is supported by the way Cholera, SARS, and Ebola are transmitted from non-human hosts to individual. Y_i is individual i 's initial income and is used here as a reference point to determine the welfare loss associated with contracting the disease (Heal and Kunreuther 2005).

Each individual has a probability, p_i , of contracting the disease if no other individual has it. This probability reflects the environmental and background risk associated with the disease. The probability that an individual who has already contracted the disease from the non-human host will infect someone else who has not been vaccinated is denoted by r . rp_i is the probability of contracting the disease from a non-human host and infecting another individual with the disease. Following Heal and Kunreuther, let $rp_i = q_i$ for simplicity. For the entire paper, it is assumed that a vaccine is fully effective, which implies that the individual has a zero

probability of contracting the disease following vaccination (Heal & Kunreuther 2005).

The Two-Individual Case

In a two-individual game, risk neutral individuals have a choice of two strategies: to vaccinate, denoted V, or not to vaccinate, denoted NV. The payoff matrix of the game is shown below (entries are row payoff, column payoff).

Table 3.1: Payoff Matrix from the Vaccination Game

	V	NV
V	$Y_1 - c_1, Y_2 - c_2$	$Y_1 - c_1, Y_2 - p_2L_2$
NV	$Y_1 - p_1L_1, Y_2 - c_2$	$Y_1 - p_1L_1 - (1-p_1)q_2L_1, Y_2 - p_2L_2 - (1-p_2)q_1L_2$

If both players are vaccinated, then the payoff to each player is their initial incomes net the cost of the vaccination. If only one player vaccinates, that player's payoff is the same but the other player's payoff is his or her's initial income net the expected loss of the disease. The player that contracts the disease runs no risk of infecting the other since the other player is vaccinated for the disease. If neither player vaccinates, the payoff is their initial incomes net the expected loss of the direct infection by the non-human host and the expected loss from infection by the other player (Heal & Kunreuther 2005).

The game has dominant strategy solutions, depending on the cell values. There are four possibilities for the dominant strategy equilibrium given the possible values of the parameters (Heal & Kunreuther 2005):

1. When $c_i < p_i L_i$ for both players, then (V, V) is a dominant strategy equilibrium.
2. For $p_1 L_1 < c_1$ and $c_2 < p_2 L_2 + (1-p_2)q_1 L_2$, (NV, V) is a dominant strategy equilibrium. This is symmetric as (V, NV) is a dominant strategy equilibrium as well.
3. For $p_i L_i < c_i < p_i L_i + (1-p_i)q_j L_i$ for both players, then both (NV, V) and (V, NV) are dominant strategy equilibria.
4. For $p_i L_i + (1-p_i)q_j L_i < c_i$ for both players, then (NV, NV) is a dominant strategy equilibrium.

The figure on the following page shows the possible dominant strategy equilibria for this game (Heal & Kunreuther 2005). The first dominant strategy equilibrium is labeled 1 and is where the cost of the vaccine is less than the expected harm from the disease. In this case, both players have the incentive to vaccinate. The second dominant strategy equilibrium is labeled 2 and is where the cost of the vaccine for one player is less than the expected loss from the disease while the cost of the vaccine is greater than the expected loss from the disease for the other player. So, the other player does not vaccinate.

The third dominant strategy equilibrium is labeled 3 and is where the cost of the vaccine is in between the expected loss from the disease and the expected loss

from contracting the disease and infecting the other player. As a result, one player chooses to vaccinate and the other player chooses not to vaccinate. The fourth dominant strategy equilibrium is labeled 4 and is where the cost of the vaccine is greater than the expected loss from contracting the disease and infecting the other player. As a result, neither player has the incentive to vaccinate. Based on the graph below, as the cost of the vaccination, c_i , changes, the Nash Equilibrium of the game changes. If the cost of the vaccine is sufficiently small, both players vaccinating is the optimal strategy. But, as the cost of the vaccine increases, one or both players may have the incentive to not vaccinate.

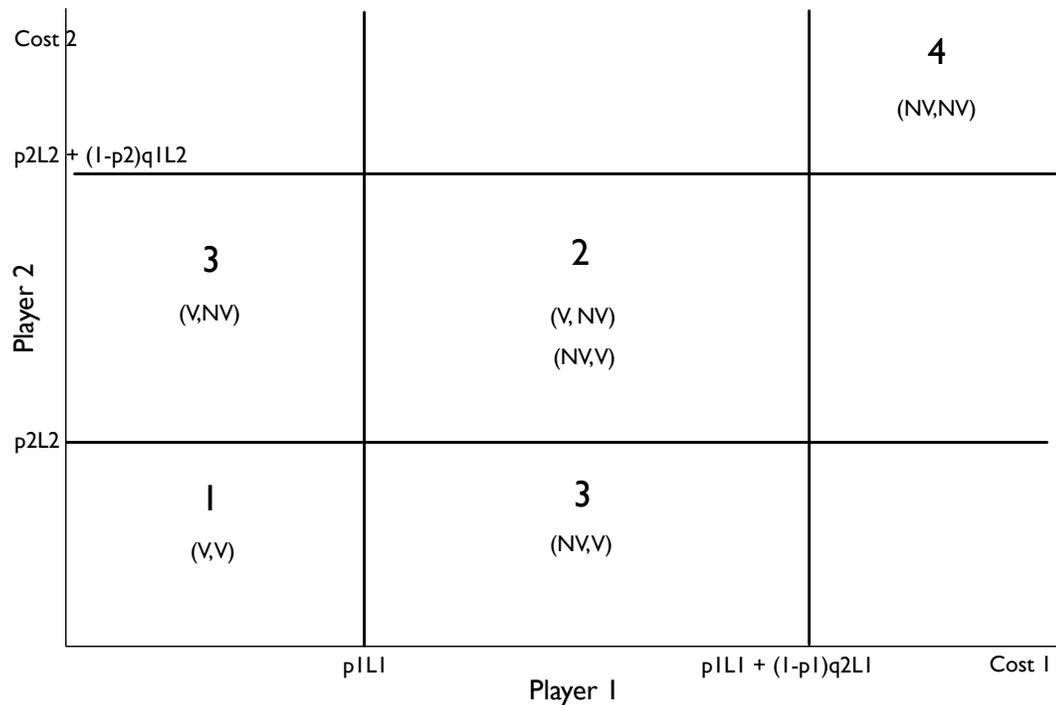


Figure 3.1: Possible Dominant Strategy Equilibria

The N-Individual Case

Heal and Kunreuther (2005) determine that the results for the two-individual case hold for the N-individual case. This result is true because each individual in the population acts in their personal self-interest and optimizes to make the decision to vaccinate. If the cost of the vaccine is sufficiently small, then all members or all but one members of the population will be vaccinated (all if the disease has a non-human host or all but one if the disease has a human host). As the cost of the vaccine increases, there are new equilibria where all but two, all but three, etc. are vaccinated until the equilibrium is reached where no one is vaccinated. So, as in the two-individual case, the cost of the vaccine is the main variable in determining the proportion of the population that is vaccinated.

What is the optimal number of individuals in the population that vaccinate?
Heal and Kunreuther develop and prove the following proposition in the paper:

“Let there be N people exposed to an infectious disease, with a probability r of catching it from an infected person and a probability p of catching it from a non-human host. c is the cost of vaccination and L the loss from catching this disease. $R(0)$ is the probability of a non-vaccinated person catching the disease if no-one is vaccinated and $R(k)$ is the probability of a non-vaccinated person catching the disease if k are vaccinated. Then, at the Nash Equilibrium, the number of people vaccinated is as follows: for $R(j)L < c <$

$R(j-1)L$, there are j people vaccinated and $N-j$ not vaccinated. For $c < R(N-1)L$ everyone is vaccinated and for $R(0)L < c$, no one is vaccinated (p. 6)."



Figure 3.2: Graph of Heal and Kunreuther Vaccination Proposition

This proposition is important because it extends the two-individual case results to N -individuals. If the expected loss from the disease is greater than the cost of the vaccine, then everyone will be vaccinated (the range represented by the dotted line to the left of $R(j)L$). This occurs because the expected cost of the disease to any individual even when everyone else is vaccinated is greater than the cost of the vaccine (everyone being vaccinated does not eradicate the disease as there is a non-human host). Also, if the expected harm from the disease when no one is vaccinated is less than the cost of the vaccine, then no one will be vaccinated (the range represented by arrowed line to the right of $R(j-1)L$). A proportion of the population will choose to be vaccinated if the cost of the vaccine is in between the reduced expected harm from being vaccinated ($R(j)L$) and the expected harm from not being vaccinated ($R(j-1)L$) (the range represented by the line in between $R(j)L$

and $R(j-1)L$). From this proposition, it is clear there are cases where no one will be vaccinated, some individuals will be vaccinated, and the entire population will be vaccinated.

The Social Optimum

Heal and Kunreuther (2005) determine that there is a case where some, but not all, of the population will be vaccinated. However, is that proportion more or less than what is socially optimal? Coffin and Nelson (2005) determine that vaccines provide direct benefits for the individual who is vaccinated but also provides indirect benefits to the community. Therefore, the social benefits of the vaccine exceed the private benefits since the vaccine reduces the risk faced by others. Suppose that k individuals are vaccinated and one more joins them, the private gain of the additional individual getting vaccinated, or the marginal private benefit, is $R(k)L - c$. That is, the private benefit of vaccination is the expected loss incurred by the disease net of the cost of the vaccine (Heal & Kunreuther 2005).

The social gain of the additional individual being vaccinated, or the marginal social benefit, exceeds the private gain of vaccination by the change in the expected losses of other individuals who are not vaccinated. This is given by:

$$SG = R(k)L + (N-k)\Delta R(k)L - c \text{ where } \Delta R(k) = R(k) - R(k+1)$$

When ignoring the extreme cases where the entire population is or is not vaccinated, the number of individuals actually vaccinated is less than the socially optimal number of individuals as the social benefits exceed the private benefits.

Thus, on a societal level, vaccines are underproduced due to the positive externality that they present (Heal and Kunreuther 2005). This has two major implications for vaccines. First, vaccines are under-utilized due to the externality since the social optimal level of vaccination is greater than the private level of vaccination. Second, vaccines are under-invented due to the externality as the pharmaceutical company has a greater incentive to produce other products instead of vaccines. Ultimately, both of these provide a major disincentive for producing vaccines. This result is shown in the graph below.

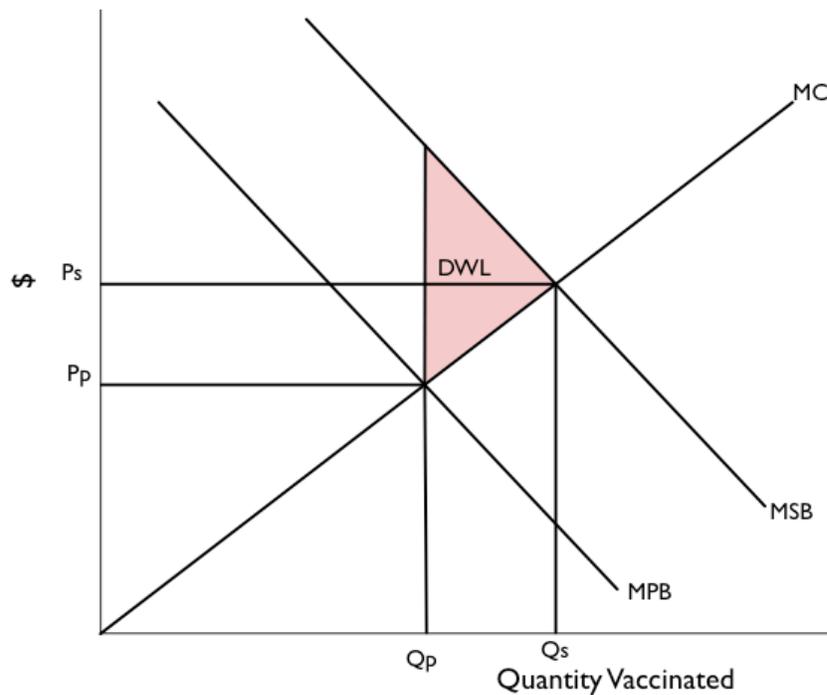


Figure 3.3: The Market for Vaccines

Implications of the Results

I believe that the Heal and Kunreuther (2005) result that a proportion of the population will be vaccinated for the disease has a major implication for a pharmaceutical company. This implication is in the pricing of the vaccine versus the pricing of an equivalent drug. Pharmaceutical companies traditionally are able to value price their products given that they have monopoly power in the market. Value pricing is setting prices for products primarily, but not exclusively, on the value to the consumer rather than on some multiple of actual cost of the product or some available market price of roughly analogous products.

Even though pharmaceutical companies can traditionally value price for their products, there are two instances where they cannot. First, when a new product enters the market, the pharmaceutical company has little information about an individual's willingness to pay. Therefore, their ability to value price for new products is diminished. Lu and Comanor (1998) studied the pricing of new drugs from 1978 to 1987. They found that pharmaceutical companies base a new product's price on the FDA's rating of the product's quality relative to existing products in the market. For example, drug molecules that created large therapeutic gains were priced about 3.2 times the level of inferior substitute products that were already available in the market (Lu & Comanor 1998). As the amount of time from product introduction into the marketplace increases, the pharmaceutical company

relies less on substitute products for pricing and more on value pricing based on the knowledge that they have gained about the market (Scherer 2004).

Second, pharmaceutical companies cannot fully value price for all of their products. They cannot value price vaccines for two reasons. The first reason is that a pharmaceutical company knows before making their production decision that the entire population will not be vaccinated due to the externality problem associated with vaccines. As the model predicts, there is an incentive for a proportion of the population to free ride on the herd immunity created by the individuals that are vaccinated. This free riding reduces the price that the pharmaceutical company can charge and the quantity of the vaccine that they can sell (this result is shown on the graph on page 30). The attractiveness of the free-rider alternative increases the elasticity of demand for the product and reduces the quantity sold at any price.

The second reason is that the pharmaceutical company does not have complete information about the population. When an individual decides to vaccinate, he or she has not yet contracted the disease. However, some individuals are more susceptible to contract the disease than others. For example, an individual who visits a mosquito-infested tropical region has a greater probability of contracting malaria than an individual who does not. In theory, a pharmaceutical company should charge a higher (value) price for a vaccine to the individual who is engaging in such behavior. But, an individual's traveling behavior would be difficult to monitor by the pharmaceutical company and as a result, the pharmaceutical

company would not be able to value price on this behavior. Therefore, the asymmetry of information does not allow the pharmaceutical company the ability to value price for a vaccine.

In contrast, pharmaceutical companies are able to value price for drugs. If an individual is seeking a drug for a disease, it becomes clear to the pharmaceutical company that he or she has contracted a disease. Since the pharmaceutical company acquires that knowledge, they are able to value price for drugs. The pharmaceutical company, in theory, should be able to charge the individual their exact willingness to pay for the drug, which is equal to the present value of the harm of the disease. Also, the pharmaceutical company can charge the value price to the individual each time he or she contracts the disease as the individual may not have other alternatives for curing the disease.

As a profit maximizer, the pharmaceutical company cares about producing the alternative that yields the greatest return and profit for the company. On a general level, the pharmaceutical company should be indifferent between producing a vaccine or a drug as they have equivalent effects. But, due to value pricing, the drug provides a higher price and greater revenue for the pharmaceutical company as they can extract surplus from the sick individual. In terms of producing the vaccine, the pharmaceutical company runs the risk that the number of individuals in the population that are vaccinated may be less than the profit maximizing quantity of vaccinations. Due to the externality problem associated with vaccine and the

inability to value price, the pharmaceutical company can and will realize more revenue from producing drugs.

The inability of a pharmaceutical company to value price for vaccines not only reduces the revenue that they can earn but it also reduces the amount of surplus that they can capture in the market. In the graph below, the total social surplus created by the vaccine is the area under the marginal social benefit curve above the social price (P_s). In the case of vaccines, the pharmaceutical company is not able to extract this entire surplus but they can extract the private surplus given by the area under the marginal private benefit curve above the private price.

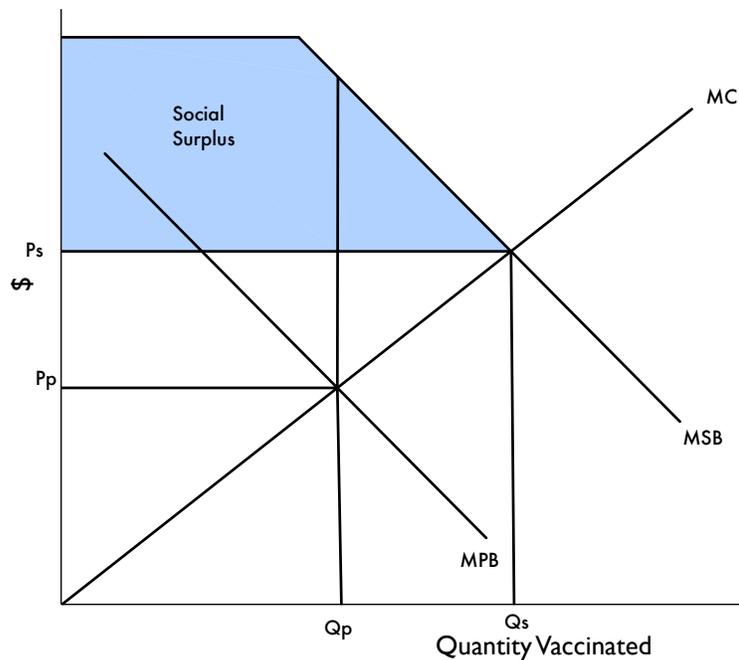


Figure 3.4: The Social Surplus Created by Vaccines

The major reason for this is that the social surplus is the indirect benefits of vaccination. The pharmaceutical company has no way to charge individuals for these benefits, as they are benefits received by individuals who are never vaccinated for the disease. The price that an individual would pay for a vaccine does not account for the entire benefits of vaccination. Any attempt by the pharmaceutical company to fully capture the indirect benefits of vaccination will drive more people into the free rider category. In the case of drugs, the price does reflect all of the benefits of the drug and the pharmaceutical company can capture the entire surplus. In short, the pharmaceutical company faces an appropriation problem for vaccines that they do not face, or do not face to the same extent, with drugs. Since the pharmaceutical company cannot value price for the vaccine and cannot capture the entire surplus due to the externality, they would favor producing an equivalent drug over a vaccine.

Heal and Kunreuther (2005) assume throughout their framework that an individual is risk neutral in considering the decision to vaccinate. However, risk aversion is an appropriate assumption here and changes the results of the model. In the subsequent section, I extend the Heal and Kunreuther (2005) model and present an example of risk aversion and how that affects an individual's vaccination decision and impacts the pharmaceutical company ability to select the appropriate price for the vaccine. Then, to address externality problem, I determine the effects of implementing a subsidy in the vaccine market.

Risk Aversion and the Market for Vaccines

The Heal and Kunreuther (2005) framework assumes that individuals are risk neutral in weighing the costs and benefits of being vaccinated. That is, individuals only consider the expected loss from contracting the disease. I do not believe that this is an appropriate assumption here because research has shown, beginning with Arrow (1965), that individuals tend to be risk averse when faced with the choice between uncertain outcomes. Risk aversion is a characterization of an individual's preference towards certainty over uncertainty. An individual is said to be risk averse if confronted with two choices that have the same expected loss, he or she prefers the option with a smaller variance. Individual decisions to purchase health insurance support this claim. In 2009, more than 85% of Americans voluntarily purchased health insurance and this is primarily due to risk aversion (Kaiser Family Foundation 2010). A vaccine can be understood as insurance against contracting a disease. Thus, risk aversion makes individuals more inclined to purchase a vaccine than to take the risk of contracting the disease.

To look at the impact of risk aversion on vaccines, consider the following numerical example under the assumption of risk neutrality. Assume that an individual's initial income is \$1000 and there is a disease outbreak. An individual has two options that are equally curative: a vaccine that prevents the individual from contracting the disease and a drug that cures the disease once it has been contracted. Absent a vaccine, one-fourth of the population contracts the disease

and if contracted, an individual experiences \$800 worth of harm. In the case of the drug, one-fourth of the population would pay \$800 because they would get sick. Therefore, the expected benefit per individual is \$200 for this drug. Equivalently, assume that the vaccine is administered to the population. Because the disease constitutes a one-fourth probability of losing \$800, the expected benefit per individual of a vaccine is \$200.

Under risk neutrality, there is a scenario where an individual would be indifferent between a vaccine and an equally curative drug as they both result in the same expected benefit to the individual. Even though this is a stylized example, it provides insight into an individual's decision to vaccinate and how much he or she would be willing to pay for the vaccine. The risk neutral assumption implies that the individual only cares about their expected benefits or losses. In the case of this example, it does not matter which alternative the individual chooses, it yields the same expected benefit. Therefore, the individual would be indifferent between the two alternatives.

How would this example be different if the individual was risk averse? A vaccine can be viewed as equivalent to actuarially fair insurance that pays for the drug if it is needed. By assumption, the vaccine is perfectly effective in preventing the individual from contracting the disease. Therefore, a risk averse individual may be more inclined to vaccinate for a disease in order to prevent the harm associated with the disease. In this case, the vaccine has a smaller variance and is a more

certain outcome than the equivalent drug. To look at how the example would change if an individual was risk averse, a utility of income model is used. Recall that the individual's initial income is \$1,000, the probability of contracting the disease is one-fourth, and the expected harm from the disease is \$800. Assume that the individual's expected utility function is given by: $U = \sqrt{Y}$.

In the absence of the vaccine, there are two possible incomes in this model: the individual does not contract the disease and is left with his or her initial income of \$1000 or the individual contracts the disease and is left with \$200 of income. The individual's expected income is given by:

$$E(Y) = \frac{1}{4}200 + \frac{3}{4}1000 = \$800$$

and the utility of the individual's expected income would be:

$$U = \sqrt{E(Y)} = \sqrt{800} = 28.28$$

The individual's expected utility is given by:

$$E(U) = \frac{1}{4}\sqrt{200} + \frac{3}{4}\sqrt{1000} = 27.25$$

Since the individual's utility of expected income is greater than the individual's expected utility, the individual is better off with his utility of expected income. This result is important in determining the certainty equivalent. The certainty equivalent is the amount of income that, if received with certainty, provides the same expected utility as the uncertain prospect. The certainty equivalent is the square of the expected utility and is given by: $CE = (27.25)^2 = \$742.71$

The graph below shows the utility of income model result.

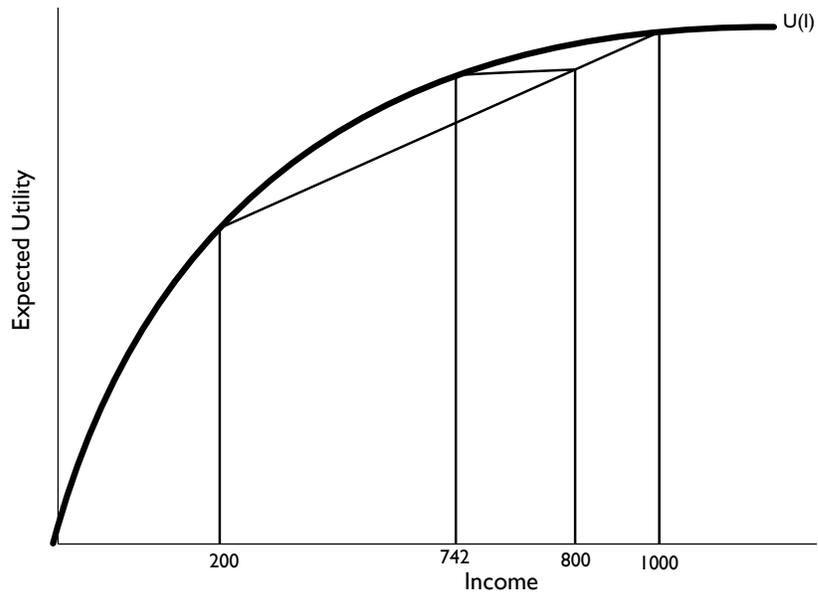


Figure 3.5: Utility of Income Model

In the case of this example, the difference between the expected income and the certainty equivalent is the additional willingness to pay for the vaccine. This implies that an individual would pay more to avoid the harm associated with contracting the disease. So, the individual would be willing to pay an additional \$57.30 for the vaccine bringing his or her expected benefit from the vaccine to \$257.30.

While this result is true for the numerical example, it generalizes to any case. A vaccine is like the equivalent drug, except that payment for the vaccine is as if an individual could buy an insurance policy that insures against the expected harm. If, instead, only the drug were available, absent separate insurance policies, individuals do not all pay the expected harm, but rather they pay the full harm but only if they are the unlucky ones who become infected. However, if actuarially fair insurance were available, individuals purchasing the policy could, in effect, convert the drug to a vaccine.

The increased expected benefit from the vaccine shows the risk averse individual's preference for the vaccine versus the risk neutral individual. Since the risk averse individual has a preference for the vaccine, he or she receives greater benefits from the vaccine than the risk neutral individual. In the context of the example, the risk neutral individual's expected benefit from the vaccine is \$200 and the risk averse individual's expected benefit from the vaccine is \$257.30. As a result, the marginal private benefit curve of the risk averse individual is greater than the marginal private benefit curve for the risk neutral individual.

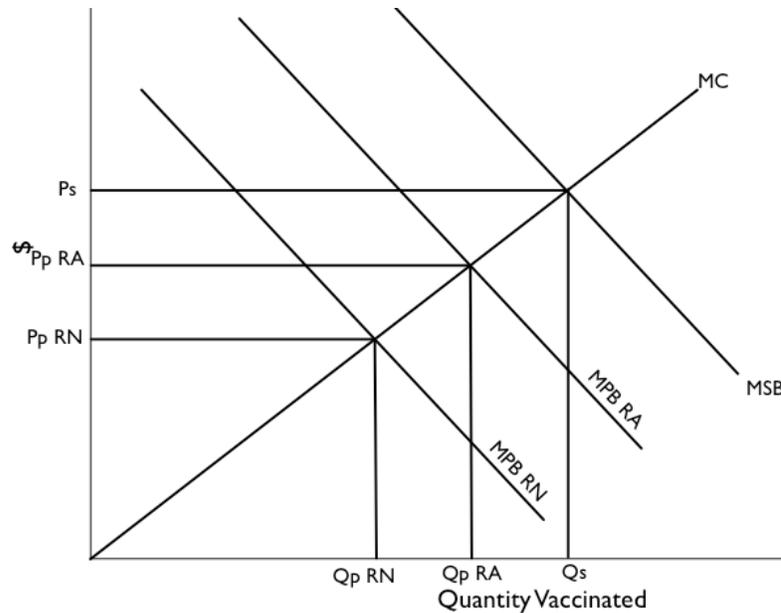


Figure 3.6: The Market for Vaccines Under Risk Aversion

Assuming that the population is risk averse impacts the implied price, quantity, and revenue that the pharmaceutical company can earn from the vaccine. Since the population is risk averse, the pharmaceutical company knows that they can charge a higher price to the population for the vaccine (this result emerges from the numerical example above). The pharmaceutical company also knows that risk aversion causes some individuals that were originally free riding on the herd immunity to actually be vaccinated. Both of these combined increase the revenue that is earned from vaccines, which could favorably impact the pharmaceutical company's return on investment and provide a stronger incentive to produce vaccines relative to drugs. So, accounting for risk aversion allows the

pharmaceutical company to more accurately estimate the demand for the vaccine and charge a higher (value) price for the vaccine than they could if the population was risk neutral. Changing the assumption from risk neutral to risk averse individuals also diminishes the implied disadvantages of vaccines for the pharmaceutical company but does not mitigate the externality.

Public Policy and the Market for Vaccines

One solution to the externality problem associated with vaccines is for the government to intervene in the market and implement some kind of public policy to encourage development of vaccines. There are two types of public policies that the government can implement in pharmaceutical markets: push or pull strategies. A push strategy, typically, is a per-unit subsidy paid to the manufacturer that addresses the supply-side issues in the market by lightening the burden of production costs. A push strategy requires the government to intervene more directly in the vaccine development process by supporting the manufacturers. A pull strategy improves demand side conditions by 'sweetening the pot' through increased demand volume or enhanced product prices. From the pharmaceutical company's point of view, push strategies improve the financial position of vaccine development (Salinsky & Werble 2006).

In the theory of public goods, the problem of under production of an item where the social benefits exceed the private benefits, a subsidy can be introduced to increase market efficiency. Assume that the vaccine market follows the Heal and

Kunreuther (2005) result (the graph on page 30). Suppose that the government introduces a producer subsidy of s dollars into the market with the goal solving the underproduction of vaccines. This policy would serve the purpose of reducing the pharmaceutical company's costs to increase the production of vaccines.

As a result of the subsidy, the deadweight loss is eliminated and a greater proportion of the population is vaccinated for the disease ($Q_s - Q_p$). But, what is the value of this subsidy s ? This subsidy is equal to the difference between the social benefits and the private benefits. That is, the subsidy is equal to the size of the indirect benefits that the vaccine creates. This is given by:

$$\text{Subsidy} = (N-k)\Delta R(k)L$$

In terms of parameters in the model, the subsidy is equal to the number of people in the population that are not vaccinated times the change in the expected loss that would occur if they were vaccinated.

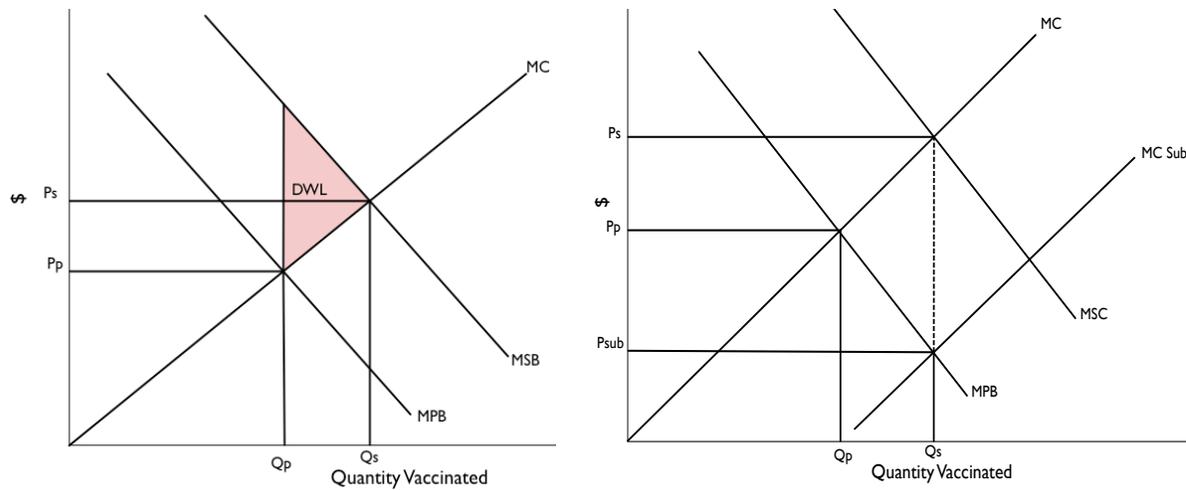


Figure 3.7: The Market for Vaccines Pre- and Post-Subsidy

The subsidy could also be thought of as a way to let the pharmaceutical company value price vaccines. Since there are indirect benefits that the pharmaceutical company cannot charge individuals for when they vaccinate, the government could, in effect, pay the pharmaceutical company the difference between the price that they would charge for the vaccine and the value price. Since, by assumption, vaccines and drugs have equivalent effects and the pharmaceutical company is able to value price for drugs, the subsidy should equal the difference between the value price of a hypothetical drug for the disease and the price of the vaccine. The market for vaccines pre- and post-subsidy is shown above.

If the subsidy is successful in reducing costs, the pharmaceutical company's revenue is affected as well. This is the result of selling more vaccines at a higher price. In the graphs below, the revenue earned for the pharmaceutical company increases from P_pQ_p (the shaded rectangle in the left graph) to P_sQ_s (the shaded rectangle in the right graph). At this level of vaccination, since the pharmaceutical company can realize more revenue, there would be a larger incentive for the pharmaceutical company to invest in vaccine development.

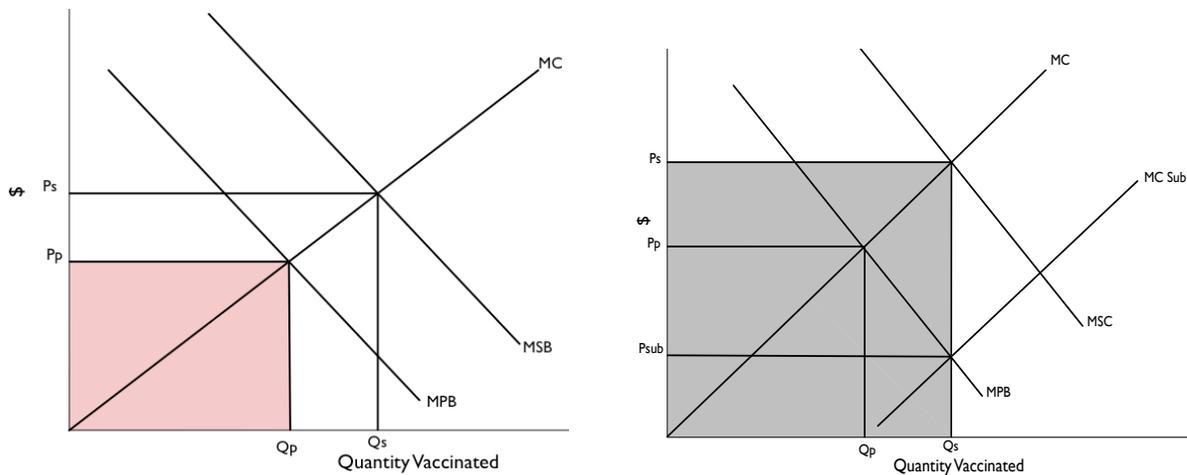


Figure 3.8: Company Revenue Pre- and Post-Subsidy

The externality problem associated with vaccines appears to be a significant barrier to vaccine production as it prevents the pharmaceutical company from value

pricing – that is, extracting the full value to a population. The pharmaceutical company cannot value price for vaccines as they can for drugs for two major reasons: not everyone is vaccinated due to herd immunity and the pharmaceutical company does not have perfect information about the population. As a result, the pharmaceutical company would prefer to produce a drug over a vaccine as they would earn more revenue by doing so. Implementing a subsidy in the vaccine market appears to be one way of solving the underproduction of vaccines and eliminating the externality.

4. Discussion

The original premise of this paper was that vaccines are a cost-effective medical intervention in the prevention of disease. They are also a mechanism that can be used to control health costs. Looking at the case of Shingles can provide support for this argument. In the United States, there is an average of one million cases of shingles diagnosed each year. An individual can be vaccinated for shingles for \$161.50 (CDC 2012) and significantly reduce his or her chance of contracting the disease and paying the health costs associated with the disease. Typical shingles health costs include treatment for a year long outbreak of shingles (\$5,000), serious complications from the disease that require hospitalization (\$20,000), and removal of precancerous lesions (\$700) (these numbers are national averages) (Associated Press 2011). So, an individual could pay \$161.50 to avoid \$25,700 worth of medical costs. This case generalizes to any disease that has a vaccine and provides a strong argument for correcting the externality problem associated with vaccines.

As I explained in this paper, value pricing is a key feature of today's pharmaceutical markets as pharmaceutical companies look to recover the large research and development costs. Pharmaceutical companies know before making their project investment decisions that the entire population will not be vaccinated due to the option of free riding on herd immunity. There is a positive relationship between value pricing and free riding as increasing the price of the vaccine (a higher degree of value pricing) leads to more free riding. The inability to value price for

vaccines due to the externality provides a strong disincentive for pharmaceutical companies to invest resources into vaccine development. This is one explanation for the fact that there are only 75 vaccines available today in the United States.

In order to solve the problem of under-utilization and under-invention of vaccines, there has to be a market intervention that allows the pharmaceutical company to receive a value price for the vaccine. By doing so leaves the pharmaceutical company indifferent between producing a vaccine and an equivalent drug since they could effectively value price for both products. Since full value pricing drives individuals to free riding, the government can intervene and pay the pharmaceutical company a per-unit subsidy. This subsidy can be thought of as a proxy for value pricing since it can be thought of as the difference in price between the value price of a hypothetical drug for the disease and the price of the vaccine. It can also be thought of as the difference in the social benefits and private benefits (the indirect benefits) and a mechanism to eliminate the externality problem associated with vaccines. Since this is a way to solve the under-utilization and under-invention problem, more diseases can have vaccines that offer an individual a cheaper option than contracting the disease and reduce his or her health costs.

The government first has to determine what type of subsidy to implement in the market. With positive externalities, there are a variety of subsidies that can be implemented that achieves a better result. Typical subsidies are research grants, direct money transfers, scholarships, and tax credits. All of these are push

strategies that impact the supply side of the vaccine market. The most popular type of subsidy implemented by the government in pharmaceutical markets is a research and development subsidy. These subsidies are aimed at funding vaccine discovery and early development efforts as they can significantly reduce the company's upfront expenditures and favorably alter the return on investment calculations.

The National Institutes of Health (NIH) sponsors approximately one-third of all vaccine related research in the United States. Their methods of distributing the money to pharmaceutical companies vary. Some money is distributed to companies through a competitive application process while government grants are also given to fund research and development projects in universities. Federally supported vaccine research and development typically focuses on basic research and vaccine discovery. Another method of subsidizing the vaccine market is offering tax credits to pharmaceutical companies that undertake certain types of research projects (Salinsky & Werble 2006).

Benefits of Implementing a Subsidy

In order to determine if this is a good policy, the benefits and costs have to be analyzed. The major benefits of implementing the subsidy are an increased proportion of individuals vaccinated and the individuals vaccinated pay for all of the indirect benefits the community receives. An increase in the proportion of individuals vaccinated benefits both society and the pharmaceutical company. As the proportion increases, the probability of transmitting the disease, rp_i , in the

model decreases. This decreased probability of transmitting the disease corresponds to a decreased probability that a person experiences the harm associated with the disease. Therefore, if a larger proportion of the population is getting vaccinated and avoids paying the full harm of the disease, health costs can be reduced.

The increased proportion of the population that is vaccinated as a result of the subsidy provides the pharmaceutical company two new sources of revenue. First, the pharmaceutical company receives revenue from the government through a grant or a tax credit. This revenue goes towards reducing the costs and the risk during the research and development phase of vaccine development. Second, the company receives additional revenue through increased sales at a higher price. These new sources of revenue could provide a stronger return on investment for the pharmaceutical company and a larger incentive for investing in vaccine development and manufacturing.

The other major benefit of subsidizing vaccines is that the externality is eliminated and that all the individuals vaccinated pay for the indirect benefits associated with vaccinations. The Heal and Kunreuther (2005) model determines that the proportion of the population that is vaccinated will be less than 100 percent and the socially optimal level. Therefore, there is a group of individuals that is receiving the benefits of vaccination but that group is not paying the cost of vaccination. If the government introduces a subsidy, there is an incentive for more

people to be vaccinated. As a result, the individuals that were free riding off the herd immunity will be enticed to be vaccinated as well and pay for the benefits they were receiving.

Costs of Implementing a Subsidy

There is one major drawback of implementing a subsidy in any market and that is paying for it. Subsidies require paying money to the pharmaceutical company up front to reduce costs and increase research and development and manufacturing of vaccines. The government has three options for paying for a subsidy: move money from another initiative or program, raise taxes to offset the cost of the subsidy, or borrow money to pay for the subsidy. The most common tactic for funding a subsidy is raising taxes.

How Large a Subsidy?

Today, the vaccine industry is one of the most heavily subsidized industries in the United States. Pharmaceutical subsidies accomplish two major goals: to encourage pharmaceutical companies to undertake vaccine development projects and to increase the proportion of the population that is vaccinated. What is the optimal size of the subsidy in order to influence the market? Determining the optimal subsidy size was the subject of Cook et al. (2009). First, their framework determines the appropriate way to measure the private and social benefits of vaccination. They also depict the optimal subsidy policy graphically in the face of the externality problem associated with vaccines. They apply their framework to

study the indirect effects of the cholera vaccine in Kolkata, India. This framework approximates the optimal subsidy given economic and epidemiological data. They determine that the optimal subsidy is less than one dollar per vaccine and can provide more than one dollar worth of benefits to the community. They also find that if the optimal subsidy is unknown, selling the vaccines at a price equal to marginal cost may be preferred to providing the vaccines for free. This is true because when vaccines are sold at their marginal cost, there is sufficient private demand to reach some critical level of coverage that confers a large indirect protection to the remainder of the population (Cook et al 2009).

Cook et al. (2009) touts this paper as different from traditional economics papers that focus on the theoretical aspects of vaccines and externalities. Their empirical approach offers an opportunity to test the economic theories about vaccines and subsidies. Given that a subsidy appears to be a way to fully eliminate the externality, their model can be used to further study the effects of subsidies on the development and selling of vaccines in the United States. Further research is also needed to determine if the subsidy amount varies depending on the assumption made about an individual's risk tolerance. Finally, further research is also needed to determine the magnitude of savings in health costs as a result of subsidizing pharmaceutical companies that produce vaccines.

REFERENCES

- Anderson, Roy M., and Robert M. May. *Infectious Diseases For Humans: Dynamics and Control*. Oxford UP, 1992. Print.
- Armstrong, Edward. "Economic Benefits and Costs Associated With Target Vaccinations." *Journal of Managed Care Pharmacy* 13.7 (2007): S12-15. *Academy of Managed Care Pharmacy*. 13 Sept. 2007. Web. 17 Nov. 2011. <<http://www.amcp.org/data/jmcp/pages%2012-15.pdf>>.
- Arrow, Kenneth J. *Aspects of the Theory of Risk Bearing*. Helsinki, Yrjö Jahnssonin Säätiö, 1965. Print.
- Associated Press. "Adult Vaccines Can Prevent Future Health Costs." *USATODAY.COM*. 7 June 2011. Web. 01 Apr. 2012. <<http://yourlife.usatoday.com/health/healthcare/story/2011/06/Adult-vaccines-can-prevent-future-health-costs---/48146592/1>>.
- Barrett, Scott. "Global Disease Eradication." *Working Paper*. John Hopkins School of Advanced International Affairs, 2003.
- Bauch, Chris T., and David J. Earn. "Vaccination and the Theory of Games." *National Academy of Sciences* 101.36 (2004): 13391-3394. 7 Sept. 2004. Web. 20 Dec. 2011. <<http://www.ncbi.nlm.nih.gov/pmc/articles/PMC516577/>>.

Boffey, Philip M. "Vaccine Liability Threatens Supplies." *The New York Times*. The New York Times, 26 June 1984. Web. 1 Apr. 2012.

<<http://www.nytimes.com/1984/06/26/science/vaccine-liability-threatens-supplies.html?pagewanted=all>>.

Bootman, J. L., Townsend, Raymond J., and William F. McGhan. *Principles of Pharmacoeconomics*. By J. L. Bootman. 3rd ed. Harvey Whitney. 1-17. 30 July 2004. Web. 1 Feb. 2012.

<<http://www.hwbooks.com/pharmacoeconomics3ed/chp1.pdf>>.

Brito, Dagobert L., Eytan Sheshinski, and Michael D. Intriligator. "Externalities and Compulsory Vaccinations." *Journal of Public Economics* 45 (1991): 69-90. 1 Apr. 2002. Web. 18 Jan. 2012.

<<http://www.sciencedirect.com/science/article/pii/0047272791900487>>.

CDC. "CDC Vaccine Price List." *US Center for Disease Control*. 1 Feb. 2012. Web. 3 Mar. 2012. <<http://www.cdc.gov/vaccines/programs/vfc/cdc-vac-price-list.htm>>.

CDC. "State-Specific Influenza Vaccination Coverage Among Adults Aged 18 Years." *US Center for Disease Control*. 21 Sept. 2007. Web. 15 Mar. 2012.

<<http://www.cdc.gov/mmwr/preview/mmwrhtml/mm5637a1.htm>>.

- Cockburn, Iain, and Rebecca Henderson. "Scale and Scope in Drug Development: Unpacking the Advantages of Size in Pharmaceutical Research." *Journal of Health Economics* 20.6 (2001): 1033-057. 1 Nov. 2001. Web. 28 Jan. 2012. <<http://www.sciencedirect.com/science/article/pii/S0167629601001084>>.
- Coffin, Susan E. and Nelson, Robert M. "Optimizing Risks and Benefits: The Case of Rotavirus Vaccine." *Ethics and Research With Children: A Case-Based Approach*. By Susan E. Coffin. Oxford UP, 2005. 46-62. Print.
- Cook, J., M. Jeuland, B. Maskery, D. Lauria, D. Sur, J. Clemens, and D. Whittington. "Using Private Demand Studies to Calculate Socially Optimal Vaccine Subsidies in Developing Countries." *Journal of Policy Analysis and Management* 28.1 (2009): 6-28. 8 Dec. 2009. Web. 12 Dec. 2011. <<http://www.ncbi.nlm.nih.gov/pubmed/19090047>>.
- Cullity, Garrett. "Moral Free Riding." *Philosophy and Public Affairs* 24.1 (1995): 3-34. 1 Nov. 1995. Web. 30 Dec. 2011. <<http://onlinelibrary.wiley.com/doi/10.1111/j.1088-4963.1995.tb00020.x/abstract>>.
- "Evaluate Pharma Analysis." *EvaluatePharma - Pharma and Biotech Commercial Insight*. 10 Mar. 2012. Web. 2 Apr. 2012. <<http://www.evaluatepharma.com/>>.

- FDA. "Is It True FDA Is Approving Fewer New Drugs Lately?" *Food and Drug Administration*. 12 Dec. 2010. Web. 13 Jan. 2012.
<<http://www.fda.gov/downloads/AboutFDA/Transparency/Basics/UCM247465.pdf>>.
- FDA. "Text of the Prescription Drug Marketing Act of 1987." *US Food and Drug Administration*. 1 Mar. 2010. Web. 12 Feb. 2012.
<<http://www.fda.gov/RegulatoryInformation/Legislation/FederalFoodDrugandCosmeticActFDCAct/SignificantAmendmentstotheFDCAct/PrescriptionDrugMarketingActof1987/ucm201702.htm>>.
- FDA. "Vaccine Safety Questions and Answers." *US Food and Drug Administration*. 23 Oct. 2009. Web. 12 Feb. 2012.
<<http://www.fda.gov/BiologicsBloodVaccines/SafetyAvailability/VaccineSafety/ucm133806.htm>>.
- Fine, Paul M., and Jacqueline A. Clarkson. "Individual Versus Public Priorities in the Determination of Optimal Vaccination Policies." *American Journal of Epidemiology* 124.6 (1986): 1012-020. 12 Sept. 1985. Web. 1 Feb. 2012.
<<http://aje.oxfordjournals.org/content/124/6/1012>>.
- Francis, Peter J. "Dynamic Epidemiology and the Market for Vaccinations." *Journal of Public Economics* 63.3 (1997): 383-406. 3 Feb. 1997. Web. 12 Jan. 2012.
<<http://ideas.repec.org/a/eee/pubeco/v63y1997i3p383-406.html>>.

Geoffrard, Pierre-Yves, and Tomas Phillipson. "Disease Eradication: Private vs. Public Vaccination." *American Economic Review* 87.1 (1997): 222-30. 1 Mar. 1997. Web. 18 Jan. 2012. <<http://ideas.repec.org/a/aea/aecrev/v87y1997i1p222-30.html>>.

Gersovitz, Mark, and Jeffrey Hammer. "The Economic Control of Infectious Diseases." *Economic Journal* 114 (2004): 1-27. 31 May 2001. Web. 21 Jan. 2012. <<http://ideas.repec.org/p/wbk/wbrwps/2607.html>>.

Grabowski, Henry and Kyle, Margaret. "Mergers and Alliances in Pharmaceuticals: Effects on Innovation and R&D Productivity." *The Economics of Corporate Governance and Mergers*. By Henry Grabowski. UK: Edward Elgar, 2008. 262-87. 1 July 2008. Web. 1 Feb. 2012. <<http://margaretkyle.net/G-K%20Merger%20chapter.pdf>>.

Heal, Geoffrey, and Howard Kunreuther. "The Vaccination Game." *Wharton School of Business*. 25 Jan. 2005. Web. 20 Dec. 2011. <<http://opim.wharton.upenn.edu/risk/downloads/05-10-HK.pdf>>.

Health Resources and Services Administration. "National Vaccine Injury Compensation Program." *National Vaccine Injury Compensation Program*. 12 Mar. 2011. Web. 1 Apr. 2012. <<http://www.hrsa.gov/vaccinecompensation/index.html>>.

Helland, Eric, Darius Lakdawalla, Anup Malani, and Seth Seabury. "Tort Liability and the Market for Prescription Drugs." *University of Chicago Economics*. 10 Oct. 2010. Web. 1 Feb. 2012.

<http://economics.uchicago.edu/pdf/Malani%20_101110.pdf>.

Herper, Matthew. "The Truly Staggering Cost Of Inventing New Drugs." *Forbes Magazines* 10 Feb. 2012. 10 Feb. 2012. Web.

<<http://www.forbes.com/sites/matthewherper/2012/02/10/the-truly-staggering-cost-of-inventing-new-drugs/2/>>.

Hershey, John, David Asch, Thi Thumasathit, Jacqueline Meszaros, and Victor Walters. "The Roles of Altruism, Free Riding, and Bandwagoning in Vaccination Decisions." *Organizational Behavior and Human Decision Processes* 59.2 (1994): 177-87. 9 Aug. 1992. Web. 15 Jan. 2012.

<<http://www.sciencedirect.com/science/article/pii/S0749597884710557>>.

Higgins, Matthew J., and Daniel Rodriguez. "The Outsourcing of R&D Through Acquisition in the Pharmaceutical Industry." *Journal of Financial Economics* 80 (2006): 351-83. 27 Feb. 2005. Web. 30 Jan. 2012.

<http://smartech.gatech.edu/xmlui/bitstream/handle/1853/10736/gt_tiger_outsourcing.pdf?sequence=1>.

Kaiser Family Foundation. "Health Care Costs Primer: Key Information on Health Care Costs and Their Impact." *Henry J. Kaiser Family Foundation*. 1 Mar. 2009. Web. 12 Aug. 2011.
<http://www.kff.org/insurance/upload/7670_02.pdf>.

Kaiser Family Foundation. "Survey of People who Purchase Their Own Health Insurance." *Henry J. Kaiser Family Foundation*. 1. June 2010. Web. 10 March 2012. <<http://www.kff.org/kaiserpolls/upload/8077-r.pdf>>.

Lu, John, and William S. Comanor. "Strategic Pricing of New Pharmaceuticals." *The Review of Economics and Statistics* 80.1 (1998): 108-18. 12 Feb. 1998. Web. 4 Mar. 2012.
<<http://www.mitpressjournals.org/doi/abs/10.1162/003465398557212>>.

Manning, Richard L. "Changing Rules in Tort Law and the Market for Childhood Vaccines." *Journal of Law and Economics* 37.1 (1994): 247-75. *Journal of Law and Economics*. 1 Apr. 1994. Web. 10 Jan. 2012.
<<http://www.jstor.org/stable/725611>>.

Offit, Paul A. "Why Are Pharmaceutical Companies Gradually Abandoning Vaccines?" *Health Affairs* 24.3 (2005): 622-30. *Health Affairs*. 5 Mar. 2005. Web. 10 Oct. 2011. <<http://content.healthaffairs.org/content/24/3/622.full>>.

Prifti, Christine. "The Vaccine Industry - An Overview." *Vaccine Ethics*. 1 July 2010. Web. 1 Feb. 2012.
<http://www.vaccineethics.org/issue_briefs/industry.php>.

- Rappuoli, Rino, Henry I. Miller, and Stanley Falkow. "The Intangible Value of Vaccination." *Science Magazine*. 9 Aug. 2002. Web. 12 Aug. 2011.
<<http://www.sciencemag.org/content/297/5583/937.full>>.
- Salinsky, Eileen, and Cole Werble. "The Vaccine Industry: Does It Need a Shot in the Arm?" *National Health Policy Forum*. 25 Jan. 2006. Web. 12 Nov. 2011.
<<http://www.nhpf.org/library/details.cfm/2506>>.
- Scherer, F. M. "The Pharmaceutical Industry: Prices and Progress." *New England Journal of Medicine* 351.9 (2004): 927-32. 26 Aug. 2004. Web. 13 Mar. 2012.
<<http://www.nejm.org/doi/pdf/10.1056/NEJMhpr040117>>.
- Seymour, Jane. "Eradicating Smallpox." *Center for Global Development*. 27 Sept. 2007. Web. 4 Dec. 2011.
<http://www.cgdev.org/doc/millions/MS_case_1.pdf>.
- Stiglitz, Joseph E., Edlin, Aaron S., and J. B. DeLong. "Advance Market Commitments." *The Economists' Voice: Top Economics Take on Today's Problems*. By Joseph E. Stiglitz. New York City: Columbia UP, 2011. 58-59.
Print.