MINING DEMAND AND SUPPLY DATA WITH METHODS OF ECONOMIC STATISTICS

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ABSTRACT

This paper presents a data mining approach for demand and supply data arising from economic statistics. It is based on demand and supply functions with different types of price elasticities, which can be used to identify interesting patterns and data dependencies. Constant, directly proportional and linear price elasticities are considered.

1 INTRODUCTION

In economics, the amount of a good that consumers are willing to buy at a given price, holding constant the other factors that influence purchases, is the *quantity demanded*. The relationship between the unit price and the total quantity desired by consumers is described by the demand curve. It is downward sloping (with some theoretical exceptions, such as Veblen and Giffen goods) because of the *law of demand* [1], which says that people will buy more of a service, product, or resource as its price falls. On the other hand, the *quantity supplied* is the amount of a good that firms want to sell at a given price, holding constant other factors that influence firms' supply decisions, such as costs and government actions. The relationship between the unit price and the total quantity offered by producers is described by the supply curve, which is upward sloping (with some important exceptions, such as if the seller is badly in need of money or if he wants to get rid of his products) because of the *law of supply* [1,2], which says that the price increases with the quantity. In the case of oil, this can be explained by the fact that small quantities will be supplied using the most efficient oil plant available, but that as quantity increases, producers will have to use less efficient oil plants with higher production costs.

When we plot the supply and demand curves for a product on the same graph, they intersect at the price where the amount producers are willing and able to supply equals the amount consumers are willing and able to purchase. The price and quantity where supply and demand meet are called the *equilibrium price* and *equilibrium quantity,* respectively [2]. If suppliers ignore demand and continue to produce units and price them too high, they will not be purchased but instead sit in the warehouse. If they produce too few, demand will go unmet and consumers will claim for more. Of course, the equilibrium varies with the observed good, service, or resource. Moreover, the equilibrium changes if a 'shock' occurs such that one of the variables we were holding constant changes, causing a shift in either the demand curve or the supply curve.

2 PRICE ELASTICITY

A measure used in economics to show the responsiveness of the quantity demanded (or supplied) of a good or service to a change in its price is called *price elasticity* of demand (or supply). It was defined by Alfred Marshall [3] as the percentage change in quantity in response to a one percent change in price, holding all the other factors constant:

$$\varepsilon = \frac{\frac{dQ}{Q}}{\frac{dP}{P}}.$$

Here, Q is the quantity demanded (or supplied) and P is the price. If Q is the quantity demanded, then ε is the price elasticity of demand and the above formula yields a negative value for exactly those goods that conform to the law of demand, which is due to the inverse nature of the relationship between price and quantity. On the contrary, while price elasticity of demand is usually negative, price elasticity of supply is usually positive, due to the direct proportion between price and quantity supplied as stated by the law of supply. Depending on whether the elasticity is greater than, equal to, or less than -1 for demand (and 1 for supply), the price elasticities for a good, service, or resource are described as relatively inelastic, unit elastic, or relatively elastic [2].

For analytical convenience in theoretical demand (and supply) analyses, a special kind of functions for which the price elasticity is constant for all price levels and all price changes is frequently used. Since the percentage changes depend on both amount of the change, or the unit change, and the starting point, or base value, of the change, slope and elasticity are different concepts. For instance, even though the slope of a linear demand (or supply) curve is constant, the elasticity is *not* constant along this curve, a straight line. This is because unit changes are identical for each segment on the line, but the base values are not. The special type of demand or supply curve for which the price elasticity is the same at every point along the curve is given by

$$Q(P) = AP^{\varepsilon},$$

where A is an arbitrary constant. Constant elasticity assumes that consumers and providers are equally sensitive to price changes whatever the price may be. Several studies, however, indicate that this is not always true by showing that price elasticity can be non-constant [4,5,6]. In particular, while the elasticity of demand usually decreases with price, the elasticity of supply usually increases with price. We shall thus consider elasticity that is directly proportional to the price level,

$$\varepsilon = aP \text{ with } Q(P) = Ae^{aP},$$

as well as elasticity that is linearly dependent on the price level,

$$\varepsilon = aP + b \text{ with } Q(P) = Ae^{aP}P^{b},$$

where a and b are constants. Linear price elasticity decreases with price if $a<0$ and it increases if $a>0$. In the case of oil, when the price increases, most consumers become more sensitive to price changes, which can be modelled using constants $a>0$ and $b<0$, in contrast to the suppliers, which become less sensitive since they have more freedom to use less efficient oil plants with higher production costs, which can be modelled using $a<0$ and $b>= 0$. In addition, a and b having the same sign are characteristic neither for demand nor for supply. Since price elasticity of demand is usually negative, $a<0$ and $b<0$ would mean that the consumers become more and more insensitive to price changes when the price increases, which is highly unrealistic. Similarly, since price elasticity of supply is usually positive, $a>0$ and $b>0$ would mean that the suppliers have unlimited production capacities.

For constant-elasticity functions demand and supply are perfectly reversible with respect to prices, which is analytically convenient since it allows us to uniquely associate the amount of demand or supply with price (injectivity). Although elasticity that is proportional to the price level does not cause irreversible demand (or supply) effects, linear elasticity causes them for some pairs of constants a and b (i.e., as soon as $ab<0$ or $a=b=0$). Linear or piecewise linear price elasticity models have been used in economics, marketing and business before but only to a limited extent [7,8,9,10]. This may be due to the fact that, until very recently, the class of all demand and supply functions with linear price elasticity has not been sufficiently theoretically studied [11].

We can use demand functions with different types of price elasticities (constant, directly proportional, linear) to search for or extract interesting patterns and dependencies from a chosen data set.

3 MINING U. S. OIL IMPORTS DATA

We focus on the data set named *Monthly U. S. Oil Imports*, which contains the data about 1000s of oil barrels purchased, the total value of oil and the unit price in $ for every month of the years 1973-2007. It was published by the Foreign Trade Division of the U. S. Census Bureau (http://www.census.gov/foreign-trade/). The monthly movements of purchased quantity and the unit price are shown in Figure 1.

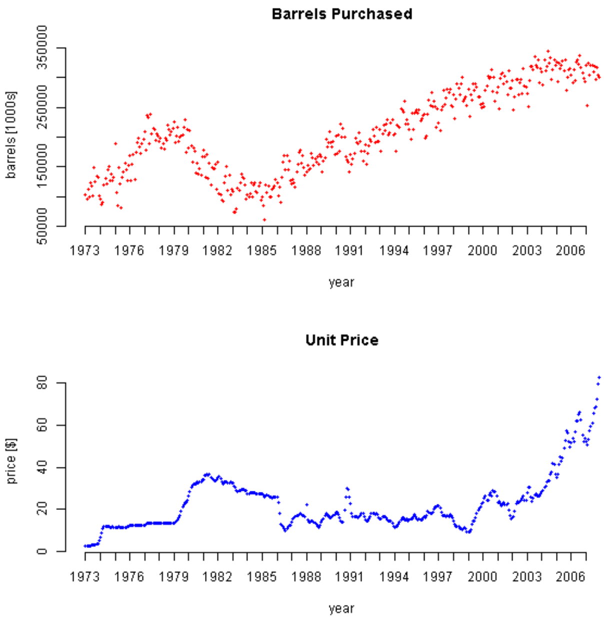

Figure 1: *Monthly U. S. oil imports in the years 1973-2007. The unit price is not adapted to inflation.*

In 2012, the United States produced 60 % of the petroleum (crude oil and petroleum products) it used, the remainder being imported. The largest sources of imported oil were Canada, Saudi Arabia, Mexico, Venezuela, and Russia. Oil imports into the US peaked in 2005 when imports supplied 60 % of US consumption. They have declined since, due to increased domestic oil production and reduced consumption [12]. However, in Figure 1, the most visible peak of imported oil quantity is when the U. S. created the strategic petroleum reserve to augment supply in case of a national emergency. It started in 1975 after oil supplies were cut off during the 1973-74 oil embargo.

We have divided the oil imports data in groups by years. For every year, least-squares regression analysis with three different regression functions has been performed: (1) constant price-elasticity function, (2) directly proportional price-elasticity function, and (3) linear price-elasticity function. The regression results for oil imports in the year 1980 are shown in Figure 2.

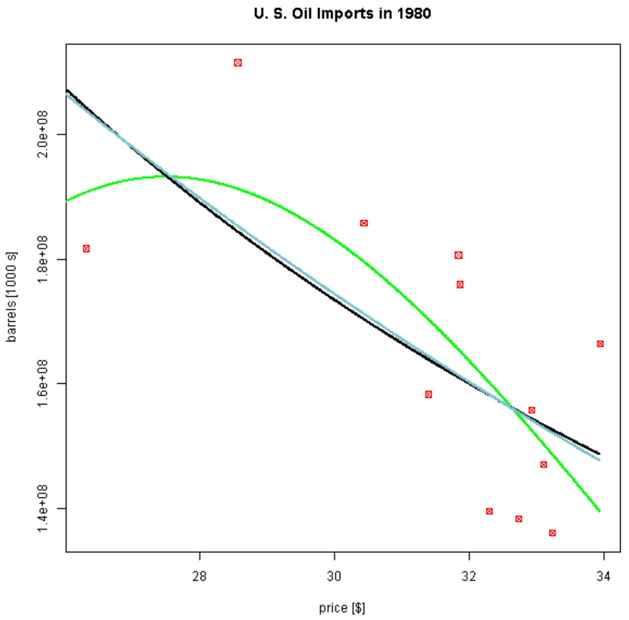

Figure 2: *Regression curves for U. S. oil imports in 1980. The black curve has constant price elasticity (R^2=0.43), the light blue curve has directly proportional price elasticity (R^2=0.44), and the green curve is the most general curve with linear price elasticity (R^2 =0.51).*

Of course, the best fit is obtained by the most general linear price-elasticity functions, but only for 11/35 of the observed years the goodness of fit and the statistical significance of the estimated parameters are high enough ($p<0.05$) to derive valid conclusions. The constant price-elasticity functions and the directly proportional price-elasticity functions, on the other hand, both produce 9/35 statistically significant regression models. The models' price elasticities are given in Table 1.

	constant ($\varepsilon = b$)	directly prop. ($\varepsilon = aP$)	linear ($\varepsilon = aP + b$)
1973	-	-	*-1.44P + 5.57*
1974	*0.71*	*0.08P*	*0.95P - 8.06*
1980	*-1.25*	*-0.04P*	*-0.50P + 13.69*
1987	*1.58*	*0.10P*	*1.36P - 20.07*
1990	*-0.41*	*-0.02P*	*-0.00P - 0.40*
1992	*0.77*	*0.05P*	*-0.40P + 7.23*
1994	*0.64*	*0.05P*	*0.20P - 2.15*
1997	*-0.73*	*-0.04P*	*-0.23P + 3.65*
2001	-	-	*-0.36P + 6.93*
2003	*-0.83*	*-0.03P*	*-0.28P + 6.88*
2006	*0.43*	*0.01P*	*0.09P - 4.74*

Table 1: *Yearly elasticities of U. S. oil imports.*

Interestingly, some of the determined price elasticities are characteristic for demand ($\varepsilon<0$), others are characteristic for supply ($\varepsilon>0$). Linear price-elasticity models with $a>0$ and $b<0$ indicate that the U. S. government was more sensitive to price changes when the price increased, which corresponds to the law of demand. On the other hand, models with $a<0$ and $b>0$ indicate that the U. S. government was less sensitive to price changes when the price increased, which is atypical for consumers. This behaviour may be explained by continuously high prices or an extreme need for oil (e.g., in years 1980, 1990, 1992, 1997, 2003).

The means of the models' yearly coefficients of determination R^2 are *0.56*, *0.57* and *0.63*, respectively, and the corresponding mean p-values for the F-test are *0.008*, *0.007* and *0.017*. Another interesting regression observation is a sequence of highly insignificant models between 1975 and 1985, which indicates an atypical, unpredictable oil purchase during the creation of the U. S. petroleum reserve.

Furthermore, assuming linear price elasticities, we have defined *monthly price elasticities* as

$$\varepsilon_i = \frac{\frac{Q_i - Q_{i-1}}{Q_i}}{\frac{P_i - P_{i-1}}{P_i}}$$

and *monthly elasticity slopes* as

$$a_i = \frac{\varepsilon_i - \varepsilon_{i-1}}{P_i - P_{i-1}}.$$

The monthly elasticity values for the oil imports data are shown in Figure 3.

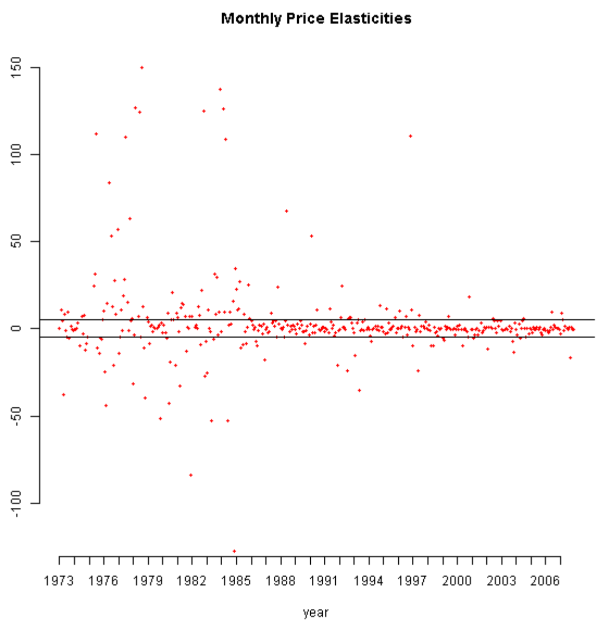

Figure 3: *Monthly price elasticities in the years 1973-2007. The black horizontal lines are the limits of the region with* $|\varepsilon_i| \le 5$.

A similar picture aroused for the monthly elasticity slopes. From this we have concluded that the responsiveness of the imported oil quantity to a change in its price stabilized with the years. No other interesting patterns have been observed.

The monthly price elasticities (and the monthly elasticity slopes) could even be used to automatically detect *stable* time intervals in which the purchased quantity changes as directed by the price change and in accordance with an assumed type of price elasticity. Hence, the advantage of this approach compared to regression is that we do not need to analyze observations in predetermined time intervals, but only monitor the changes that happen from observation to observation. When the changes of monthly price elasticities and/or monthly price elasticity slopes are substantial, boundaries between stable time periods may be set. Substantial changes or instabilities can occur for various reasons, including oil embargos, wars and other drastic changes in the population size or governmental policy. On the other hand, usual changes in the population size or undramatic inflations should not cause substantial differences in the price elasticities or price elasticity slopes.

4 CONCLUSION

We have proposed a data mining approach for demand and supply data arising from economic theory and applied statistics. It is based on demand/supply functions with different types of price elasticities, which can help us searching for interesting patterns and data dependencies.

In this paper, we have applied the approach on U. S. oil imports data, and it has given some useful results. For instance, we have detected an 11-year period of highly unstable oil imports data, which indicates radical changes (the creation of the U. S. petroleum reserve) in the governmental actions. Also, local peaks of purchased quantity have been detected by linear price-elasticity models atypical for demand. In addition, monthly price elasticities and monthly price elasticity slopes have been introduced as a method for detecting stable time intervals. Within stable time intervals, all the other factors except quantity and price may be considered constant, and price elasticities as defined by Marshall [3] may be determined using statistical regression.

Unfortunately, due to a large number of factors that influence oil imports the data analysis was quite complex and not as clear as it could be. A thorough empirical analysis on simpler demand and supply data thus needs to be performed to see the real potentials of the approach.

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