Economic Benefit of Research

Interactive Qualifying Project submitted in partial fulfillment of the

Bachelor of Science Degree Requirements

Worcester Polytechnic Institute

Worcester, MA

Corey Adams

Chris Barnes

Submitted to:
Professor Joseph C. Bagshaw
Department of Biology
D01
IQP 4900

ECONOMIC VALUE OF RESEARCH

INTRODUCTION

In this paper we will investigate the economic benefits that can arise unexpectedly as a result of basic scientific research. The specific example that we will be studying is that of the permanent wave, particularly its annual contribution to the Gross National Product (GNP). The ability to put permanent waves in hair was discovered accidentally through basic research of the protein keratin. Since it's discovery the permanent wave has become an incredibly popular beauty accessory resulting in a significant contribution to our economy. None of this would have been possible without the basic research that led to its discovery.

Basic research has become increasingly unpopular and under funded throughout the years since the discovery of the perm. The basis behind the drop in basic research is due to the advances in technology and science that have occurred in recent history. As a result of the tremendous progress made, both science and research have become more precise. This has led to an increase in financial support for directed research, or projects that are meant to solve a particular problem. This increase has resulted in basic research becoming under funded, which reduces the chance of unexpected economic benefits.

The initial approach of this project was to explore the relationship between the amount of GNP that the permanent wave generates every year and the budget of the National Institute of Health (NIH). Specifically, it has been rumored that the annual economic contribution of the perm is greater than the total amount of NIH-funded research since its creation after World War II. The method that we used to investigate this issue consisted of contacting several major beauty companies that produce permanent wave products and inquiring their annual GNP and the percentage of that which results from the perm products. We then compared the information that the companies gave us to the annual budget of the NIH, which is readily available to the general public.

HAIR STRUCTURE

Hair is composed primarily of proteins (88%). These proteins are of a hard fibrous type known as keratin. Keratin protein is comprised of what we call "polypeptide chains." The word, polypeptide, comes from the Greek word "poly" meaning many and "peptos" meaning digested or broken down. In essence, if we break down protein, we have individual amino acids. Many (poly) amino acids joined together form a "polypeptide chain". Two amino acids are joined together by a "peptide bond", and the correct number of amino acids placed in their correct order will form a specific protein; i.e. keratin, insulin, collagen and so on. The "alpha helix" is the descriptive term given to the secondary structure of the polypeptide chain that forms the keratin protein found in human hair. Keratin molecules form a coiled coil. The amino acids link together to form the coil and there are approximately 3.6 amino acids per turn of the helix (coil). Each amino acid is connected together by a "peptide bond". The peptide bond is located between the carbon atom of one amino acid extending to bond with the nitrogen atom of the next amino acid.

In the organization of a single hair, three alpha helices are twisted together to form a "protofibril". This is actually the first fibril structure of the hair. Nine protofibrils are then bundled in a circle around two or more to form an eleven-stranded cable known as the "microfibril". These microfibrils are embedded in an amphorous unorganized protein matrix of high sulfur content, and hundreds of such microfibrils are cemented into an irregular fibrous bundle called a "macrofibril".

These macrofibrils are grouped together to form the cortex (or the main body) layers of the hair fiber. Packed dead cells surround these structures and are known as the cuticular layers of the hair. In the center of these structures lies the medullary canal, which is actually apart of the excretory system and houses any foreign debris, heavy metals, synthetics and medications that are thrown off by the body and eventually released through the canal.

BONDING IN KERATIN PROTEIN

When the hair is in its normal unstretched state, it is referred to as alpha keratin. The original configuration of the hair is held in place by the bonding found in the cortex layers of the hair. As stated earlier, keratin protein begins with an alpha helix building into protofibrils, microfibrils, macrofibrils, then cortex layers. The bonds in hair are located within each alpha helix.

The first bond we will discuss is the hydrogen bond. This bond is located between the coils of the alpha helix and is responsible for the ability of the hair to be stretched (elasticity) and return back to its original shape. The hydrogen bonds enable us to change the shape of the hair temporarily with the aid of water. These bonds are electrolytically controlled and are the most readily broken down and the most readily reformed. These bonds are responsible for approximately 35% of the strength of the hair and 50% of the hair's elasticity (some would argue up to 99.9% of the hair's elasticity).

The salt bond is also an ionic (electrolytically controlled) bond formed by the electron transfer from the side chain of an acidic amino group (an amino acid with an OOC- group) to the side chain of a basic amino acid, i.e. NH3+. (This is two positive and negative charges attracting one another.) This occurs in a position parallel to the axis of the helix of the hair. The salt bond is responsible for approximately 35% of the strength of the hair and 50% of the hair's elasticity.

The cystine bond also known as the disulfide bond, is formed by cross-links between cysteine residues (amino acids) of the main polypeptide chains. This bond is perpendicular to the axis of the hair and between the polypeptide chains. Because of its position in the hair, it is responsible for the hair's toughness or abrasion resistance. (It actually holds the hair fibers together.)

These cross-links are frequent in the hair fiber, with maximum of frequency of one cystine bond every four turns of the alpha helix. This is what enables the modern form of the permanent wave.

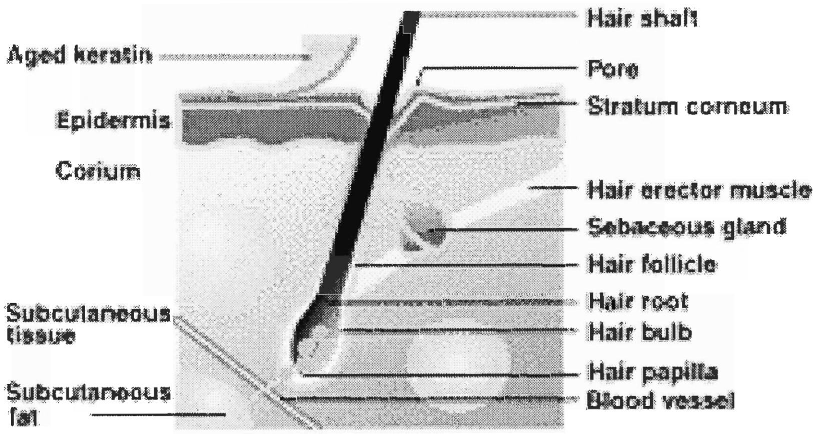


Figure 1. The Structure of Hair

HISTORY OF PERMANENT WAVES

Attempts at putting permanent waves in hair go back to early civilization. Egyptian and Roman women attempted to “perm” their hair by applying a mixture of soil and water, wrapping it on primitive wooden rollers, and then baking it in the sun. Obviously it didn’t work very well. In 1905 Charles Nessler invented a heavily wired machine that supplied electrical current to metal rods around which hair strands were wrapped. These heavy units were heated during the perming process. They were kept from touching the scalp by a complex system of counterbalancing weights, suspended from an overhead chandelier mounted on a stand. When the hair strands were wrapped around the metal units, two methods were used. The first technique was called *spiral wrapping* and it involved winding hair that was long from the scalp to the ends. The second technique called the *croquignole* was introduced after World War II when women began to cut their hair into the short "bobbed" style. This involved winding shorter hair from the ends toward the scalp.

The idea of being hooked up to an electrical contraption and possibly receiving a shock or burn that led to the development of alternative methods of curling or straightening hair 'permanently'. In 1931, the *pre-heat* method of perming was introduced. Hair was wrapped using the croquignole method, and then clamps, pre-heated by a separate electrical unit, were placed over the wound curls. An alternative to the electrical machine perm was introduced in 1932 when chemists Ralph L. Evans and Everett G. McDonough pioneered a method that used external heat generated by chemical reaction. Small, flexible pads containing a chemical mixture were wound around hair strands. When the pads were moistened with water, chemical heat was released into the hair that created long lasting curls. Thus, the first machine free permanent wave was born.

CHEMISTRY OF THE MODERN PERM

There are numerous bonds formed between keratin molecules in cystine, and the most important are disulfide and hydrogen bonds. When hair is wet, water molecules will sneak into the protein molecules of the hair and bond with the hydrogen and oxygen atoms. In the wet hair, most of the protein molecules aren't bonded together; instead they are both bonded to a water molecule, which is bonded to another water molecule, which is bonded with a protein, and so on. This structure is much less durable than normal proteins that are bonded directly to one another, which is why wet hair is easier to shape than dry hair. Anyway when the hair dries, the water leaves its bonds with protein molecules, which will in turn form bonds between oxygen and hydrogen atoms in whatever shape they were in before. This is why people try to curl or straighten their hair when it is wet. The only problem with this technique is that when the hair gets wet again, the hydrogen bonds break with the addition of water, and the hair reverts to its original shape. A permanent wave is called 'permanent' because it forms disulfide bonds between the protein molecules, and these bonds will not break when exposed to water.

In the 1930's scientists discovered a new method of permanent waving. They developed the waving lotion, a liquid that softens and expands the hair strand. After the waving lotion has done its work, another lotion called a neutralizer is applied. The neutralizer hardens and shrinks that hair strand, allowing it to conform to the shape of the rod around which the hair is wrapped. It also stops the action of the waving lotion. Because this perm does not use heat, it is called a "cold wave." Cold waves replaced virtually all predecessors and competitors, and cold waving and permanent waving became almost synonymous terms. Modern versions of cold waves are usually referred to as alkaline perms.

David Goddard first discovered the permanent wave in the 1930's. Goddard was a research biologist who was interested in protein structure and was awarded a National Research Council fellowship at the Rockefeller Institute in New York to study protein. There he worked with another scientist, Leonor Michaelis, who had been the first to ascertain that organic compounds were oxidized in single electron steps, also called semiquinones. These two scientists then began their investigation into the composition of different protein molecules, and particularly keratin.

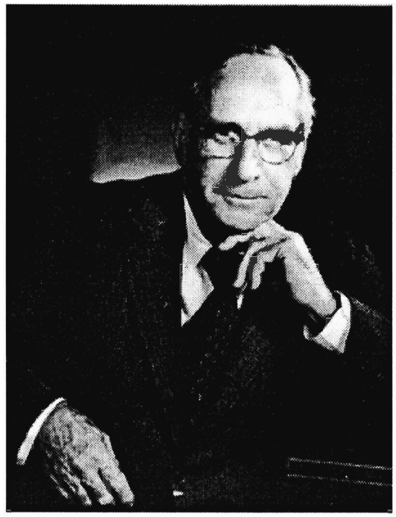


Figure 2. David Goddard.

Although the two scientists were working together, Goddard was the one that discovered that the protein keratin could be dissolved using agents that broke the bonds that hold it together. Before Goddard and Michaelis, little was known about the structure of keratin, other than that it can not normally be dissolved by the usual protein solvents, and that it was high in the amino acid cysteine.

Goddard and Michaelis discovered in 1934 that the disulfide bonds that hold together cysteine, and in turn keratin itself, as well as give hair its basic structure, can be broken using reducing agents such as thioglycolic acid or sodium sulfide. The reaction itself occurs as follows:

$$2\,H^{+} + R*S*S*R * 2\,R*SH$$

and this changes the keratin proteins that had been basically inert into a chemically and biologically reactive form. Goddard and Michaelis and published their discovery in 1934 under the name *A Study on Keratin.* Since then it has been found that many thiol compounds can also dissolve disulfide bonds, and one of those thiols is almost always the basic reactive agent for permanent wave solutions.

Goddard and Michaelis discovered the next year that after keratin had been dissolved it could be reformed using oxidizing agents. This meant that the natural structure of hair could be broken by soaking it in reducing agents, and that hair could then be set up into a different formation while the bonds were still dissolved. The keratin molecules could then be oxidized again, after which the bonds would reform leaving the protein structure in a new, 'permanent' shape. This is the basic process that occurs in any permanent wave given today. Although many of his colleagues advised Goddard to patent his discovery in order to profit from it, he decided against patenting it because he was only interested in the scientific ramifications of his findings regarding protein structures. This might be one of the reasons why Goddard isn't as famous as he would have been if he had used his invention to found a cosmetics company or sold it an existing beauty products company to make a profit.

Perms are available today in many different formulas for a wide variety of hair types. Waving lotions and neutralizers for both acid-balanced and alkaline perms are being formulated with new conditioners, proteins, and natural ingredients that help protect and condition the hair during and after perming.

Stop action processing is included in many waving lotions to ensure optimum curl development. The curling takes place within a fixed time without the risk of over processing or damaging the hair. The main active ingredient or *reducing agent* in alkaline perms, *ammonium thioglycolate,* is a chemical compound made up of ammonia and thioglycolic acid. Because the lotion is more alkaline, the cuticle layers swell slightly open, allowing the solution to penetrate more quickly than acid-balanced lotions. Some alkaline perms are wrapped with waving lotion, others with water. Some require a plastic cap for processing others do not. The benefits of alkaline perms consist of stronger curl patterns, fast processing time and room temperature processing. Neutralizers for the alkaline perm have to function to permanently establish the new curl shape. Neutralizing is a very important step in the perming process. If the hair is not properly neutralized, the curl will relax or straighten within one to two shampooings. Generally, today's neutralizers are composed of a relatively small percentage of hydrogen peroxide, an oxidizing agent, at an acidic pH.

In order to reduce the disulfide bonds a reducing agent must be used, such as ammonium thiodiglycolate or glycerylmonothioglycolate. When using ammonium thiodiglycolate, two thiodiglycolate molecules combine with the sulfur atoms that form the disulfide bond, thus creating cysteine (which is one of the twenty major amino acids) and releasing two hydrogen atoms. A picture of the molecular structure of cysteine is shown below.

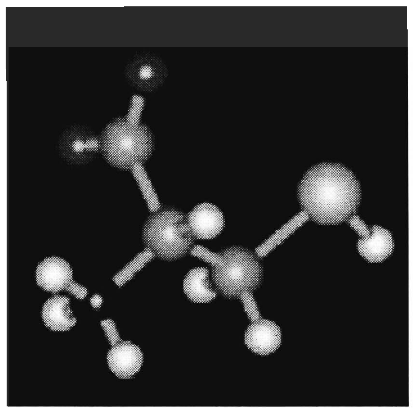
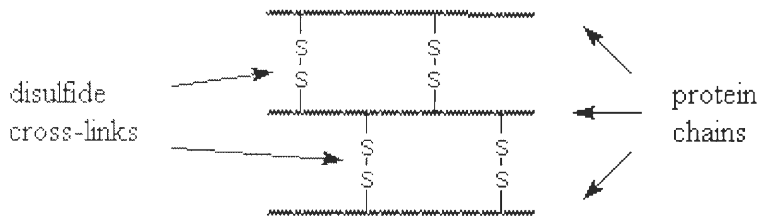


Figure 3. Molecular Structure of Cysteine.

The formation of cysteine and the changing of the two thioglycolate molecules into dithiodiglycolate now take place. At this point, the dithiodiglycolate will readily accept the return of the hydrogen it released. But, if there is an excess of thiodiglycolate present the cystine bond will remain broken and allow the polypeptide chains to slip along side one another in response to the pressure placed on them by wrapping them around a perm rod. In order to stop the reducing process, there must be an excess amount of thiodiglycolate on the hair for it to process. Therefore, all that is needed to stop the reducing action is to rinse the rods with water. With an acid wave it is very important to rinse well as the solution is not compatible with the neutralizer.

If the neutralizer is applied on top of the lotion the rods will become hot. Neutralizing solution contains the oxidizing agent hydrogen peroxide or sodium bromate. The oxidizing agent releases oxygen in the hair. This combines with the hydrogen of the cysteine to form water, as well as a new cysteine bond. Allowing oxygen in the atmosphere to neutralize the perm and reform the cysteine bonds is important. This process reforms the cysteine more slowly and completely because the hair is allowed to shrink and the cysteine bonds are brought back together naturally. It also eliminates the fear of over oxidation. To be effective, hair must dry naturally and slowly on the rods for twenty-four hours.

Overall, the chemistry of permanent waves is straightforward. As we know hair is made of keratin, a protein that contains a lot of the amino acid cystine. The amino acid cystine can form disulfide bonds between protein chains. A disulfide bond is a bond between two sulfur atoms and disulfide bonds cross-link the protein strands in a hair, causing it to hold its shape. The cross-links look something like this:



A permanent wave treatment has three steps:

1. Break the disulfide bonds with a reducing agent.

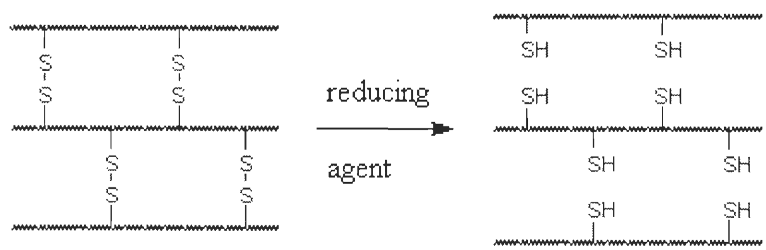


Figure 4. Three steps of Permanent Wave treatment.

2. Shape the hair into the desired configurations, usually with curlers; the size of the curler will determine the tightness of the resulting curl.
3. Reform the disulfide bonds in new positions, using an oxidizing agent.

RESEARCH SUPPORT

In order to conduct the research that led to the discovery of the permanent wave, David Goddard had to apply to an outside organization to fund and support his living expenses and experiments. He was awarded a National Research Council (NRC) fellowship in 1933 to help him with his research. The National Research Council was founded in 1916 by the National Academies of Science (NAS) to help provide the scientific and technological advice the US Government would need in anticipation of its entry into World War I. Although the NRC was established only because of war, it continued its operation after 1918 because of the many successful discoveries and innovations for which it was responsible. Since 1919, the NRC has established and preserved a continuous, mostly cooperative organization in which the concerns of the different fields of the scientific and technical community are discussed, and provided leadership towards solving specific problems. Since then the NRC has grown exponentially, as it now comprises of about 1000 subcommittees and approximately 10,000 members, and it has helped thousands of scientists make important discoveries. Most of these committees are appointed in response to a specific request from a government agency or independent company. Scientists typically spend about 2 years on average evaluating a scientific or technical topic and conducting research before offering their findings in a written report. In addition to its advisory services, the NRC also helps by contributing to building our country's scientific and technical network. The NAS and NRC have sponsored fellowship programs, helped strengthen industrial research, established foreign scientific organizations, and operated international scientific exchange programs.

The government does not directly fund the NRC itself, but it does help to distribute research grants from federal agencies to any members that might need them during their research. This is the reason the NRC has been criticized in recent years, as it has been forced to rely on some biotechnology corporations and federal agencies to fund the operations of the committee itself. This has led to accusations of the NRC putting its benefactors' interests before those of the general public, which the NRC was founded to serve.

The other main organization in this country that was founded to help scientists conduct biomedical research is the National Institute of Health, or NIH. Unlike the NRC, the NIH was founded to make advances solely in scientific fields directly relating to human health and medicine, and it is funded directly by the US Congress. The NIH was founded in 1887 as a one-room laboratory within the Marine Hospital Service (MHS), with only one full time member, Joseph J. Kinyon, and it was actually named the Hygienic Laboratory. As Kinyon made several discoveries that helped cure or limit diseases, the Hygienic Laboratory began to grow in size, and was responsible for the sanitation at and around military bases during World War I. In 1930, the Ransdell Act officially changed the organization's name to the National Institute of Health. This marked a change in US science history, as it was the first time a major research organization existed funded solely by the US government, as well as the first time the scientific community in the US accepted government funded research projects.

During the 1930's the NIH grew every year, and when the US entered World War II, the NIH was given a number of war-related tasks to solve. The NIH proved equal to the task, as it was successful in developing new vaccines and other innovations that helped the US armed forces. The NIH was so successful, in fact, at the end of World War II that it was widely recognized that the NIH had proved to be one of the deciding factors in the struggle. Congress passed the 1944 Public Health Service Act, which defined the shape of medical research in the post-war world. The Public Health Services Act moved the National Cancer Institute (NCI), which had been created in 1937, under the control of the NIH, and increased the total amount of public funding that the NIH received. Putting the NCI under the control of the NIH established the NIH as a governing body for a number of new government-funded research institutes dedicated to solving particular health related problems, such as mental health, dental diseases, and heart disease. The early organization of the NIH is shown below.

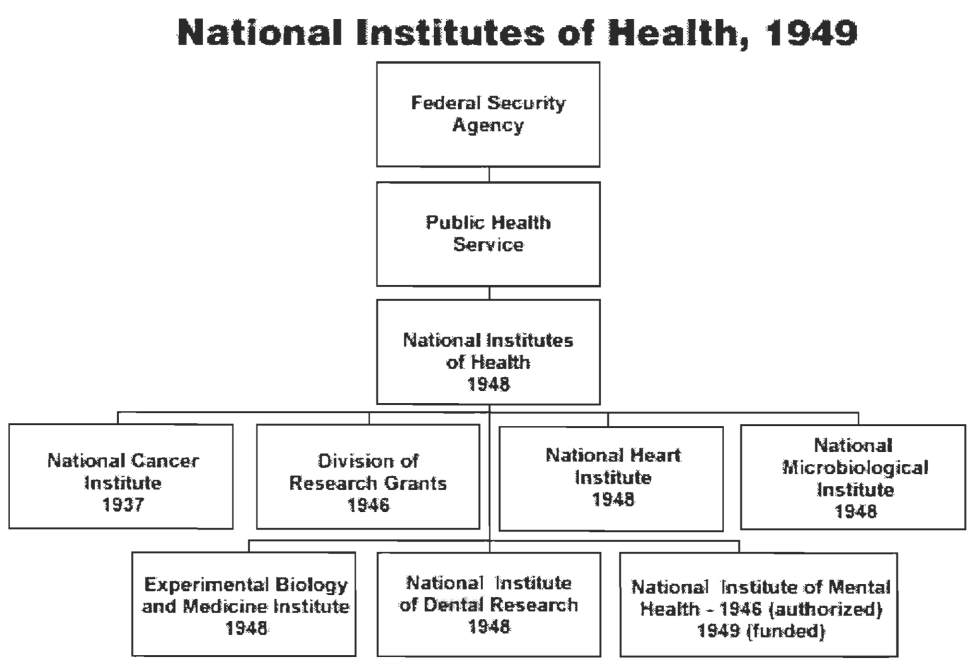


Figure 5. Organization of the NIH in 1949.

Also, the budget began growing quickly. It increased from just over $4 million in 1947, to more than $100 million in

1957, and $1 billion in 1974. The entire NIH budget expanded from $8 million in 1947 to more than $1 billion in 1966. Below is a graph showing the increase in funding for the NIH since 1950, when it became the largest research funding body in the United States, to the present:

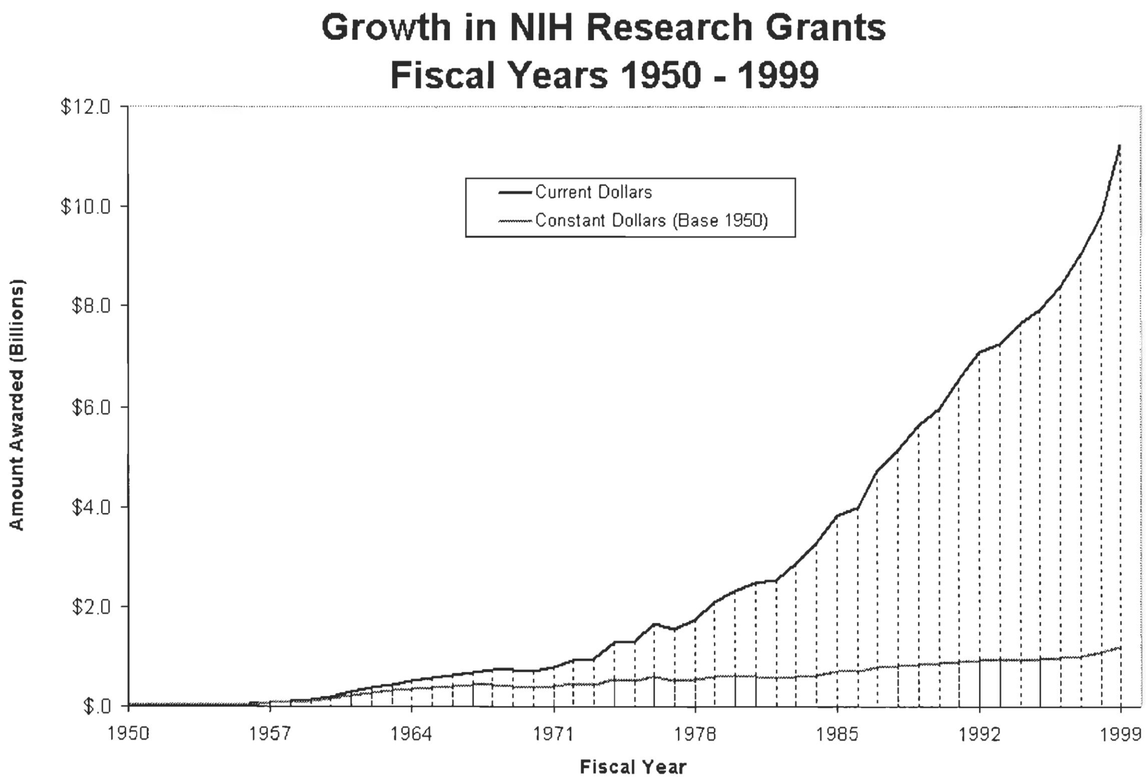


Figure 6. Growth in NIH Budget.

As we can see, the overall budget of the NIH as grown exponentially since 1950, but when adjusted for inflation, has more of a linear trend.

The increases in different organizations and overall budget have continued, and the NIH now has 27 different institutes under its control and a total budget of about

$13 billion. The budget itself is divided up as follows: the vast majority, about $10.8 billion funds extramural research, or research that the NIH funds but that is not conducted in an NIH laboratory (like David Goddard's research that took place at the Rockefeller Institute). The other $2 billion was divided equally between research that took place at NIH laboratories and the operation of the organization, including operating the laboratories, training new employees, etc. Below is a graph describing the distribution of research grants by the NIH for the last 10 years:

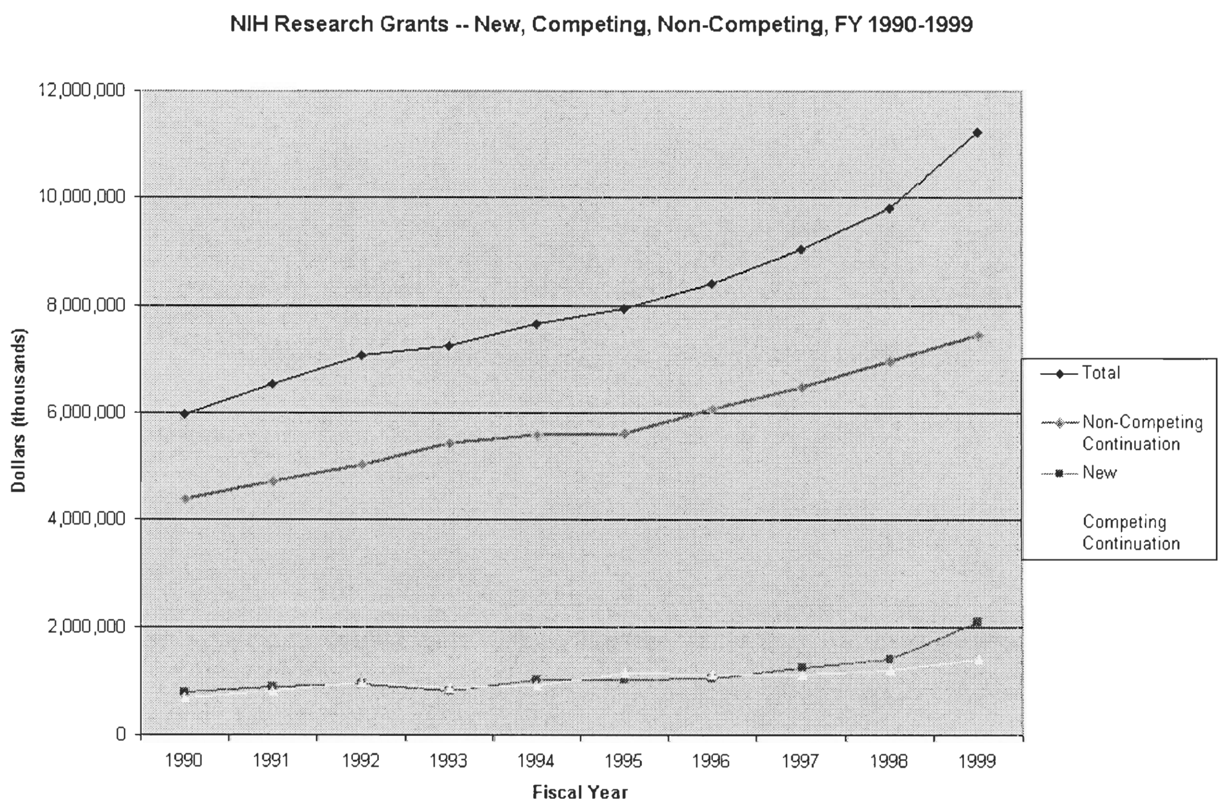


Figure 7. NIH Research Grants.

THE COST/BENEFIT RATIO FOR PERMANENT WAVES

In order to complete the goal of this project, which was to compare the GNP generated by permanent waves with cost of the research projects, we had to find a way to estimate the annual contribution of perm products to the annual GNP. We began thinking that the easiest way to approximate the contribution would be by talking to beauty product companies that produce permanent wave products. This proved harder than we thought, however, as many of the companies were reluctant to disclose their financial information, or were unable to give a reliable estimate of the percentage of their business that was in permanent wave products. The following is a summary of the companies that we talked to and the data (or lack thereof) that these companies were willing to part with:

First, the merger *Colomer USA* was kind enough to give us their yearly income and what percent the perm is responsible for. This information is as follows:

Colomer USA- total company sales were $90,846,000; Perm sales totaled $4,450,000 or 4.9% of total business.

(**Colomer USA* is a merger composed of many of the top perm competitors in the past few years such as *Revlon)*

The *Janól* company was also very helpful by not only giving us their financial report but directing us to other top competitors which we had overlooked such as *Johnson Company* of Chicago, *Proline* of Dallas, *Hawaiian Silky* of Mississippi, along with *Lesters* and *Add one with Nature.* The report for Janól is as follows:

Janól- total company sales were $4,000,000 Perm sales were 8% of total business. After spending a few hours on the phone contacting perm companies, these were the only two that conveniently cooperated within the duration of our phone conversation. We are still waiting for callbacks, emails or financial reports being shipped to us from *Alberto-Culver*, *Carson*, *Vidal Sasson* and *Nexxus*. We have found that a few companies such as *Revlon*, *Unilever* and *Johnson & Johnson*, no longer carry perm products. Other obstacles we have encountered include *Proctor & Gamble* claiming that "they cannot release that type of information to the public", and the representatives from *L'Oréal* and *Shiseido* were unable to speak English. Because of the paucity of actual number amounts and financial information given by the perm companies, we decided that we would have to use other methods to find an estimate for the total economic contribution of perm-related products.

The next idea that we had was to see if there had been any recent articles or books written about the size of the beauty product industry, and to determine whether any of those article had useful information. After some searching, we discovered an article in *Salon.com* that gave us the information that we were looking for, specifically the total gross income of beauty-care manufacturers and the fraction of that number that was due to perm products. This article specifically stated that in 1996 the total sales of beauty products was a little over $10 billion, and that hair-care products dominated that number. Shampoos totaled about $1.5 billion and a little over $1 billion; more importantly, the article stated that about $600 million was spent on permanent wave products, which is the estimated number that we had been looking for. This number makes sense because most of the beauty-care companies that we talked to told us that somewhere between 5-10% of their business was in perm products, and that $580 million is about 6% of the total amount of beauty product sales.

The average amounts of money spent by the NIH on a research grant over the last 30 years are summarized in this table:

Year	Total Amount Spent On Research	Average per Project
2000	$11,741,613,813	$291,502
1996	$5,937,096,879	$240,460
1988	$3,789,624,533	$156,143
1978	$1,239,781,773	$74,273
1968	$489,316,069	$35,149

Table 1. NIH Research Money Numbers.

David Goddard's project was begun as a simple National Research Council fellowship. The return since then is simply astounding, as perm products now help contribute about $600 million to our GNP annually. This is almost 2,500 times greater than what the research project conducted back in the 1930's would have cost to conduct right now, as the average amount of money spent on every research project in 1996 was $240,460.

The best comparison to make with economic contribution of the permanent wave is probably to compare it to the cost of basic research funded by the National Institute of General Medical Sciences (NIGMS). The NIGMS is a component of the NIH, and supports basic biomedical research that is not targeted to specific diseases, but that increases understanding of life processes and lays the foundation for advances in disease diagnosis, treatment, and prevention, namely what we have been calling basic research throughout the paper. The NIGMS spent about $290 million on research project grants in 1996, or less than half the amount of money generated every year by permanent wave products. There were approximately 1,700 NIGMS projects in 1996, which translates to about $170,588 per project, meaning that every year the GNP generated by the permanent wave is equal to the grants of approximately 3,400 hundred projects. Also, the average NIGMS project takes approximately 2.2 years to complete, so an average project gets $77,500 a year; using this data, the permanent waves' GNP generated every year is equal to 7,500 projects.

CONCLSUION

Although research begun with a specific goal in mind can solve a particular problem rather well, basic research into the nature of how things work can have unexpected side effects. The case that we looked at was that of the permanent wave, discovered by David Goddard doing basic research on protein structure back in 1930's. We specifically examined the idea that the GNP generated by the sales of permanent wave-related products is greater than the total amount of NIH-funded research since its modern era began after World War II. This is clearly untrue, as the budget for the NIH in the 1996 alone was about $10.7 billion, while the total sales of perm products the same year was about $580 million. These data do not preclude us from being able to state that the basic research that led to the discovery of the perm, a simple basic research project conducted almost 70 years ago, has not provided a great return considering the original amount invested.

BIBLIOGRAPHY

Journal Articles

Goddard, David and Michaelis, Leonor. “A study on keratin.” *J. Biol. Chem.* 106:605-14.

Goddard, David and Michaelis, Leonor. “Derivatives of keratin.” *J. Biol. Chem.* 112:361-71.

Lundgren, Harold P. and Ward, Wilfred H. “Levels of Molecular Organization in a-Keratins.” *Archives of Biochemistry and Biophysics.* 1:78-111.

Scott, Allene. “Some Aspects of the Comparative Biochemistry of Human Keratins.” *Brit. J. Dermatology.* (June 1965) 291-301.

World Wide Web Documents

Earl Hutchinson. Nappy and Proud. 7 Dec. 1998 <http://www.salon.com/news/1998/12/07news.html>.

The Organiation of the National Research Council. 10. Jan. 1998 <http://www4.nas.edu/arc.nsf/web/nrcorganization?OpenDocument>.

Ralph O. Erickson. David Goddard. 15 Feb. 1999 < http://www.nap.edu/readingroom/books/biomems/dgoddard.html>.

Consumer’s Guide to Perms and Relaxers. May 2000. <http://www.hairsite.com/PermsRelax/PR-buyersguide.htm>.

Dan Berger. How Permanent Waves were Discovered. 16 April 1998 <http://www.madsci.org/posts/archives/may98/892764277.Ch.r.html>.

Alan Bruzel. Making Pemanent Waves. 31 May 1999. <http//chemistry.about.com/science/chemistry/library/weekly/aa053199a.htm>.