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A QUALITY-ADJUSTED PRICE AND GASOLINE

Abstract

This paper analyzes the problems on the computation of price indexes when there are improvements in the goods' quality. These problems arise because we use price indexes that measure the prices of the goods that consumers buy rather than the prices of the services that consumers enjoy. In order to see this, I compute a true price for gasoline that is based on the services that it provides. We ask for the cost of moving one ton at a speed of 40 mph for a distance of 100 miles. This true price is compared with the official price for gasoline. The average annual bias (the rise in the official price relative to the true price) is 3.2% per year for the 1925-1992 time period. We also compute the hours of work required to cover that cost. We find that in 1925 there were needed more than 1.5 hours of work, while by 1992 there were just needed about 8 minutes to move one ton as specified above.

Resumen

Este documento analiza los problemas sobre la construcción de los índices de precios cuando hay incrementos en la calidad de los bienes. Estos problemas se presentan porque utilizamos índices que se basan en los precios de los bienes que los consumidores compran en vez de basarse en los precios de los servicios que los consumidores disfrutan. Para analizar esto, construimos un índice de precios "verdadero" para la gasolina que está basado en los servicios que ésta proporciona. Nos preguntamos por el costo de transportar una tonelada a una velocidad de 40 millas por hora en una distancia de 100 millas. Este precio verdadero es comparado con el precio oficial de la gasolina. El sesgo promedio anual (el incremento en el precio oficial relativo al precio verdadero) es 3.2% al año para el periodo de 1925 a 1992. También calculamos las horas de trabajo necesarias para cubrir ese costo. Encontramos que en 1925 se necesitaban más de 1.5 horas de trabajo, mientras que para 1992 se necesitaban sólo alrededor de 8 minutos para transportar una tonelada como se especificó anteriormente.

Introduction

Nowadays, there is an increasing concern about the calculation of price indexes. There are problems in these indexes when we try to account either for improvements in the quality of the existing goods or for the introduction of new goods. The problems with the quality change arise because we use price indexes that measure the prices of the goods that consumers buy rather than the prices of the services that consumers enjoy. Thus, prices do not capture the changes in efficiency of these goods or the change in the efficiency of delivering services when new goods are introduced into the market. The construction of the actual price indexes does not capture the effects that product innovations and process innovations have on prices. A great example is the case of light by Nordhaus (1997b). He finds that the true price is 1,000 times lower than the official price. This implies a 4.9% average upward bias per year in the estimation of this price over the 1850-1992 period.

The purpose of this paper is to compute a quality-adjusted price (a "true" price) for gasoline and compare it to the official price.

There is no discussion about the improvements in the quality of the gasoline marketed in the United States over the last 100 years.[1] The gasoline produced during the nineteenth century was too volatile and had an unpleasant odor. It generated many combustion problems in the internal combustion engines of the day. The content of sulfur was very high. Nowadays, the volatility has decreased a lot; its odor is not unpleasant, it causes almost no combustion problems in the modern engines. The content of sulfur is now minimal. However, the improvements in the power characteristics, or octane number, has been the most important because it generates more power in a given engine. For example, given the increase in the octane number, the same amount of gasoline delivered about one-third more power in the 1960s compared to that delivered in the 1930s.

One of the most significant changes in the industry is on the number of different octane levels of gasoline available to the consumers. In the 1950s, there were basically just two grades of gasoline to be purchased: regular (85 octane) and premium (87 octane). Today, the octane levels range from 82 to 95 with various grades in between. Now, we have regular leaded[2], midgrade unleaded, regular unleaded, and premium unleaded.[3]

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[1] As is pointed out in Williamson, et. al. (1963): "While their cost to consumers, compared to general commodity prices, remained relatively stable, there was a continued improvement in the quality of petroleum products distributed during these years".

[2] Production of leaded gasoline ended in 1992.

[3] This is largely a reflection of the adoption and spread use of more advanced refining techniques, particularly the catalytic and reforming processes, and continued research and development by the oil companies.

These improvements made the development of the technology for refining crude petroleum oil into sophisticated fuel products one of the most important stories in modern history. Gasoline, which is one of the most important chemical mixtures produced today, is the largest component of domestic petroleum products obtained from crude oil. The following figures give us an idea of the importance and the value involved in the production of gasoline. In 1899, gasoline accounted for 25% of the value to the refinery industry; by 1919, it was 55% (Williamson, et. al., 1963). In the 1980s, the American automobiles and trucks were consuming between 100 and 120 billion gallons of gasoline to travel over one trillion miles at a cost of about $130 billion. The expected demand for gasoline by the year 2010 is about 352.8 million gallons per day at a price of $1.51 per gallon (Energy Information Administration, 1991).

Given the facts stated above about the improvements in the quality of gasoline, the following question arises naturally, Does the official price of gasoline account for the changes in the gasoline's quality?

If we look at the time series for the nominal price of gasoline, we see that this price fluctuated between 15 and 25 cents per gallon (excluding taxes) from 1920 to 1970. However, the oil crisis in the 1970s and 1980s generated very sharp movements in this price. As a result, the price of a gallon of gasoline was about 110 cents in 1980. On the other hand, the times series for octane ratings shows a steadily increase, from 55 to about 95, over the same period of time. From these numbers, it seems that the official price has not accounted for the quality improvements of gasoline.

Based on the available information we are able to construct quality indexes for the gasoline sold in the United States. We then go on to construct a price for gasoline by taking into account the improvements in quality. We ask for the cost of moving one ton at a speed of 40 miles per hour for a distance of 100 miles. After that, we get a "true" price index for gasoline. This price index is compared with the official price index of gasoline. We find that the official price of gasoline does a very poor job in accounting for quality changes in this product. The average annual bias (the rise in the official price relative to the true price) is 3.2% per year over the 1925-1992 period. If we take these findings as a proxy for all the products in the petroleum industry, we can see that there is a considerable bias in the computation of the Consumer Price Index.

On the other hand, we also compute the hours of work per 100 miles (as specified above), which is a kind of labor price for gasoline. We find that in 1925 there were needed almost 1.5 hours of work to move one ton for a distance of 100 miles, while by 1992 there were just needed about 8 minutes. This is another clear fact about the increase in the quality of gasoline that shows the problems faced by the Consumer Price Index when accounting for improvements in quality.

In the construction of the above quality index for gasoline we have assumed that all the gains from the improvement in octane number are used to get more mileage at constant performance (constant accelerating conditions, that is constant speed). We are omitting important gains in other performance characteristics from a better gasoline. Some examples of these are the following: (a) more rapid acceleration; (b) quicker starting and warm-up characteristics; (c) availability of full power at all times; (d) gasoline with less sulfur will keep the engine clean for a longer period of time. Moreover, the increase in the quality of gasoline has allowed the Automobile Industry to produce bigger cars with bigger engines. Finally, there are two important points that we have ignored in our analysis. First, there are gains in the yield of gasoline from a barrel of oil that are obtained when a new and better process replaces another. For example, the yield of gasoline has increased from 10% to about 50% over our sample period. These gains are reflected in the official price for gasoline but not in our quality-adjusted price. Second, we have focused just on the octane ratings based on the gasoline's properties, which are called chemical octanes. We have ignored the mechanical octanes, which are based on the improvements in the engine designs. These improvements also increase the mileage.

From these additional gains is clear that we can construct a characteristics index that takes into account the improvements in the gasoline as well as the improvements in the cars. This would give us a better measure of the improvements in quality and would allow us to get more striking results. Therefore, what we find in this paper is a lower bound on the average bias of the official price of gasoline.

The rest of the paper is organized as follows: Section I presents a brief history of gasoline. Section II states the principal characteristics of gasoline that are going to be used to determine its quality. In Section III we set up the theoretical model to account for the quality changes of this product. In Section IV we propose a quality index for gasoline. The computation of the official price is discussed in Section V. A quality-adjusted price for gasoline is computed in Section VI. Conclusions are given in Section VII.

I. History

The first use of the term *gasoline* was to refer to the light fractions that resulted from the distillation of crude petroleum oil. At that time this was the nature of the product, which consisted mainly of paraffinic hydrocarbons, with some minor proportions of other hydrocarbon families such as aromatics and naphthenes. These fractions were highly flammable with a boiling point between 40°C and 90°C.

The origins of gasoline can be traced to the early nineteenth century when there were many small refineries in Britain, the United States, and elsewhere. The main output of these early refineries was the production of burning oil, a type of kerosene, starting from raw materials known as 'coal oil'. The hydrocarbon fractions obtained from this refining process were highly flammable and almost useless. These fractions were a rudimentary form of gasoline and much of this material was burned to waste. In 1836, small amounts of gasoline were used as a raw material for producing illuminating gas.

Another use of gasoline was in the so-called dry-cleaning process for clothing, a discovery made by a Parisian named Mr. Belin in 1849. Around 1866, it was introduced to Britain and the turpentine used in the process was replaced by the cheaper light petroleum fractions distilled from kerosene (some kind of gasoline). However, it was not used because it was very volatile and flammable. At that time there existed a less volatile product, known as "French Cleaning Spirit", which was used until 1939. This was a type of gasoline without the lighter and heavier fractions. Later uses for gasoline included solvent applications in chemical and industrial plants. It was also used as a household fuel for cooking and heating. However, gasoline was not a commercial product before 1861. The reason is that the petroleum refining industry was established by 1862. By the end of the 1890s, all but a small proportion of the total sales of gasoline went to satisfy the demand for solvent.

Even though there were some uses for the gasolines produced by these early refineries, there was essentially no market for them some 125 years ago. The most profitable products at that time were kerosene as a fuel for lamps and lubricants for machinery. Naturally occurring or "straight-run" gasoline was a by-product in the process of refining crude petroleum oil to produce those products. Gasoline, the first of the by-products, entered commercial usage in the United States by 1863. Its main use was as a local anesthetic. During the late 1880s, people living in the Midwest and in the South were using gasoline stoves. Even though the American petroleum industry was producing mainly illuminating oil and lubricants at the beginning of the nineteenth century, by 1907, the Texas Company was selling two types of gasoline: deodorized and high-test gasoline (suitable for use in automobiles) and deodorized stove gasoline.

There were some events taking place in the last part of the nineteenth century that affected the composition of products obtained from the refining process of crude oil. The most important events were the widespread use of Edison's electric lights and the invention of the automobile. These events made the development of the technology for refining crude petroleum oil into sophisticated fuel products one of the most important stories in modern history where gasoline is one of the most important chemical mixtures produced today.

The use of the electric lights reduced the demand for kerosene –as an illuminating oil-, which generated a sharp decrease in its price. It decreased from 45 cents per gallon (excluding tax) in 1863 to 6 cents per gallon in the mid-1890s. This forced the refineries to find more profitable products to substitute for the production of kerosene, which was for many years the most important and sometimes the only petroleum product made.

The invention of the automobile generated a considerable increase in the demand for gasoline. This was made possible by the invention of the internal combustion engine by Nikolaus August Otto of Cologne, in Germany in 1876.[4] He constructed a practical four-cycle engine that became the basis for all modern gas engines, regardless of the type of fuel utilized. After 1900, in the United States, these engines were adapted to use kerosene and gasoline. About 99% of the world's internal combustion engines use some kind of fuel derived from petroleum. The best useful fuel for these engines is gasoline. By 1904, gasoline engines had already been accepted as the power unit by the great majority of automobile manufacturers, although both steam and electric models were still being produced in 1919.

Motor vehicles using these internal combustion engines appeared first in the late 1880's. During the mid 1880s Gottlieb Daimler and Karl Benz introduced the first successful road vehicles equipped with internal combustion engines in Germany. At the end of the nineteenth century, the use of automobile was expanding in France, United Kingdom, and the entire continent. By the end of the 1890s, the United States were importing European automobiles. In the meantime, Charles E. Duryea and J. Frank Duryea were the first to build and put on the road the first gasoline-powered automobile in the United States in the fall of 1893. Others who were building automobiles were Elwood Haynes and F. W. Lanchester in 1894, Randsom E. Olds and Henry Ford in 1896.

In1903, Henry Ford founded the Ford Motor Company where he started the mass production of automobiles powered by an internal combustion engine. By 1916, he was marketing his famous Model T touring car at a price under $300. This event created a huge new market for gasoline. To see this, we have that in 1899 virtually all of the approximate 6.2 million barrels of gasoline sold domestically was utilized in cleaning establishments, for use as solvents in chemical and industrial plants, and to a limited extent as a fuel for household cook stoves and portable space heaters. By 1919, about 85% of the total domestic distribution of 87.5 million barrels was purchased by users of automobiles, trucks, tractors, and motor boats. By 1920, the principal component of the demand for gasoline was for using it as an automotive fuel.

The following numbers give us an idea of the gasoline needs of the automobile owners. In 1920 the demand for motor gasoline in the United States was around 12.6 million gallons per day. In 1930, 18.5 billion gallons of this "waste product" were sold. In 1941, 26.91 billion gallons were distributed domestically. By the 1980's gasoline production averaged around 110 billion gallons per year. In the 1980s, the American automobiles and trucks were consuming between 100 and 120 billion gallons of gasoline to travel over one trillion miles at a cost of about $130 billion. The expected demand for the year 2010 is about 352.8 million gallons per day.

Given this increasing demand for gasoline, the refinery owners faced the problem of how to supply enough fuel for the automobile industry.

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[4] The concept of an internal combustion engine dates back at least to the 17th century when C. Huygens (1680) in France and D. Papin (1690) in Holland began experimenting with pistons.

Table 1. Important Events in the History of Gasoline

Year	*Event*
1862	The Petroleum Refining Industry is established
1863	Beginning of commercial use of gasoline
1890s	Widespread use of Edison's electric lights
1893	Charles E. Duryea and J. Frank Duryea built and put on the road the first gasoline-powered automobile in the United States
1903	Henry Ford founded the Ford Motor Company
1911	The Standard Oil is divided into regional companies
1913	Introduction of the thermal cracking process
1916	Mass production of Ford's famous Model T touring car at a price under $300
1924	Discovery of TEL
1936	The introduction of the catalytic cracking process
1970	The Clear Air Act is passed
1970s	The oil prices crisis
1977	The Clean Air Act is modified
1980s	The oil prices crisis
1989	Regulations on summertime volatility
1990	The Clean Air Act is modified

This was realized as early as 1908, when some people recognized the need for new chemical processes that could provide substantial increases in the availability of gasoline to power these new automobiles. Expecting to make huge profits, they began to look for new processes to produce gasoline to take advantage of this fact. The next fifty years in the industry were characterized by the discovery of new processes that increased the quality and the amount of gasoline obtained from a barrel of petroleum. During this period of time, the yield of gasoline manufactured from a barrel of crude oil increased from 10% to 50% with a substantial increase in the octane ratings.[5]

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[5] Table 2 shows the most important processes to produce gasoline.

Table 2. Important Processes in History of the Production of Gasoline

Process	*Year*	*Characteristics*
Fractional distillation by direct firing	1862	The major purpose was simply to distill off the gases, gasoline, and naphtha fractions as fast as heat and condensation could permit. Very low efficiency in terms of yield and working time.
Fractional distillation with ordinary steam	1862	Reduction of fire hazards compared to direct firing. Substantial fuel economies and greatly extended life of equipment. It avoided malodorous compounds formed by inadvertent cracking or destructive distillation. Its utility was restricted to the lighter fractions, from naphtha to kerosene.
Fractional distillation by superheated steam	1862	Designed to surmount the temperature limitations of ordinary steam.
Fractional distillation by vacuum distillation	1862	Secure a cleaner fractional distillation of the heavier components of crude oil without decomposition.
Continuos distillation	1860s	Improvement over previous distillation processes.
Straight-run distillation	1913	Gasoline was too volatile with very low octane rating. The yield of gasoline was about 8.61 gallon per barrel of oil charged.
Compression process (natural gasoline)[a]	1913	Poor in terms of uniformity. Very volatile.
Oil absorption process [b]		Better than compression process. Still volatility problems.

Table 2. - Continued

Process	*Year*	*Characteristics*
Charcoal process (absorption process)[c]	1918	Less volatile and more stable than natural gasoline from the compression process. Still have volatility problems.
Thermal cracking (Burton Process)[c]	1913	Increased the yield of gasoline to 9.79. Improved the octane rating to 55. Bad odor, yellow color. 3 cents cheaper. Not a continuous process
Dubbs Process[e]	1917	23% yield of gasoline.
Holmes-Manley process[e]	1918	Makes the thermal cracking continuous. 27.72 yield of gasoline. The octane rating was 72.
Cross process[e]	1922	Makes the thermal cracking continuous.
Tube and tank process[c]	1922	The yield of gasoline was 16.38 and the octane rating was 72.
Thermal reforming	1920s	Commercial importance in the early 1930s. It improves antiknock characteristics by increasing the olefin and aromatic content and by shifting the boiling range of the product to a greater volatility.
Catalytic cracking process (Houdry process)[f]	1936	Discovered in April 1927. High-octane gasoline (88 RON) at quality and yield levels never before realized. Not a continuous process.
Fluid catalytic cracking process[g]	1939-1940	The first plant was installed in 1942. The octane rating was 94. The yield of gasoline was 24.

Table 2. - Continued

Process	*Year*	*Characteristics*
Isomerization	1941	Applied to the low boiling fractions of petroleum –containing predominantly straight-chain paraffin hydrocarbons- to increase the proportion of high-octane branched molecules.
T.C.C. process[g]	1944	Makes catalytic cracking continuous.
Houdriflow process[g]	1940s	Houdry later version of catalytic cracking.
Catalytic reforming	1940s	High-octane gasoline (98 RON).
Catalytic Hydrocracking	1960	High-octane gasoline by using hydrogen.

[a] First process for natural gasoline.
[b] Second process to get natural gasoline.
[c] Third and last of the modern processes for the extraction of natural gasoline.
[d] First wave of cracking processes (thermal non-continuous).
[e] Second wave of cracking processes (thermal continuous).
[f] Third wave of cracking processes (catalytic non-continuos).
[g] Fourth wave of cracking processes (catalytic continuous).

II. Characteristics

The word gasoline is really the word used to refer to the motor fuel for the spark ignition engine. Finished motor gasoline is a liquid fuel designed to give off vapors that can be ignited within each cylinder of a spark-ignited internal combustion engine. According to Gruse (1967), "the two basic requirements for a motor fuel are: (1) that it shall burn with the controllable production of a maximum amount of heat energy and a minimum of anything else; and (2) that it shall continue to do so in the given equipment as long as required".

Modern gasoline, a complex chemical mixture, frequently consists of over one hundred of different chemical substances. Its manufacture is a complicated sequence of physical separations and chemical changes. The main compounds are carbon and hydrogen. The mixture consists of volatile hydrocarbons primarily saturates, olefins, and aromatics, and small amounts of additives, such as detergents, that perform a number of specialized functions.[6]

Gasoline is blended principally from straight-run gasoline from crude oil distillation and an assortment of blendstocks derived from several downstream refining processes. The refiner will blend appropriate combinations of chemicals in order to achieve maximum efficiency from an internal combustion engine working under a given set of performance and environmental requirements. The exact composition and characteristics of the gasoline vary with the quality of the raw materials used in the production process, the refining techniques employed, the additives selected, seasonal and geographic factors, and the specific requirements of the end-use market.

The following characterization and specification of gasoline is taken from The Energy Information Administration (1991). Specifications for gasoline have been established by the American Society for Testing Materials (Specification D439) and the Federal Government (Specification VV-G-1690B). These include a range in distillation temperatures from 122 degrees to 158 degrees Fahrenheit at the 10 percent recovery point and from 365 degrees to 374 degrees Fahrenheit at the 90 percent recovery point. Finished gasoline includes:

- **Leaded Gasoline**. Contains more than 0.05 gram of lead per gallon or more than 0.005 gram of phosphorous per gallon. Premium and regular grades are included, depending of octane rating. Also included is leaded gasohol.

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[6] A typical premium gasoline with a boiling point range of 30°C-210°C contains about 6% n-pentane and 3.5 % isopentane. The next few members of the series are called hexanes, heptanes, and octanes. Gasoline contains about 12% total hexanes but much less of the heptanes. A typical sample of gasoline may contain only 1-2% octanes. Cyclopentane is present at the 1-3% level in gasoline. Benzene is limited to 5%. For a premium gasoline, each of the major hydrocarbon chains contains between four and twelve carbons, and most of these compounds vaporize within the temperature range of 30°C to 210°C. Butane is the smallest alkane found in gasoline, and thus it has the lowest boiling point. Only n-butane is present in gasoline, its typical concentration is 3-4%.

- **Unleaded Gasoline.** Contains not more than 0.05 gram of lead per gallon and not more than 0.005 gram of phosphorous per gallon. Premium, midgrade, and regular grades are included, as is unleaded gasohol.
- **Gasohol.** A blend of leaded or unleaded gasoline and alcohol (generally ethanol but sometimes methanol). The alcohol content of gasohol is limited to 10 percent by volume.

A given gasoline is characterized by its density, antiknock rating, gravity, volatility, lead content, sulfur content, boiling point, freezing point, etc. However, two of the main characteristics of a gasoline's quality, which have a great impact on its performance in an internal combustion engine, are its octane rating and its volatility. The actual measures of these two characteristics are as follows: between 78 and 100 for its octane rating (depending on the method used to rate the gasoline) and between 9.0 and 15.0 pounds per square inch for its Raid Vapor Pressure for its volatility. A gasoline's antiknock characteristic is determined by its octane rating, while the tendency of the fuel to vaporize is affected by its volatility.

Octane Rating

Knock (the term used for spontaneous ignition) has been a problem in the spark-ignition engine ever since the engine was invented. There are different kinds of abnormal combustion that affect the gasoline engine, for example, autoignition, preignition, misfire, spark knock, etc. However, spark knock is the most important combustion problem. Engine knocking, or pinging, occurs when the air-fuel mixture is ignited prematurely, which is most common in the smaller, high compression ratio engines. The principal effect of engine knocking is the loss of power in the engine and it can cause damage to the engine if it is not corrected. Using fuels with high-octane rating fixes the engine knock problem.

At the beginning of the nineteenth century there were some studies that separated spark knock from the other combustion abnormalities that were all too common in the engines of those days. This work was made by Ricardo in Great Britain. He used a test engine, in which the compression ratio[7] could be varied between 3.7:1 to 8:1, to measure the knock resistance of a fuel in terms of the highest useful compression ratio (HUCR) attained to the fuel before the onset of knock.[8]

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[7] The compression ratio is the ratio of the relative volumes of the cylinder space at its two extremes, one when the piston is fully extended by the intake stroke and the other when the piston is fully compressed at the moment of firing.

[8] The "knock problem" was detected at the beginning of the 1900s when Charles F. Kettering's invented the self-starter for automobiles and the installation of battery ignition. This

On the other hand, in the USA, where the automobile industry was expanding very rapidly, there was a need for a standard method to assess the knocking characteristics of fuel components and additives as well as of finished gasolines. At that time there were many methods (each laboratory had its own one) to rate a given gasoline, but the ratings were not comparable among themselves. Laboratories chose two standard references, a knock-prone and a knock-resistant material. A straight-run paraffinic gasoline was chosen as the knock-prone and benzene was chosen as the knock-resistant. An unknown gasoline was rated by the percentage of benzene, in a mixture of the two, which matched the knocking tendency of the unknown fuel. However, there was a lot of dispersion in these measures. The Cooperative Fuel Research Committee (CFR) undertook the standardization of knock testing under the auspices of the Automobile Manufacturers Association, the American Petroleum Institute, the National Bureau of Standards, and the Society of Automobile Engineers. The new standard method adopted by the CFR, in 1929, was the combination of the octane scale proposed by Graham Edgar in 1926 and the use of a variable compression ratio engine developed by the Waukesha Company. This method has been used ever since.

The octane number for a gasoline is determined by comparing its antiknock performance against a reference fuel with a known octane number. The reference fuel adopted by the CFR is a blend of iso-octane (2,2,4-trimethyl pentane) with normal heptane. Iso-octane was arbitrarily assigned an octane number of 100 because of its high antiknock value and normal heptane an octane number of 0 because of its poor antiknock characteristics. The antiknock performance of a gasoline with an unknown octane rating is computed by using a test engine to compare it with various reference blends of iso-octane and normal heptane. A gasoline with an octane rating of 80 will behave similarly to a mixture of iso-octane and normal heptane that has an iso-octane concentration of 80 percent. The octane ratings and methods used to rank gasolines today have changed a lot compared with those used in the early 1930s. However, they still are related to this basic scale. This octane scale ends theoretically at about 128.

There are three octane measures that are used to rate a given gasoline. The Research Octane Number (RON) is a measure of the performance of a gasoline under laboratory conditions. The Motor Octane Number (MON), formally adopted by the CFR on September 12th, 1932, is a measure of the performance of a gasoline under more severe operating conditions like the ones faced by an automobile on the road.[9] Nowadays, the octane quality of the gasoline sold in the USA is specified by the ASTM in terms of its Anti-knock Index,

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problem was associated to preignition accompanying the new battery-type ignition rather than to the knocking tendency of the higher boiling components present in the gasoline sold at that time.

[9] This new measure was introduced after the realization of some tests with some vehicles on the road. People found that the performance on the road was not highly correlated with the octane number assigned by the Research Method.

$$Anti-knock\ \ Index = \frac{RON + MON}{2}$$

The system developed for aviation gasolines[10] based on the Army Navy Performance Number is used to rate fuels with octane numbers greater than 100 (usually the gasolines that have higher proportions of additives). The Performance Number is a measure of knock-limited power and one octane number is equivalent to three performance numbers.

There has been a continuous search for antiknock compounds to increase the octane ratings of a given gasoline. Some of these are aniline, tetraethyl lead, selenium oxycholeride, diethyl selenide. All but tetraethyl lead were impractical because of their extremely penetrating odor. The discovery of aniline as an antiknock compound in 1919 was important. It allowed increasing the compression ratio from 4:1 to 7:1, with an improvement of 40% in mileage. However, the discovery and commercialization of tetraethyl lead, as an antiknock agent in motor fuels, was one of the most important innovations in the industry.

Volatility

The term volatility refers to the tendency of a fuel to vaporize under given conditions of temperature and pressure. The volatility of motor gasoline affects engine operations in different ways. If it is too low, starting is difficult and warm-up is slow in cold weather. On the other hand, if it is too volatile, it might cause carburetor icing under adverse atmospheric conditions. Producers of gasoline must find a balance between these two extremes.

The measure of volatility used by the petroleum industry is given in pounds per square inch (psi) of Reid Vapor Pressure (RVP), which is the surface pressure required to prevent vaporization at 60 degrees Fahrenheit under atmospheric pressure. The refiners try to produce a gasoline that vaporizes easily in the combustion chamber when the engine is cold (during the winter) but is not so volatile that it vaporizes in the fuel system when the engine is warm (during the summer). Some gasolines can vaporize in the fuel system leading to a condition known as vapor lock. The engine could stall if there is a formation of vapor in the fuel line because the gasoline pump is no longer able to draw fuel; the engine will not restart unless the vaporized gasoline in the fuel line is condensed. Another measure of volatility is related to the boiling points at which a given percent of the gasoline is evaporated.

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[10] Aviation fuel is a different substance than automobile fuel. Only light aircraft with spark ignition engines use normal, unleaded gasoline with a lower boiling range of 30°C-150°C and a lower freezing point range.

According to Gruse (1967), the volatility of a gasoline must be so adjusted and controlled that the fuel will

1. Enable an engine to start readily under all expected weather conditions;
2. Provide satisfactory performance during complete warm up;
3. Enable the engine to accelerate quickly and to furnish power enough for normal use after warming;
4. No vapor-locking during operation nor stall when starting from a heated condition;
5. Not cause stalling because of ice formation in the carburetor or intake system;
6. Afford reasonable fuel economy on both short and long trips;
7. Not dilute the crankcase oil with a content of high boiling material;
8. Not promote formation of engine deposits by a content of unstable compounds which do not burn cleanly.

Finally, because the requirements about the volatility of a gasoline depend a lot on the environmental situation, the appropriate RVP for a gasoline will change with geographic location, altitude, and season.

In the recent years, the characteristics of gasoline have been modified because of the regulation that has been imposed by the Environmental Protection Agency (EPA) about evaporative and exhaust emissions.[11] These regulations tend to reduce the lead content of gasoline and to restrict the volatility of gasoline (by reducing the vapor pressure) during the summer.[12] Over the past decade, the refining industry has adjusted to EPA regulations by changing considerably the composition of gasoline. This tendency is likely to continue in the future because the EPA is considering restrictions on benzene, heavy aromatics, and light olefins, all of which are large contributors to the octane rating of the gasoline pool.

III. Estimation of Price Indexes

The construction of the actual price indexes does not capture the effects that product innovations (new products) and process innovations (better products) have on prices. This problem is more severe in the case of radical innovations like the introduction of TV, computers, penicillin, etc. The point is that these price indexes are not able to account for the quality improvements of the products. Thus, price indexes miss much of the action during periods of major technological changes.

There are two main sources of problems in measuring prices. First, the classical index-number problems. Second, the problems associated with new products and quality changes of existing products. Index-number problems arise primarily from using inappropriate weights in the construction of the aggregate price

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[11] The Clean Air Act was passed in 1970. It was amended in 1977 and in 1990.

[12] The summertime gasoline volatility regulations were adopted in 1989.

index. Current evidence points out that the CPI overstates price increases by 0.5% per year (Nordhaus, 1997b).

The problems with the quality change arise because we use price indexes that measure the prices of the goods that consumers buy rather than the prices of the services that consumers enjoy. Thus, prices do not capture the changes in efficiency of these goods, neither the change in the efficiency of delivering services when new goods are introduced into the market.

We should use a characteristics price index rather than a goods price index if we are trying to measure the true cost of living. The real problem is posed by the introduction of new goods and the improvements in existing services. The current policy is to "link" these goods into the price index rather than to reprice the basic category taking into account the quality change. This was the policy used when cars replaced horses; computers replaced typewriters, etc. Therefore, any major changes in efficiency that occur when radical new consumer products are introduced are simply eliminated under the conventions of current price measurements.

Traditional prices can go wrong in three ways. First, they can use the wrong weights. This is unimportant for our purposes because the true price can suffer the same problem. Second, they do not account for the quality improvements on the existing goods. Third, they can mismeasure prices for new goods if the service-good price ratio is lower for the new good than for the old good.[13] This is severe if new goods are introduced late in their product cycle (as is typical in the construction of the Consumer Price Index).[14]

Let us set up a model to compute the right price indexes (a kind of quality-adjusted price indexes). Assume that the utility function of a representative consumer is given by $U(C_1,\dots,C_N)$, where C_i is the quantity of characteristic i. The service characteristics are produced by the goods $(X_1,\dots,X_M)$. The production function by which good j produces characteristic i at time t is given by $C_{it} = f_{ijt}(X_{jt})$. Here, we are assuming that that each good can produce only one characteristic. The budget constraint is $\sum_{i=1}^{M} p_{it}X_{it} \le I$, where I is the nominal income at time t and p_{it} is the price of the good i at time t.

The problem faced by this consumer is the following:

$$\max_{X} U(C_1,\dots,C_N) \qquad \text{s.t.} \qquad \begin{aligned} & C_{it} = f_{ijt}(X_{jt}) \\ & \sum_{i=1}^{M} p_{it}X_{it} \le I \end{aligned}$$

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[13] For example the substitution of phonograph records by audiocassette recorders.

[14] U.S. air conditioners were introduced into the CPI 13 years after their widespread introduction. VCR's and computers were introduced in 1987. Cellular telephones will be introduced into the CPI this year.

The first-order conditions for this problem are

$$\lambda = \frac{1}{p_j}\frac{\partial U}{\partial C_i}\frac{\partial C_i}{\partial X_j} \tag{1}$$

for all purchased goods j that deliver characteristic i.

Equation (1) gives the optimal conditions for the consumer's maximization problem in terms of purchases of goods.

Define the shadow price of characteristic i as $q_i = \frac{p_j}{\frac{\partial C_i}{\partial X_j}}$. Then, we can rewrite Equation (1) as follows:

$$\lambda = \frac{1}{q_i}\frac{\partial U}{\partial C_i} \tag{2}$$

Equation (2) gives the optimal conditions for the consumer's maximization problem in terms of the service characteristics.

A traditional price index, P_t, measures goods or inputs prices,

$$P_t = \sum_{j=1}^{N} p_{jt}\eta_{jt} \tag{3}$$

where p_{jt} are the prices of the goods and η_{jt} are the appropriate weights on the goods.

A true price index, Q_t, measures the trend in the prices of the service characteristics,

$$Q_t = \sum_{i=1}^{M} q_{it}v_{it} \tag{4}$$

where q_{it} are the prices of the characteristics and v_{it} are the appropriate weights on the service characteristics.

Therefore, we can see that these two price indexes are different. By design, price indexes can capture the small changes in economic activity, but revolutionary jumps in technology are completely ignored by these indexes.

Nordhaus (1997b) makes an estimation of a "true" price for light. He finds that the true price for light is 1,000 times lower than the official price index. This gives a 4.9% upward bias per year in the estimation of this price. In the case of computers, the hedonic price for performance has increased about 15% per year more slowly than the computer unit price over the last three decades (Nordhaus, 1997b). The increase in variety would reduce the trend in the price for cereals by about 0.8% per year (Hausman, 1997). There is an upward bias of 3.2% per year in appliances and an upward bias of 5.9% per year in radios and TV's (Gordon, 1990). Nordhaus (1997a) makes an estimation of 0.6-1.4% per year for the upward bias in the CPI.

According to Nordhaus (1997a) the implications of this upward bias are that the real U.S. wages from 1959 to 1995 grew by 70% rather that by 10%; and that Total Factor Productivity growth was 1.8% rather that 0.6%.

Nordhaus (1997b) divides the goods into three groups according to the performance of the price indexes in accounting for quality changes. In the first group (*run-of-the-mill changes*) we have all the goods for which the price index does a pretty good job; it accounts for all the changes in quality in these products. In the second group (*seismically active sectors*), we have goods for which the price indexes miss some of the changes, but still account for some of those. In this group, the good or service in question is about the same through the time of study. Finally, the price indexes for the goods on the third group (*tectonic shifts*) miss all the quality changes. The case of light lies in the third group. As we sill see later, gasoline also lies in the third group.

IV. Measure of Quality

The most important criteria of quality for a gasoline fuel are based on three main characteristics: (a) burning qualities; (b) chemical qualities; and (c) volatility. These characteristics were discussed in the previous section. In this section we will construct some measures to account for the changes in quality of gasoline by focussing on each one of these characteristics at a time.

Burning Qualities

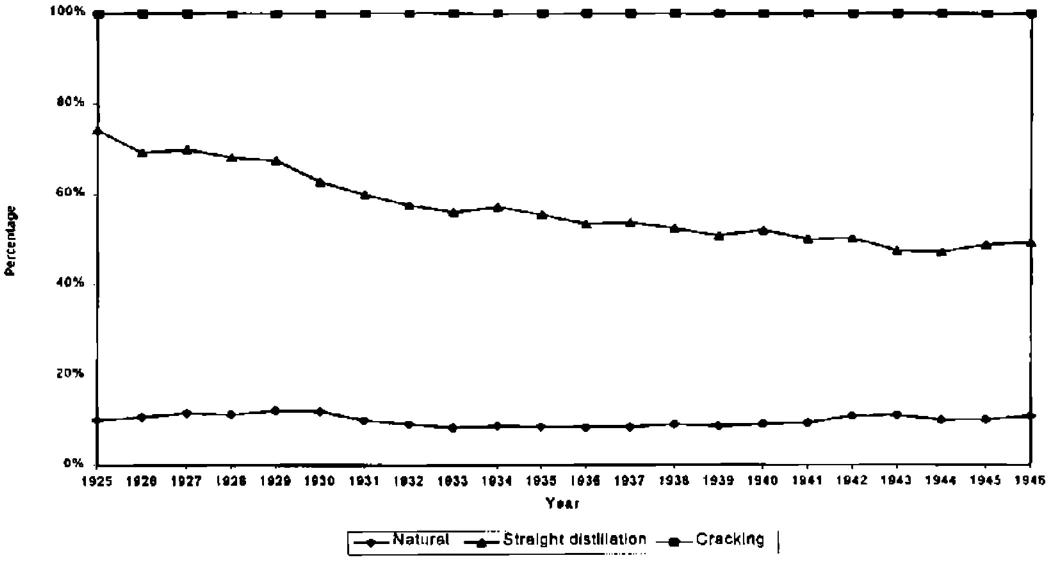
Let us start with the burning qualities, which are reflected on the octane ratings of a motor gasoline.

During the 1920s most refiners identified quality with odor and color, seeking an odor free, water-white product. The use of visible gasoline pumps intensified this identification in the consumer's mind. At the beginning of the period some refiners still used low gravity as the sole indication of quality. A simple distillation test –the Engler test- probably was the most important step forward in determining the quality of gasoline for it measured the percentage of extremely low boiling hydrocarbons present as well as that of high boiling ones. The octane scale and the anti-knock testing methods marked perhaps the climax of considerable reorientation of testing and treating gasoline during the decade.

The advancement of technology and the commercialization of the process innovations that were being carried on by the end of World War I generated major improvements in the quality of motor fuel during the decades of the 1920s and 1930s. The most important new processes were the Thermal Cracking and the

Catalytic Cracking[15] introduced by Dr. W. M. Burton and Eugene J. Houdry, respectively. These processes allowed refiners not only to increase the gasoline yields, but to produce a superior product as well (a gasoline with good anti-knock qualities), compared to straight-run distillation. The increasing use of these cracking processes improved the average quality of gasoline and increased its supply, which in turn supported the modern intensification of motorization, while lowering the refiner's raw material costs. The quality of gasoline (and in general, of products from the petroleum-refining industry) has been improved as one process replaces another. This improvement has arisen from various sources, for example, by keeping processes closer to the distillation specifications, by improving the combustion characteristics, and by eliminating the corrosive, gum-forming, and ash-forming constituents.

Figure 1. Proportion of Gasoline by Process of Production



Source: Williamson, H.F., Andreano, R.L., Daum, A.R., and Klose, G.C. (1963). *The American Petroleum Industry. The Age of Energy 1899-1959.* Evanston, IL: Northwestern University Press.

In the early 1930s, the quality of the motor fuel demanded was affected by the automobile manufacturers who raised the efficiency of their product by increasing engine compression ratios. This development brought in the octane race, begun in the 1920s with the discovery of the thermal cracking process, and put pressure on the refiners to expand their thermal cracking capacity and to explore the possibilities of catalytic cracking. By the end of the 1930s, Sun Oil was selling an

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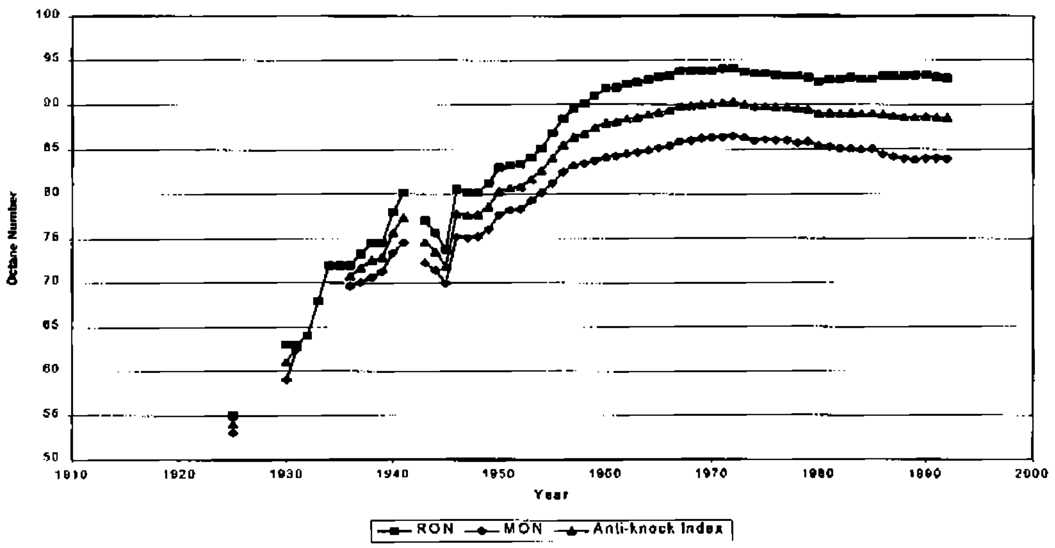
[15] The advantage of these cracking process is that they the break up higher molecules of petroleum hydrocarbons into smaller ones of greater value within the boiling range of gasoline.

unleaded premium quality gasoline, produced with the catalytic cracking process, in competition with regular leaded grades.

The improvements of refined products, principally the increase of octane ratings of motor fuels, during the 1929-1941 period was due to the non-price competition among members of the refining industry. One of the most important events that led to this improvement in quality was the introduction into the market of the premium grade ethyl (leaded) gasoline with higher octane rating in the late 1920s, which attracted many motorists. However, the sales of premium grade gasoline dropped sharply during the early depression years, which directed the attention of the refiners toward increasing the octane ratings of regular grades. After 1935-1936 the sales of premium fuel began to expand and octane ratings for both regular and premium grades kept increasing over time.

After World War I the increase in the quality of gasoline was generated by the decline in the proportion of straight-run capacity and by the growth in the cracking (thermal and catalytic) production (see Figure 1 for the tendency of the 1925-1946 period). The catalytic cracking and reforming processes, which had contributed importantly to the wartime production of high-octane aviation gasoline – during the World War II- played a crucial role in shifting the proportions of gasoline produced by different processes.

Figure 2. Annual Octane Ratings



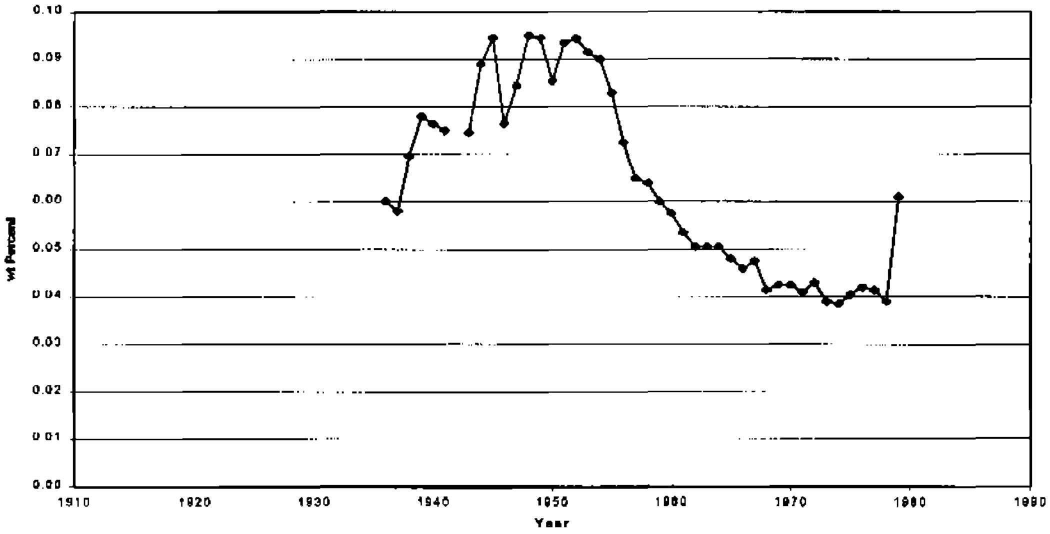
Sources: U.S. Bureau of Mines, "Information Circular". U.S. Bureau of Mines, "Report of Investigations". Motor Gasolines. Various Issues.

Given the characteristics of gasoline described above, we can construct an index to measure a gasoline's quality in terms of its octane rating. In this way we can see how the quality of gasoline has changed over time. There are three measures that can be used, the Research Octane Number (RON), the Motor Octane Number (MON), and the Anti-knock Index.

I have collected data for these three measures for Leaded Regular Gasoline and for Premium Gasoline. In this paper, I am going to use the data for Leaded Regular Gasoline. For the RON and MON, the time series go from 1925 to 1992 with some missing years because there is no available data. For the Anti-knock Index, data begins in 1971, when it started to be computed, and ends in 1992. I have extended this measure back by taking the average of RON and MON for years where both are available. These measures are given for the summer and winter seasons. I have computed the annual octane rating by taking the average of summer and winter for years where both are available.

Since the octane ratings for summer, winter, and annual do not differ significantly, I will focus just on the annual average. In Figure 2 we have the annual average octane ratings for Leaded Regular Gasoline. The octane ratings for 1925 are based on estimations made by the Ethyl Corporation (Petroleum Facts and Figures). For the MON there is no data available from 1925 to 1930. These data come from surveys made by the Bureau of Mines during the summer and the winter of each year. However, there were no surveys between the summer 1931 and the winter 1935-1936. Neither there were surveys for winter 1941-1942 and summer 1942.

Figure 3. Annual Sulfur Content



Sources: U.S. Bureau of Mines, "Information Circular". U.S. Bureau of Mines, "Report of Investigations". Motor Gasolines. Various Issues.

Data for RON come from the same source except for 1930 to 1940 which come from Enos (1962). We can see that the RON has increased by about 40 points while the MON has increased by about 30 points. Both reached their highest rating in the early 1970s. Since then there has been a slight decrease in both measures mainly because of the EPA's regulations. From these Figures we see that the quality of gasoline has increased during this period of time. This can be related to increased power and mileage. The better gasoline provides more power to the engine, by increasing the compression ratio, so that a given automobile can travel more miles per gallon.

Chemical Qualities

Let us now go to the chemical qualities of a gasoline. We will analyze these qualities by focusing on the sulfur content of the gasoline, which is related to corrosion and odor. The less sulfur content in the gasoline the less is corrosion in the engine and the better odor. In Figure 3 we have the series for the average of sulfur content for Leaded Regular Gasoline.

Volatility

Finally, we will analyze the changes in quality by focusing on the volatility characteristics of gasoline. The volatility is related to the boiling points at which certain percentage of the gasoline is evaporated. For example, the boiling point at which 10% is evaporated, or at which 50% is evaporated. These values are related to the driveability index that says how hard is to drive a vehicle according to the volatility of gasoline, particularly under cold temperatures. This index is given by

$$DI1 = Driveability\ \ Index = 0.5T10 + T50 + 0.5T90$$

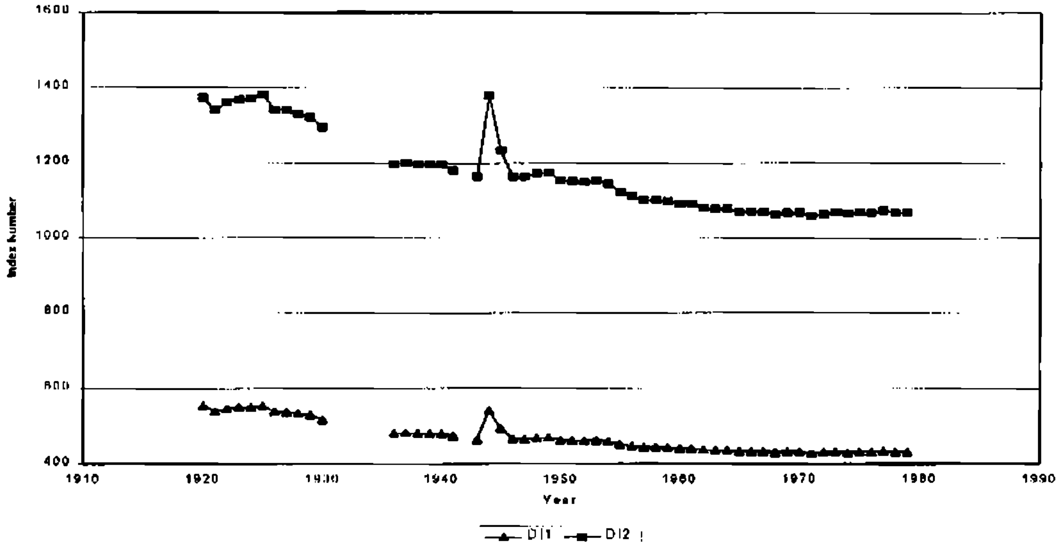
where $T10$, $T50$, and $T90$ refer to the temperature at which 10%, 50%, and 90% of the gasoline is evaporated, respectively. The CRC use a different index, which is given by

$$DI2 = Driveability\ \ Index = T10 + 3T50 + T90$$

In Figure 4, we have the time series for both Driveability Indexes.

From Figures 2, 3, and 4, we conclude that the quality of Leaded Regular Gasoline has increased over this period of time. The question now is whether or not the price for gasoline has taken into account the changes in quality of this product. In Section VI we will construct quality indexes based on the findings found in this Section.

Figure 4. Annual Driveability Indexes



Sources: U.S. Bureau of Mines, "Information Circular". U.S. Bureau of Mines, "Report of Investigations". Motor Gasolines. Various Issues.

V. Prices

At the end of the nineteenth century and beginning of the twentieth century, gasoline was sold in grocery stores, hardware dealers, drugstores, machine and bicycle shops, automobile and implement dealers, and garages. Since these retailers faced little competition, their pricing tactics were often unfair and provoked considerable dissatisfaction among customers. They used to make a profit of 10-15 cents a gallon for filling the gas tank with no other service being provided. Garages charged the highest prices thanks to their strong market position. A greater problem was that they often alter the gasoline by mixing it with kerosene. This situation, poor services and high prices, encouraged the emergence of more efficient and economic retail outlets. One of the first firms to introduce the drive-in station was The Automobile Gasoline Company of St. Louis, which sold gasoline at 8-10 cents a gallon less than the garages in 1907.

The Standard Oil Trust was the leader in the industry from late 1870 to 1911. It set the price structure of the petroleum products and was followed by competitors. The independent oil producers and distributors entering in the southwest market from 1900 and 1911 challenged the Standard's leadership in the fuel oil markets, which extended to gasoline after 1911. However, members of the former Standard Oil Trust continued to play a leading role in the determination of prices in their respective marketing territories after 1911.[16] The market situation during the period 1911-1919 was characterized by the quality competition by offering more services at the drive-in stations or by offering a better gasoline for the same price. One important fact that it must be noted is that the members of the Standard Oil Trust were not competing among themselves. During the 1920s, the Standard companies still were the leaders in setting prices and the effect of their pricing policies was to delay the adjustment between costs and wholesale and retail prices. This gap between costs and prices encouraged many newcomers enter the market by setting lower prices; then they followed the Standard and set a higher price. Major entrants and the established Standard companies engaged in competition by using various forms of non-price discrimination.

The most common strategy to increase sales used by new entrants and Standard companies after World War I was the marketing of different grades of gasoline. Premium gasoline was sold at prices 3-8 cents a gallon above regular grades. It was very popular during the winter among people living in cold climates because of its better starting qualities. On the other hand, the sales of "ethyl" (leaded) gasoline at prices 4 to 7 cents a gallon above premium and regular grades started in April 1923.

During the decade of the 1930s, prices of gasoline were first affected by an increase in crude oil production and the impact of the depression. During 1931, prices dropped in some places as low as 9.5 cents per gallon plus 3 cents of tax. This decade was characterized by some price wars, which usually began at a local level when a particular dealer or supplier attempted to increase sales by offering secret discounts to his customers. The major oil companies tried to offset the effects of price wars on its sales by introducing a "third grade" motor fuel. With lower octane rating than regular gasoline, the third grade motor fuel might compete with the gasoline offered at lower prices. As a result of these price wars, the price for gasoline reached 8 cents per gallon (including tax) in New Orleans in 1933.

After 1933, prices were affected by the controls over the outputs of crude and economic recovery. Moreover, as the leadership and relative market share of the Standard companies were declining, they were no longer able to hold prices while rivals set lower ones in their original sales territories. Neither could they or any other major company fix prices above the levels established by the market conditions. Under these circumstances the prices of refined products were following the laws of supply and demand by the end of the 1930s. The price controls that were in effect during World War II were abandoned in June 30, 1946.[17]

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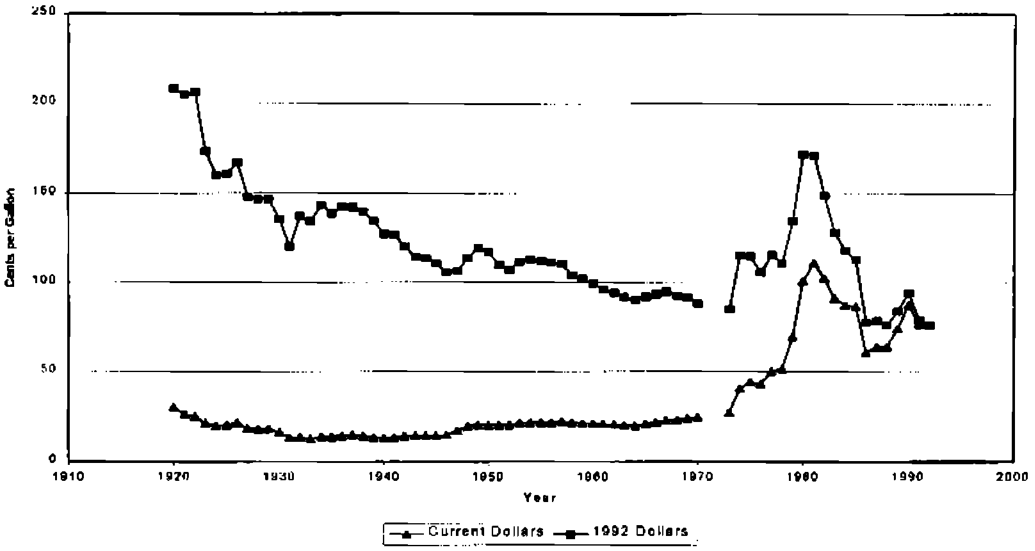
[16] This practice does not imply that the former members of the Standard Oil Trust were imposing higher prices. For example, Standard Oil of Ohio set the prices according to the market forces (Edmund P. Learned, 1960).

[17] Office of Price Administration (OPA) started to decide prices for petroleum products at the end of 1941.

Figure 5. Annual Average Price (Excluding Taxes)



Sources: American Petroleum Institute, *Petroleum Facts and Figures.* Petroleum Marketing Annual. Petroleum Marketing Monthly. Various Issues.

On the other hand, taxes have affected the price faced by consumers. Taxes began to be collected in 1919 when the State of Oregon imposed a retail sales tax of one cent per gallon.

I have prices for leaded regular and for premium gasolines, excluding taxes. We will use only prices for leaded regular gasoline in this paper to compute a quality-adjusted price for gasoline. The annual price series, excluding taxes, are drawn in Figure 5.

We can note the effects of the severe instability in oil prices, which are reflected in the sharp movements in the price for gasoline during the 1970s and 1980s. The Federal price and allocation controls on crude oil implemented after the oil crisis of 1973-1974 established a ceiling on domestic oil prices that kept crude oil prices artificially low. As a result of this policy, motor gasoline prices in the United States remained lower than comparable prices in other parts of the world, particularly Europe. When the oil prices are stable, the principal sources of variation in the retail price for gasoline are the seasonal components. Important in today's complex oil market is the price of oil on the futures market. Gasoline futures began to be traded on the New York Mercantile Exchange in 1981 and crude oil futures in 1983.

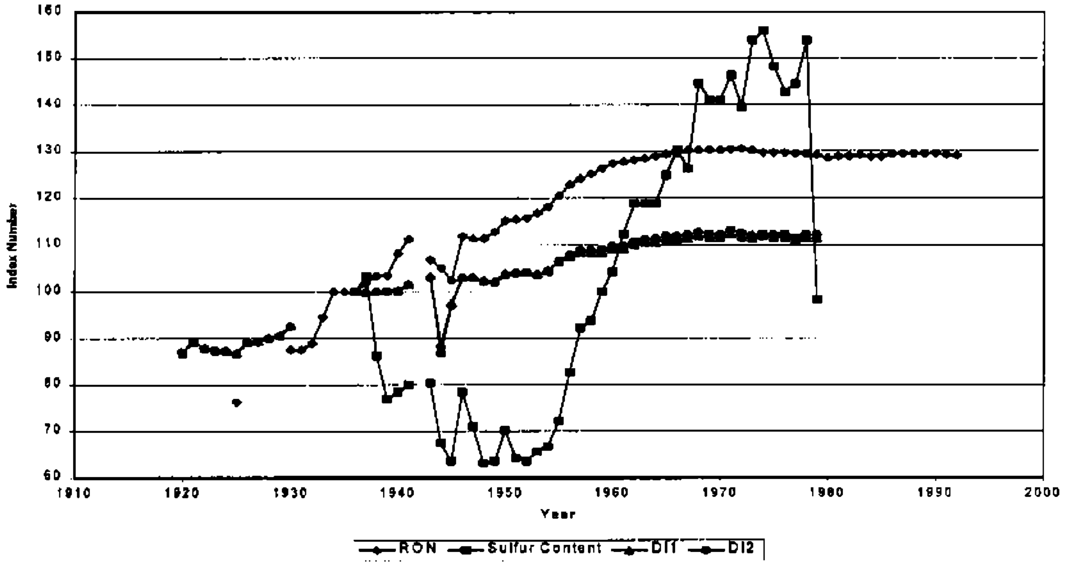
The average price for leaded regular gasoline in 1992 dollars is also given in Figure 5.

VI. Quality-Adjusted Price

Since the series for the summer, winter, and annual measures for octane ratings, sulfur content, driveability indexes, and prices are very similar, we will focus just on the annual series. Also, since the paths for MON, RON, and Antiknock Index series are very similar, we will use the longer one, which corresponds to the RON.

To see how the quality of gasoline has changed in terms of the characteristics given in Section IV, we compute an index for each one of them. These indexes are drawn in Figure 6. We can see that the octane improvements are a good approximation to the over-all improvements in gasoline quality. DI1 and DI2 address the improvements in volatility (easier starting in winter and less vapor locking in summer). Sulfur content points out the reduction in corrosion and the better odor of gasoline. Moreover, since the petroleum and automobile industries have emphasized mainly the importance of higher octane ratings, I will focus just on the octane measures. Thus, I assume that the over-all quality improvements of gasoline are proportional to the improvements in its antiknock ratings.

Figure 6. Quality Indexes

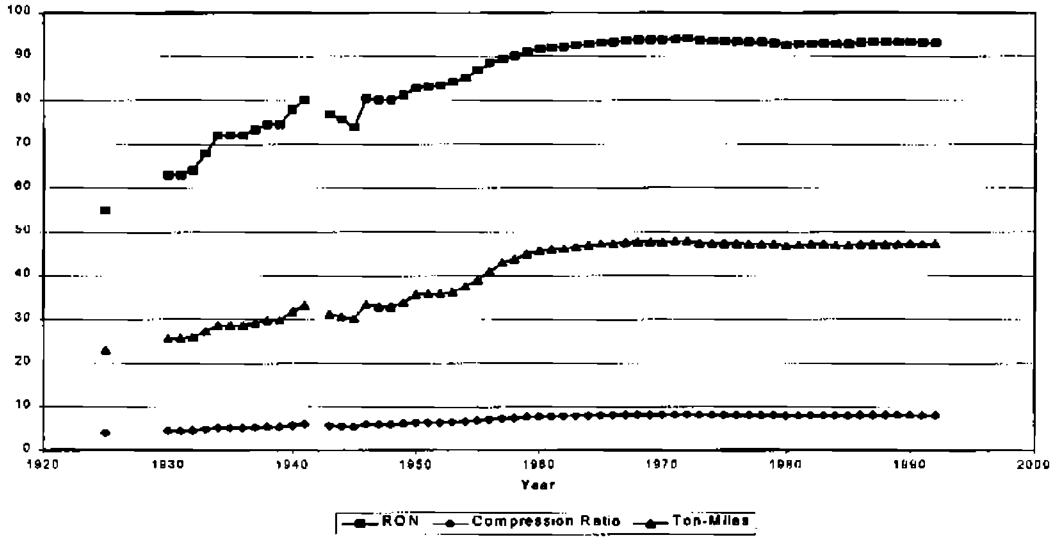


In order to compute a price that takes into account these improvements in the quality of gasoline, we must relate the octane numbers with some measure of performance. We know that a gasoline with higher octane rating allows the use of an engine with a higher compression ratio, which in turn gives more power to the engine. For example, a gasoline with an octane rating of 55 allows the use of a compression ratio of 4.01; a gallon of this fuel carries one ton at a speed of 40 mph for a distance of 23 miles. On the other hand, a gasoline with an octane rating of 93 allows the use of a compression ratio of 8.0; a gallon of this fuel moves the same weight at the same speed for 47 miles.

This example raises the concern about whether or not the engines could take advantage of the increase in the gasoline's octane ratings. If that is the case, we can assign the full gains in mileage to the increase in the gasoline's octane rating. However, if that is not the case, we must then take into account the costs of improving the engine design to take fully advantage of the improvements in the quality of gasoline. In this case, only a proportion (or in the worst case, none) of the gain in mileage can be attributed to gasolines with higher octane ratings.

The automobile industry and the petroleum industry have found that it is costly to increase the engine's compression ratio and the octane ratings of the gasoline, respectively. Moreover, they must know whether or not they can match the increase in the requirements of each other's product. For these reasons, higher-octane gasolines and higher-compression ratios have gone hand in hand. Therefore, we can assume that at each point in time, the automobile industry can take fully advantage of the higher octane ratings.

Figure 7. RON, Compression Ratio, and Ton-Miles per Gallon

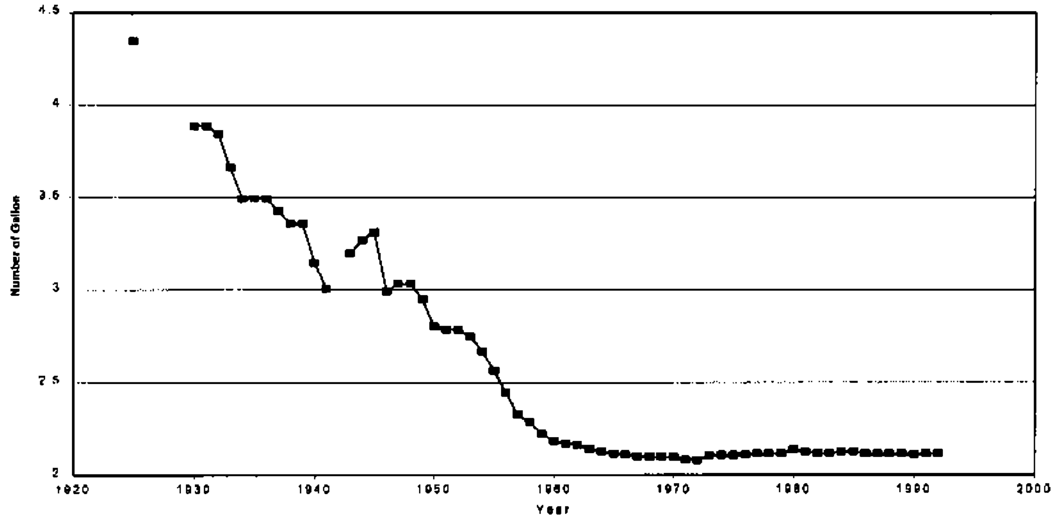


Sources: U.S. Bureau of Mines, "Information Circular". U.S. Bureau of Mines, "Report of Investigations". Motor Gasolines. National Petroleum News, *Market Facts 1993*. National Petroleum News, *Fact Book*. Various Issues. Murphree, E.V., Cunningham, A.R., Haworth, J.P., and Kaulakis, A.F. (1953). "The Trend to High Octane Number Gasoline is Sound". Paper presented at SAE Metropolitan Section Meeting, New York, October 15.

Given this assumption, I can assign the full gains in mileage to the higher octane ratings of gasoline. Thus, we need to find the compression ratio and the ton-miles assigned to each octane rating in order to get a quality-adjusted price for gasoline. In Figure 7, we have the time series for the compression ratio, the ton-miles, and the annual average of RON corresponding to leaded regular gasoline.

With this information, we compute the number of gallons of gasoline that are needed to transport one ton at a speed of 40 mph for a distance of 100 miles. This is given in Figure 8.

Figure 8. Gallons of Leaded Regular Gasoline Required to Move One Ton at a Speed of 40 mph for a Distance of 100 Miles



The cost (in current and in 1992 dollars) of moving one ton at a speed of 40 miles per hour for a distance of 100 miles is given in Figure 9.

This measure is taking into account the improvements in the gasoline's quality.[18] We can see that this cost (in 1992 dollars) has decreased all the way, except for the period of time when the oil crisis affected this industry. Thus, by 1992 that cost was about 4.3 times lower than it was in 1925.

In Figure 10, we have three price indexes; one for the official price of gasoline and the other for the quality-adjusted price of gasoline computed above; we also include the CPI. 1925 is taken as the base year. We have that the official price of gasoline has increased more rapidly than the quality-adjusted price. The average

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[18] In this analysis, the increase in quality is measured by the increase in the octane rating of the gasoline. However, there is another important gain that is not taken into account in the computation of this quality-adjusted price, the increase in the yield of gasoline per barrel of oil. This quality improvement is taken into account by the official price.

annual bias (the rise in the official price relative to the true price) is 3.2% per year over the 1925-1992 period.

Figure 9. Cost of Transporting One Ton at a Speed of 40 mph for a Distance of 100 Miles

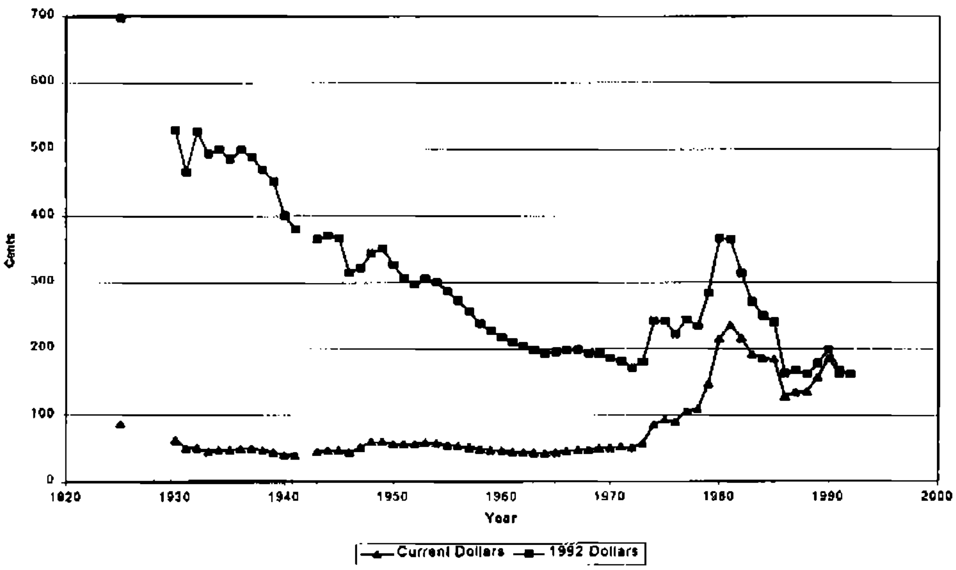
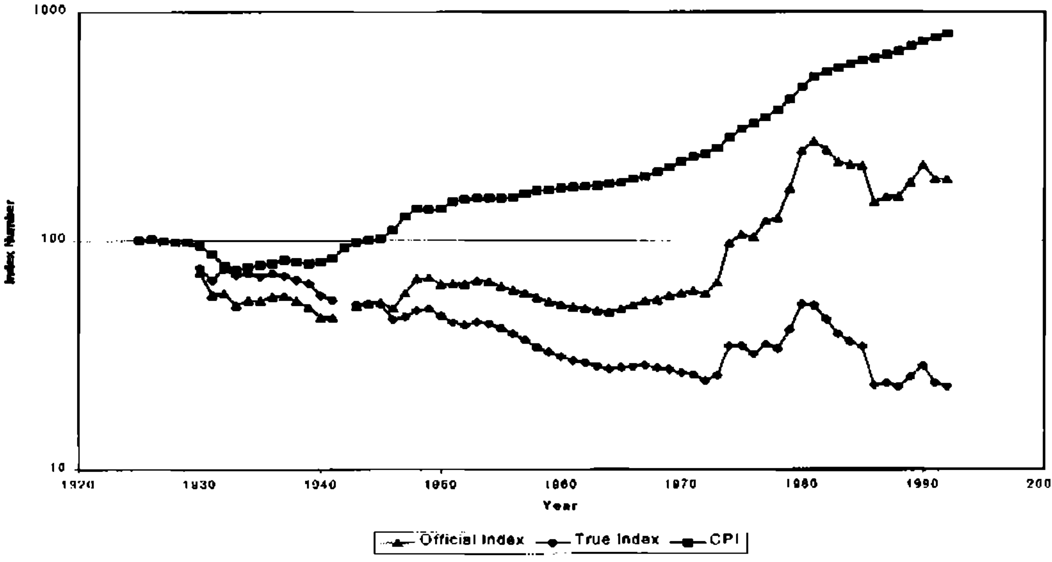


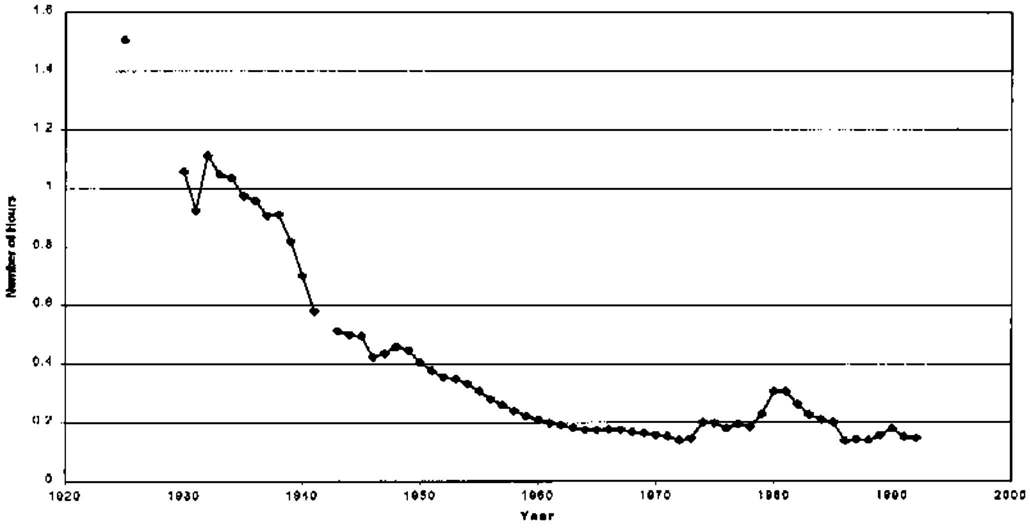
Figure 10. Price Indexes for Leaded Regular Gasoline and CPI (1925=100)



The difference between the two price indexes for gasoline has been growing over time. These same trends are also found for the summer and winter series.

Finally, since we are using the CPI in our analysis and we find that it is misleading, we turn to the average hourly wage required covering that cost. We can compute the labor cost of moving the same one ton at a speed of 40 mph for a distance of 100 miles. The number of hours that a worker needs to work in order to cover that cost is given in Figure 11. We can see that in 1925 a worker needed to work almost 1.5 hours in order to get enough income to pay that cost. However, in 1992, a worker needed to work just about 8 minutes.

Figure 11. Hours of Work Needed to Move One Ton at a Speed of 40 mph for a Distance of 100 Miles



Therefore, from Figures 9, 10, and 11, we clearly see that the official price index for gasoline has not accounted for the improvements in the quality of this product. Moreover, if we assume that the change in quality of gasoline is a good proxy for the change in quality in all the other products from the petroleum refining industry, we can guess that the actual consumer price index has missed much of the improvements in quality in this industry.

VII. Conclusions

We have computed a quality-adjusted (a "true") price for gasoline. This gives us the total cents that are needed to move one ton at a speed of 40 mph for a distance of 100 miles. By doing that, we take into account the improvements in the quality of gasoline, measured by the octane ratings of the leaded regular gasoline from 1925 to 1992. In order to make this calculation I have assumed that the compression ratio has increased at the same pace as the octane ratings. This is a reasonable assumption given the strategies followed by the petroleum refining industry and by the automobile industry. They have tended to go hand in hand in their developments on compression ratios and octane ratings.

We find that the official price index for gasoline has increased more rapidly than the quality-adjusted price index for gasoline. On average, the upper bias in the official price is 3.2% relative to the true price. This means that the actual calculation of the price for gasoline is misleading. It has missed much of the improvements in the quality of gasoline.

Since we are using the CPI in our analysis, which we find is misleading, we turn to the average hourly wage needed to cover the cost of carrying one ton at 40 mph for a distance of 100 miles. We find that the number of hours to cover that cost has decreased from almost 1.5 hours in 1925 to about 8 minutes in 1992. Therefore, we confirm our findings that the official price index misses the quality changes of gasoline.

Finally, if we take this as a proxy for the complete petroleum refining industry, we might guess that the price index has missed much of the improvements in the quality brought in by process innovations in this industry.

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