Energy Demand Elasticity Survey: A Primer and Progress Report

by

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Abstract

Tight oil and gas markets with high and rapidly rising prices and pundits' warnings of peak oil have again put energy in the news. Many want to know how much and when demand will respond to these high prices. (e.g. Will Americans give up our Humvees for more humdrum horsepower.) Conventional wisdom suggests that there will be little quantity response to these prices, at least in the transportation sector. However, decades of econometric work suggests otherwise. Although the response is small in the short run, over time consumers do adjust. High prices in the 1970's caused a switch in the U.S. to smaller cars in the early 1980's, much to the chagrin of Detroit. Low prices and high income in the 1990's caused a switch in the U.S. towards sports utility vehicles (SUVs), much to the delight of Detroit. At the Colorado School of Mines, we are currently working on a large project seeking to answer such questions as how much and when energy demand responds to a variety of variables for all types of energy products. Our goal is to critically analyze the existing work, summarize what we can learn from the existing studies, consider areas for promising future work, and raise the quality of analysis by creating a check list of what constitutes superb craftsmanship in energy demand analysis. This article is a progress report on our larger study. We consider the definition and uses of energy demand elasticities, the historical evolution of demand theory and empirical studies, provide a check list for reseachers and referees to consider when doing and evaluating econometric demand work, and provide an example summary of elasticities for gasoline

1 Introduction: Energy Elasticities and Their Uses

The concept of price elasticity of demand is thought to have been first verbally articulated by Cournot(1938). Marshall (1890) mathematically described and popularized the concept while Moore (1929) generalized it to include cross price elastiticies and use of partial derivatives.

Intuitively, the elasticity of demand for energy (ε_X) with respect to variable X (ε_X) shows how much energy consumption (E) responds to a change in variable X. We can more formally write the definition of elasticity as the percentage change in energy consumed divided by the percentage change in variable X or

$$\varepsilon_X = \frac{\frac{\Delta E}{E}}{\frac{\Delta X}{X}} \tag{1}$$

In economic analysis, it is most commonly written in either of two derivative forms as

$$\varepsilon_X = \frac{\partial E}{\partial X}\frac{X}{E} \tag{2}$$

$$\varepsilon_X = \frac{\partial log(E)}{\partial log(X)} \tag{3}$$

These popular measures are simple, intuitive, units free, and have a variety of uses in economic reasoning. Demand curves can be formed from elasticities for use in forecasting and policy analysis. They help indicate:

- how energy consumers will respond to rising energy prices,
- how easily a market can respond to energy disruptions,
- how energy taxes and subsidies will be distributed across suppliers and demanders,
- the effects of energy taxes and subsidies on government budgets,
- how energy prices and sales will change across the business cycle,
- how demand changes as countries develop,
- how fast renewable fuels might be phased into the market,
- the size of environmental policies, such as carbon taxes, necessary to meet evironmental objectives, and
- the welfare effects of price and policy changes by forming compensating or equivalent variation functions

Elasticities of substitution, developed by Hicks and Allen, considered in the larger report are also crucial imputs into nested Constant Elasticity of Stubstitution (CES) for use in computable general equilbrium analysis.

In the next section, I consider a brief history containing both the theory of demand and empirical studies. A more complete survey with much more theoretical detail will be given in the longer report. However, this paper will try to touch upon many of the issues that will be considered in more detail in the longer report.

2 History of Demand Analysis in Theory and Practise

Scientific work evolves in layers, with new layers building on the past and expanding the level of understanding. When conducting any scientific study, a quality piece of work will consider the work that already has been done, put the new work into the context of this preceding work, and clearly indicate what contribution the study makes and how it moves the discipline forward. When conducting survey work, an historical perspective also helps give a deeper understanding of the topic. Thus, I begin with a brief history of both empirical demand work as well as the evolution of the theory of demand. Although this survey is primarily interested in empirical estimates of

demand, quality empirical work rests upon a strong theoretical foundation - so you can't have one without the other.

The first theoretical demand curve is thought to be Verri's 1771, hyperbolic demand curve, price times quantity equal to a constant (PQ=c). The more general demand schedule Q = f(P) was defined by Cournot (1838) and popularized by Marshall (1890). Although many budget studies looked at expenditure by goods, income was not formally considered in consumer theory until Slutsky (1914) and Hicks and Allen (1932)

Stigler (1954) summarizes work on consumer demand up to Henry Moore in the 1920's. In the early years of demand analysis, theoretical and empirical work evolved independently. The effect of price on quantity demand and income on quantity demand were also separate lines of research. Stigler (1954) found four early quantititative studies that tabularly relate price and quantity. The first empirical demand schedule relating quantity to price that we know of, variously attributed to Davenant or to King, was published in 1696 by Davenant. It is a Table that related the deficiency of the corn crop to the price of corn above the common rate. Engel (1861) used data on Prussian rye from 1846-61 relating the deviation of harvest to the deviation of prices from their means. Laspeyres, of index fame, compared the percent of fourteen year potato harvests to the percent of 14 year prices to their averages for Saxony potatoes in 1875. Farguhar in 1891 compared changes in per capita production of potatoes to the changes in their value. He generalized his tabular results into what is close to an elasticity when he concluded that for a 1% crop variation there was a 1.3 % price variation in the opposite direction. Although none of these studies considered energy demand, they tried to develop general laws of demand and set the stage for further work.

Stigler (1954) argues that in the late 1800's, advances in statistics spurred more formal studies of demand including regression analysis and he summarizes a number of them. Benini (1907) did multiple regression and included an own and a cross price in his demand equations. Gini (1910) included the first known energy price elasticity, with an own household price elasticity for petroleum of (-0.65). He concluded that elasticities were smaller the more necessary the good and that elasticities declined as wealth increased. Lenoir (1913), considered by Stigler to have founded statistical demand curves, is unique because he developed a theory of demand and supply along with his empirical studies. He recognized the problem of identification (separating demand from supply) and noted that the short run shifts in supply such as in agricultural products would help identify a demand curve, whereas for industrial goods, such as coal or castings, supply might be relatively stable in the short run but shifts in demand would help identify the supply curve.

Moore is considered by Stigler to be the father of quantitative economic theory. Stigler (1954) notes that four necessary developments had occurred to enable Moore to proceed with his statistical work. Marshall and Pareto had formulated the necessary economic theory, government data collections were improving, statistical theory had improved, and mechanical calculators eased the computation burden.

Stigler cites three goals that appear in Moore's empirical work:

- to test abstract theories
- to estimate parameters of theoretical models
- to develop general economic laws

These goals are as relevant to empirical work today as they were when Moore begin his empirical explorations in 1911 and they will be important criteria for me in evaluating more recent empirical

studies. Although Moore's work is primitive by modern standards, Stigler considers Moore's three fundamental contributions to be:

- reliance on theory, albeit weak theory,
- search for causation, and
- use of empirical estimation as an integral part of his economic investigations.

Stigler also notes Moore's superb craftsmanship with clear and careful exposition of both his data and methodology. After wading through hundreds of studies, I can clearly appreciate such a tendency and careful and complete exposition of data and methods will have considerable weight in my article evaluation scheme.

Although Moore recognized other things besides price were not equal in the real world, as Marshall had assumed, he did not make the leap to control for those other things in his statistical investigations except for the general price index. Moore had more influence on agricultural economists at the time than on the more general economics profession and many agricultural demand estimates were made in the 1920's and 1930's including those of his best known student Henry Schultz.

Stigler (1954) also traces the empirical evolution of demand and income studies. Davies (1975) conducted a U.K. budget study considering the percent of household expenditures on different goods at different income levels for agricultural workers. His tabular results suggest that household expenditures on fuel average around 3 % with an increasing and then decreasing share as households get richer. Government data collection as the result of worker unrest in the mid 1800's led to a number of budget studies. The most famous of these is Engel (1857) in which his famous law that the share on food expenditure falls as household expenditure increases. In subsequent analysis, Engel (1985) found that the percent of household income spent on clothing rose and the percent spent on housing, fuel and light fell as expenditure increased. In his Belgian workmen budget data for 1853, fuel and light was between 5 and 6 % of family expenditure.

Curve fitting also progressed in income studies at roughly the same time and pace as for the price studies. Ogburn (1916) fit curves for a number of expenditure categories on 200 housholds for the District of Columbia in 1916. He included family size in one of his formulations and found an income elasticity of demand for fuel and light of 0.73. [Stigler (1954)]. Allen and Bowley (1935) consider 23 sets of budget data that include fuel and light for the U.S. and various European countries. Average fuel and light expenditures varied from 1 to 6 % of total expenditures across the various budgets and the income elasticity of family expenditure varied from 0.2 to 0.9.

Schultz (1938) became the standard work on demand analysis at the time. He brought together the theortetical work including both income and price on quantity demanded. He also incorporated price, income and other prices into his empirical analysis. He included estimates on linear and log linear functions. He found that he got different functions depending on whether price or quantity was the dependent variable. He suggested that theory be relied on to pick the dependent variable, but if theory did not provide the answer then the choice became an empirical question with the best statistical fit providing the answer.

Empirical developments followed the theoretical developments and researchers started to use the constraints suggested by theory in their estimation. Stone (1954a) started with a linear in the logs demand function. He then used the Slutsky decomposition of demand elasticities and homogeneity restrictions to get his estimating equation

$$logX_i = \alpha_i + \beta_i log(\frac{Y}{P}) + \sum_{j=1}^{N} \beta_{ij} \frac{P_i}{P} \tag{4}$$

Where X_i is the quantity demanded for good i, Y is total income, P is a price index for all goods, and P_i is the price of good i. Because Stone has a small sample (1920 - 38) with few degrees of freedom, he estimated β_i, the expenditure elasticity, separately from budget data. To reduce serial correlation, he estimated the model in first differences. The elasticities estimated from this model are compensated elasticities. To further increase the degrees of freedom, he deleted compensated cross price elasticities between goods he believed were not substitutes or complements to each other.

In the first systems modeling approach, Stone (1954b) further reduced the number of estimated parameters by including adding up, homogeneity, and symmetry conditions. In an N good model, there are $N^2 + N$ estimated coefficients. Deaton and Muellbauer (1980) note that Stone's assumptions reduce the number of estimated coefficients to $(N-1)(\frac{1}{2}(N+1)$.

Stone starts with the function:

$$P_i X_i = \beta_i X_i + \sum_{j=1}^{N} \beta_{ij} P_j \tag{5}$$

After adding in the three restrictions, he ends up with the famous linear expenditure system:

$$P_i X_i = P_i \gamma_i + \beta_i (Ex - \sum_{j=1}^{N} P_j \gamma_j) \tag{6}$$

where Ex is expenditures. The choice of the above functional form yields only $2N$ parameters to be estimated, of which, only $2N-1$ are independent. Since the above function contains parameters from other equations, it is the first known example of a whole system being estimated. Further, since it is not linear in its parameters, β's and $\gamma's$, Stone estimated it using a cumbersome iterative procedure. Stone has six categories of goods, but none of his categories include only energy. Fuel and light are included in his household operation category, for which he finds an expenditure elasticity of 1.2 and a price elasticity of -0.6 on U.S. data for 1920-38.

The linear expenditure system model is quite restrictive because it does not allow complementary goods without the violation of principles of utility maximization. [Deaton and Muellbauer (1980)]. Much subsequent work on consumer expenditure systems sought to develop more general models including the Rotterdam, Almost Ideal Demand System (AIDS), and Translog Models. A desirable property sought in such models was the ability to test rather than impose the restrictions implied by utility maximization. (For summaries of these models see Deaton and Muellbauer (1980)). Banks et al. (1997) apply a further variant, the quadradric almost ideal system (QAIDS) to five household categories including fuels and Nicol (2002) applies the model to six household categories including gasoline. In addition, non-parametric and semiparametric techniques have been developed. For example, Hausman and Newey (1995), Schmalensee and Stoker (1999), and Yatchew and No (2001) apply such techniques to gasoline demand.

When such models are applied to household budget data often many demographic, spatial, and household characteristics are included. For example, see Halvorsen and Larsen (2001b) for an application to Norwegian electricity demand.

By the time of Marshall, producer theory recognized that factor demands in a competitive market should correspond to marginal revenue products. We know that such a marginal revenue product can be derived from output price and the production function. According to Schumpeter (1954), the concept of a production function was clearly know by 1900, but its exact paternity is not known. Wicksteed formally wrote down a production function, but other marginalist also contributed to its formulation.

Hicks (1939) and Samuelson (1949) mathematically formalized the marginal revolution into the mathematical elegance of neoclassical econonomics using calculus and optimization. Consumer demand curves are derived by consumers maximizing utility subject to a budget constraint and factor demands are derived by producers maximizing profits or minimizing costs subject to an output contraint.

There were post World War II forays into set theory and the axiomatic approach to consumer and producer theory, which did not require the neoclassical smooth continuous functions of differential calculus. However, empirical estimation of continuous demand functions, even today, usually falls back on the neoclassical calculus optimization approach for its theorectical underpinnings.

Empirical work on producer theory, did not at first focus on factor demands but more often took the form of estimating the production function beginning with the classic study by Cobb and Douglas (1928) and extended by Douglas (1948). Their function held empirical sway until it was superceded by the constant elasticity of substitution, introduced by Dickinson(1954) and popularized by Arrow et al. (1962). However, none of these studies contained energy as a factor or production.

Neoclassical theory assumed that factor demands were derived by maximizing profits given input and output prices and technology that was represented by a production function, while consumer demands were derived by maximizing utility subject to a budget constraint. Duality works out other ways of representing producer and consumer optimal sets and deriving demand equations. If we substitute factor demand functions back into a cost function, we get costs as a function of input and output prices prices. Shepherd (1953) has shown that the derivative of this indirect cost function yields a demand function. Thus, demand can be derived more easily starting with an indirect cost functon. If demand functions are substituted into the profit function, we get an indirect profit function. Hotelling has shown that the derivative of the indirect profit function with respect to output price yields the output supply function and minus the derivative with respect to input prices yield factor demands. These producer duality relationships are summarized in Figure 1.

If we substitute consumer demand functions back into a utility function, we get utility as a function of prices and income called the indirect utility function. Roy has shown that the derivative of this function with respect to price of good X divided by the derivative of this function with respect to income yields normal or what are often called Marshallian demand curves. If one solves the indirect utility function for income, it gives the minimum expenditure required for a given level of utility. The derivative of the indirect profit function with respect to output price yields what are compensated or Hicksian demands. In such functions, the consumer is compensated enough for a price change to leave real income constant. These duality relationships are summarized in Figure 2.

An important implication of duality theory for demand estimation is that you can develop systems of demand functions by differentiation that are consistent with economic optimization behavior. This derivation is typically easier than maximizing utility subject to a budget constraint or maximizing profits given the production function. This is particularly true as production and utility functions

Figure 1: Duality Relations between Producer Concepts

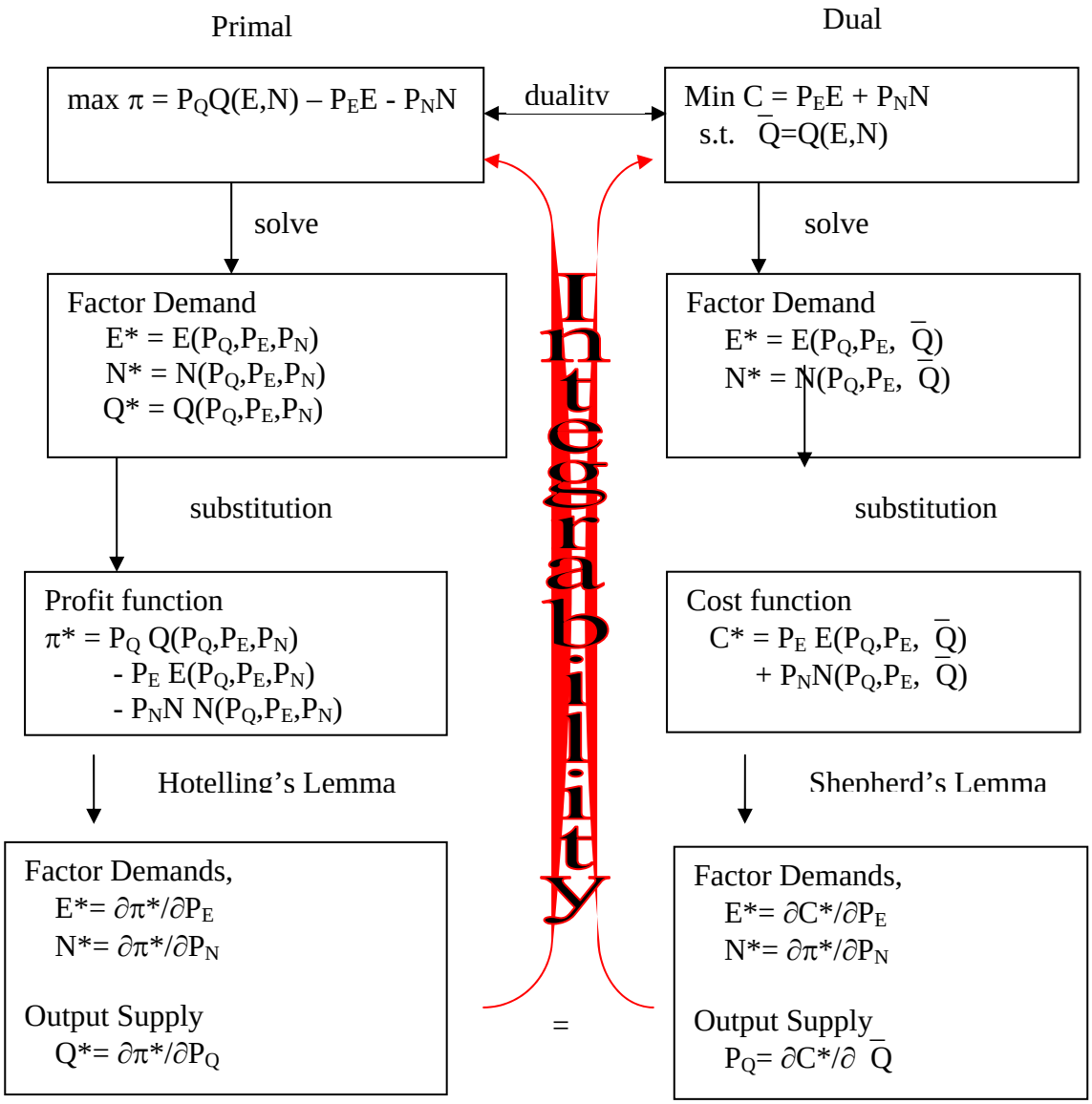
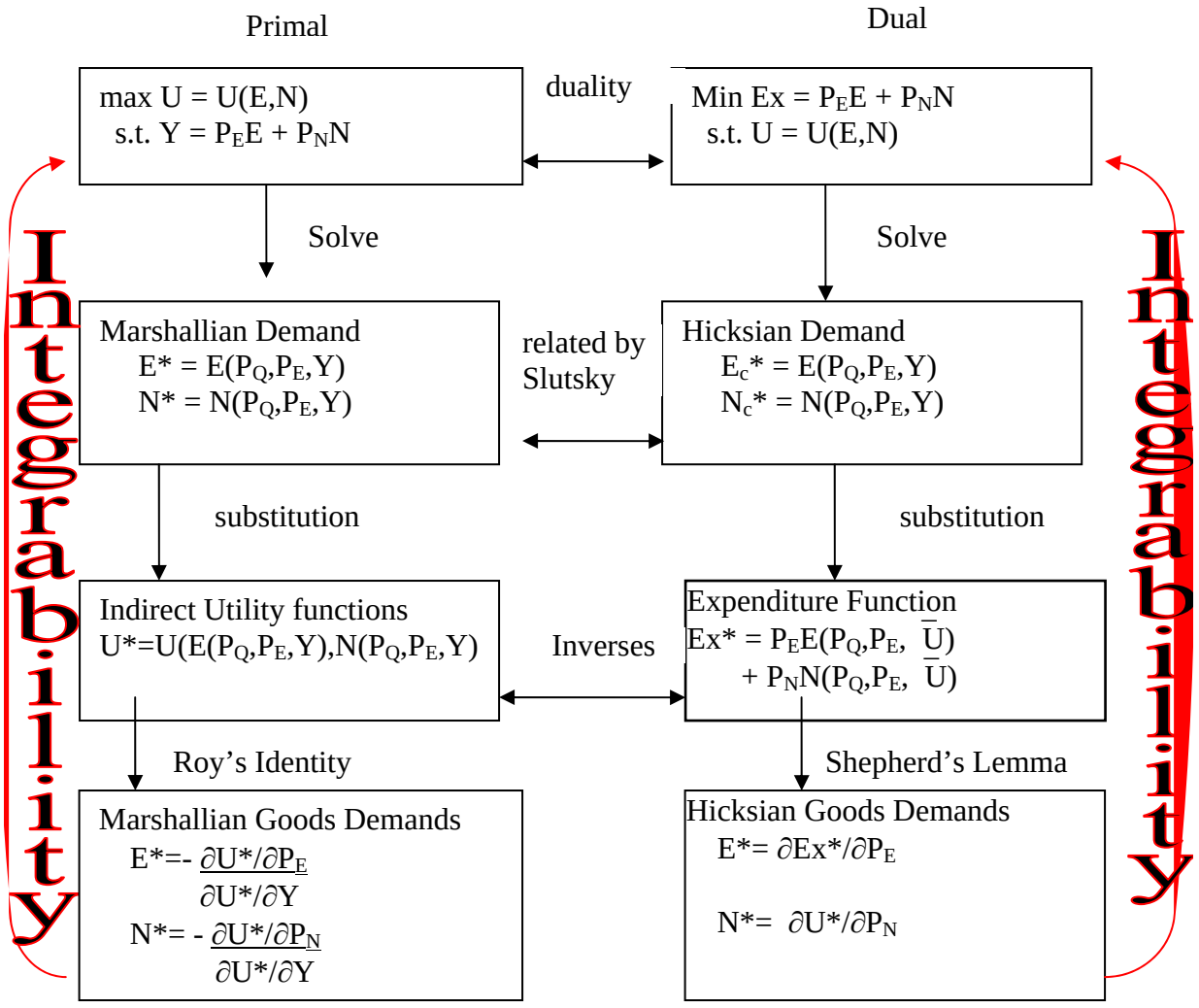


Figure 2: Relationships between Important Concepts in Consumer Theory



were generalized to less restrictive functional forms including the translog, generalized Leontief, AIDS, and linear logit beginning in the 1970's and applied extensively to energy analysis. Their duals were formulated as costs and indirect utility functions and demands were derived via Roy's Identity and Shepherd's lemma.

As the required theoretical underpinnings of functions for optimization were being worked out for individual producers and consumers and all goods, the econometric demand analysis was most often being conducted on aggregate data - either across goods or across economic entities. For example, Allen and Bowley (1935) aggregated cross section consumer expenditures into 6 categories and subsequent budget studies all aggregate goods to various degrees to make the estimation tractable. Other studies aggregate across economic entities. Fisher and Kaysen (1962), the first electricity study I have found, considered aggregate electricity data by state. Some studies aggregate both across goods and across time. Adams and Miovic (1968), the first aggregate energy demand study I have found, aggregated all types of energy into one energy composite and then used data aggregate by country. Some studies place micro restriction on aggregations of data and/or goods, but it is not clear that aggregate functions obey the laws developed for individual economic decision makers. The next secton considers requirements for aggregation more extensively.

3 Aggregation Theory

Hicks (1936) and Leontief (1936) provide the first guidance on aggregating across goods. They find that if commodity prices within a group move in parallel or have a fixed ratio, the whole group can be treated as one commodity. If the underlying commodity demand satisfy the requirements for consumer maximization, the aggregated commodity demand will too. Lewbel (1996) weakens the aggregation requirement to be that the log of individual ratio ofa good's price to the group price index have a probability distribution independent of the log of prices and the log of total expenditure.

Felipe and Fisher (2001) survey aggregation conditions for production functions. Leontief (1947) is the first to work out the conditions required to aggregate across factors. If the marginal rate of substitution betwen every pair of factors within the group are independent of all factors outside the group (called weak separability), the factors can be aggregated.

The second type of aggregation is across economic entities. Here also, Deaton and Muellbauer (1980) provide some insights on aggregating across utility maximizing consumers. They show, that if all consumers face the same prices, expenditures are exogneous and vary across household, and Engel's curves are identical and go through the origin, then market demand will be identical to the sum of the individual demands. For this demand curve to be consistent with utility maximization, individual preferences must also be quasi-homothetic. A second popular approach that has spawned much work is exact nonlinear aggregation in which case the conditions are considered for demand to be associated with a representative consumer. This consumer's income is not aggregate income but will be some income within the expenditure distribution. Deaton and Muellbauer derive results for a couple of cases for this representative consumer that they refer to as generalized linearity.

Felipe and Fisher (2001) also consider the literature on aggregation across firms, to get an aggregate production function. Nataf (1948) concluded that firms could be aggregated if the microproduction functions are additively separable in factor inputs. Gorman (1953) added to this literature by working out that the marginal rates of substitution between factor i and j had to be equal across firms. These and numerous other examples discussed lead Felipe and Fisher (2001) to conclude

that aggregate production functions as underlying theory for aggregate factor demand analysis are exceedingly problematic.

4 Econometric and Statistical Theory

Proper statistical methodology is another checklist prerequisite for quality empirical work. Although space and time will preclude consideration of much statistical analysis in this paper, the longer report will include the statistical evolution of demand analysis beginning with problems of identification, simultaneous systems bias, and proper specification through methods of dynamic modeling, estimation of systems of equations, to the more recent non-parametric and time series analysis including co-integration, error correction models, and vector autoregressions.

Since time series analysis has become increasingly popular in recent econometric work on energy demand, I will include here a brief overview of some of the more popular aspects of time series based on Dahl and Kurtubi (2001). Start with a simple demand function

$$Q = \beta_o + \beta_1 P + \beta_2 Y \tag{7}$$

Assume that Q, P, and Y are nonstationary. "A series of data $\{X_t\}$ is said to be stationary or integrated of order zero, I(0), if the joint distribution of $\{X_t, X_{t+1}, X_{t+k}\}$ is independent of t for all finite k. Trended, random walk, and random walk with drift are classic examples of nonstationary variables."

We worry about non-stationary variables because regressions using non-stationary variables may give very good fits (high R^2 and significant t statistics) even if the variables are non-related. Granger and Newbold (1974) refer to such cases as spurious regression where the regression may be picking up a relationship between the trend in both variables rather than an underlying relationship between the economic variables.

Therefore time series methodology always begin with tests for stationarity of all the variables in the model. These tests include the correlogram technique, the Box-Pierce Q statistic, the Ljung-Box statistic and unit root-based tests "—"Dickey-Fuller (DF) test, the Augmented Dickey-Fuller (ADF) test, and the Phillip-Peron test. In the ADF, probably the most popular, we run the regression:

$$\Delta X_t = \delta X_{t-1} + \Sigma_{i=1}^{n} \delta_i \Delta X_{t-i} + \mu + \gamma t + \varepsilon_t \qquad \varepsilon_t \sim iid(0, \sigma^2) \tag{8}$$

The lagged X is used for the unit root test and the trend variable t is included to give power to the alternative hypothesis of trend stationarity. The i lags in ΔX_{t-i} are chosen to give the shortest lag consistent with white noise regression residuals, as confirmed by a Box-Pierce, Ljung-Box or other appropriate statistical test. If the variables are not stationary, test to see if the first differences are stationary. If the first differences are stationary, the variables are integrated of order 1, I(1). If the second differences of the variables are stationary the variable is I(2), etc.

If all variables are I(1), we can run the model on first differences without the danger of spurious regression, valuable information is lost in the process and we may be unable to estimate the long-run relationship between variables. However, if a linear combination of I(0) nonstationary random variables are stationary, the variables are said to be co-integrated. Since these variable move

together such a linear combination is called a co-integrating relationship; it is said to represent the long-run relationship between the variables. In a bivariate model, the number of co-integrating relationships can be at most 1. In a multivariate model where the total number of nonstationary variables is m, the maximum number of co-integrating relationships is $m - 1$. (Engle and Granger (1987)).

Johansen has generalized this procedure to a vector autoregression error correction approach that will test whether one or more co-integrating equations exists. The longer report will include a complete discussion of these and other time series techniques along with a comparison of more traditional econometrics techniques.

5 Demand Study Checklist

Because of their usefulness, energy demand elasticities are often the target of empirical energy demand analysis and numerous econometric studies have sought to estimate energy demand elasticities over the last three decades and even earlier. In surveying this work, we have collected articles that look at demands for various sectors, fuel aggregations, and geographic regions using a wide variety of models. I have now entered the second stage of the project to do a critical analysis of these studies. In doing such survey work one is impressed with the number of studies that are poorly done. Models are misspecified, data or techniques are poorly documented, econometric techniques are misapplied, and many writers barrage readers with a bewildering array of results with no attempt to give preferred estimates. To pick the best or state of the art work from the morass, we are developing a primer or check list on what constitutes proper economic analysis for demand studies including

I. Context

   A. the study is put into the context of the literature
      1. relevant studies are referenced
      2. elasticities are compared and contrasted to other studies
      3. reasons are hypothesized where differences are are found

II. Contribution

   A. contribution of the paper is clearly stated and could include
      1. testing abstract theories
      2. estimating parameters of theoretical models
      3. applying results to forecasting, policy analysis, and structural analysis
      4. developing general economic laws
      5. clear statement and defense of preferred results

III. Methodology

   A. correct models are used based on underlying economic theory
   B. correctly applied econometrics and statistical analysis
   C. assumptions are tested where possible

IV. Reproducible

A. clear, concise, and complete documentation of data, which should include
   1. years
   2. exact source
   3. exact level of aggregation
   4. type of data: time series, cross section, or cross section time series
   5. sample size and degrees of freedom
   6. any adjustments to the data
   7. table with exact definition of the data and any abbreviations

B. clear, concise, and complete documentation of the methodology
   1. clear description or good reference for econometric methodology
   2. exact equations estimated
   3. all economic and statistical assumptions being made

C. clear description or clear reference for any statistical tests
   1. hypothesis being tested
   2. formula for the test statistic and its distribution or asymptotic distribution
   3. test critical value and rejection region reported
   4. intuitive measure of overall fit such as R^2 should be included
   5. measure of fit for individual parameters should be reported in the most reader friendly manner. For me, the statistics in order of information and reader friendliness are
      a. the P value - being sure to indicate whether it is a one tailed or two tailed P value.
      b. t or asymptotic t statistics
      c. absolute value of t or asymptotic t statistic - keeping the sign on the t values is preferred because it sometimes warns that there may be a typo in the data
      d. standard errors

V. Results

A. Reasonable
   1. consistent with theory
   2. anomalies discussed

B. Presentation
   1. All results are reported in elasticity form if possible
   2. All possible results are reported or at least summarized
   3. Paper is well written and easy to follow
      a. well organized with ideas following logically from each other
      b. correct grammar and free of typos
      c. arguments are logically correct and conclusions are well supported
      d. variables are given intuitive and easy to remember names
   4. Use of Tables

a. to define variables and abbreviations, particularly if there is a large list of them
b. results tables elasticity clearly indicate which column represents price and which represents quantity
c. the table includes information on sample data, equation estimated and estimation technique used.

Based on this check list, we will take the best, note where studies agree and disagree, try to explain inconsistencies between studies, attempt to come up with summary elasticities, discuss the scope and breadth of the work that has been done, and make suggestions for further research.

6 Some Summary Statistics for Recent Studies

So far we have collected over 1900 references that relate to the theory or practice of energy demand estimation. Out of these, about 950 have reported econometric estimates of some form of energy demand elasticities. The breakdown of studies relating to various categories of energy are as follows:

- Total energy demand - 160 studies
- Coal - 110 studies
- Electricity - 410 studies
- Natural Gas - 177 studies
- Oil or oil products - 260 studies

We are now finishing checking our summary tables and beginning more formal analysis of the studies. In this last section of the paper, we include some sample statistics and histograms to summarize the results we have collected for gasoline demand. Since we are still finishing up checking all our variables, these are still considered preliminary results. We have found 173 studies relating to gasoline demand that span the years 1966 to 2006. They include estimates for over 50 individual countries as well as cross section time series for groups of countries. Further work will stratify and analyze this data much more carefully, picking out preferred estimates, and stratifying temporally and spatially to look for patterns in the data. In this paper, we only look at the whole sample and a stratification of studies done before 1990 and since 1990.

Table 1 contains summary statistics for the whole sample as well as two stratifications. Some studies are static and include only current values of the variables They estimate only one price and one income elasticity. The elasticity from these type of models will be labelled intermediate run and designated as Pir for price and Yir for income. Other models are dynamic and include both current and lagged values to explain gasoline consumption. Such models can give elasticity estimates for the current period (called short run - Psr, Ysr) and elasticities that measure the total adjustment over time (called long run - Plr, Ylr). A popular dynamic model is one that includes lagged gasoline consumption as an explanatory variable. Because of the popularity of this model, we also include summary statistics for the coefficient on the lagged variable in the Table. Mean is the simple average of all elasticities in the sample, median is the median elasticity, stdev is the standard deviation, min is the minimum elasticity, max is the maximum and count is the number of elasticities in a category.

The means and medians are well behaved with the median tending to show less elastic response than the means. Short run mean response is close to -0.25 over both times periods, although the variation across studies is quite large. More careful scrutiny of the studies with the elimination of those that are poorly done may reduce this variance. Summary statistics for long income elasticity and coefficients on the lagged endogenous variable show this same stability across the stratifications. The other summary statistics show more elastic price but less elastic income response after 1990. But again the variations around these means are quite high.

Table 1: Summaries of Gasoline Demand Elasticities

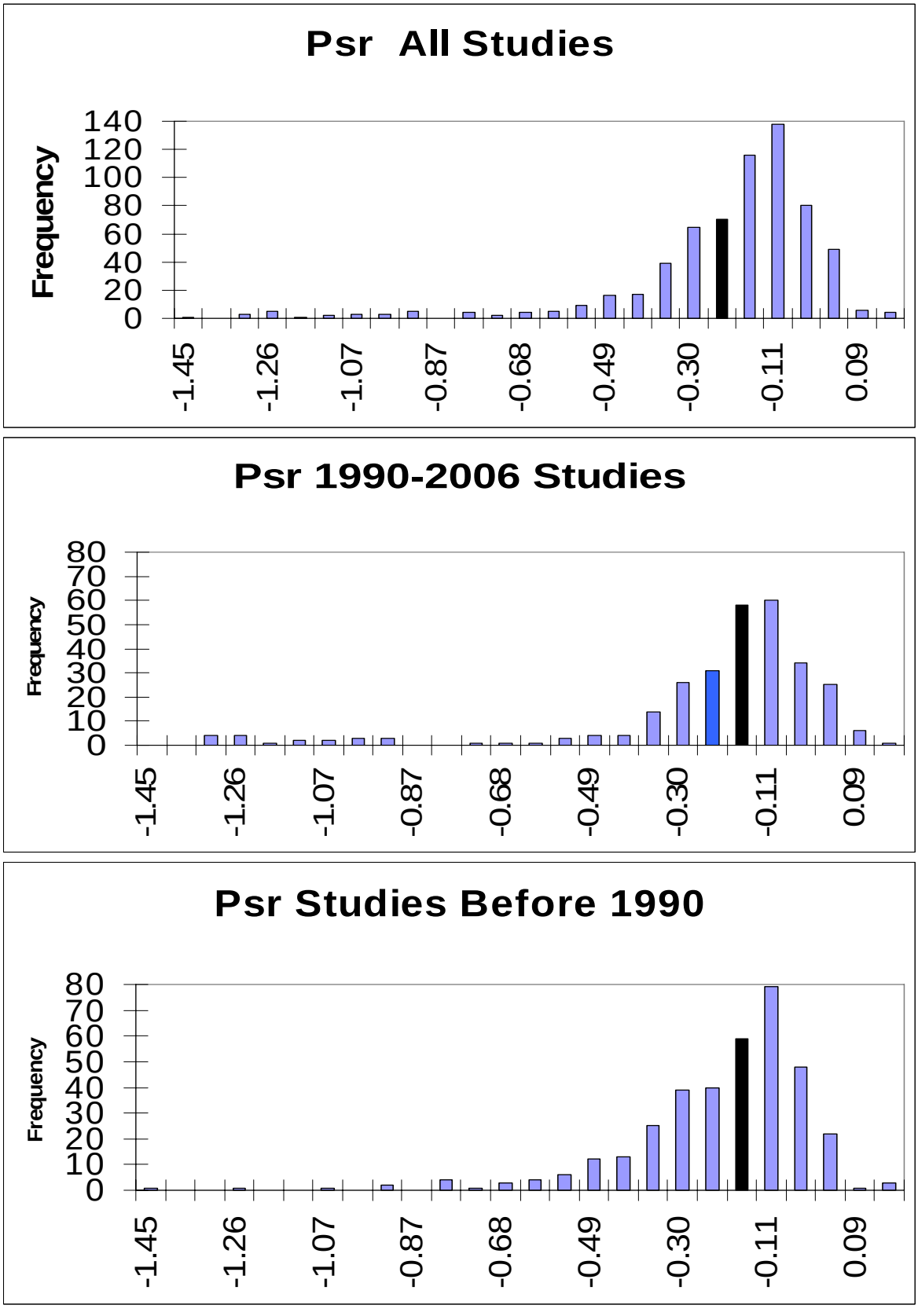
	Psr	Pir	Plr	Ysr	Yir	Ylr	Q(-1)
All Studies							
Mean	-0.25	-0.47	-0.76	0.38	0.83	1.02	0.67
Median	-0.18	-0.36	-0.68	0.300	0.82	0.96	0.74
Stdev	0.25	0.48	0.62	0.53	0.56	0.66	0.23
Min	-1.71	-2.90	-3.92	-0.7	-2.80	-1.31	-0.34
Max	0.63	0.72	2.70	8.67	2.84	5.58	1.12
Count	643	592	573	635	528	578	432
Studies to 1990							
Mean	-0.24	-0.45	-0.70	0.46	1.00	1.01	0.65
Median	-0.20	-0.30	-0.61	0.36	1.02	0.97	0.71
Stdev	0.22	0.50	0.62	0.63	0.60	0.63	0.25
Min	-1.71	-2.90	-3.26	-0.60	-0.74	-1.04	-0.34
Max	0.63	0.61	2.70	8.67	2.84	4.46	1.12
Count	360	333	220	356	276	208	197
Studies 1990-2005							
Mean	-0.26	-0.51	-079	0.29	0.64	1.02	0.68
Median	-0.18	-0.41	-0.73	0.20	0.63	0.96	0.74
Stdev	0.27	0.44	0.62	0.33	0.45	0.67	0.21
Min	-1.36	-2.11	-5.00	-0.70	-2.80	-1.31	0.00
Max	0.08	0.72	0.88	1.76	2.03	5.58	1.06
Count	278	258	347	273	252	363	229

Figures 3 - 8 show the histograms for all the price and income elasticities for the whole sample and for the two disaggregations. The dark highlighted cell is the one that contains the median elasticity. The axes labels show the middle of the cell. Although there is wide variation across studies, all elasticities tend to be bunched around the median cells. The price elasticity histograms are all skewed in the negative direction and the vast majority are negative and inelastic. The intermediate run price elasticities tend to be the most spread out. The vast majority of income elasticies are positive and the income elasticity histograms tend to look more like normal distributions than those for price.

Bibliography

See most recent draft of the project posted at http:\\ dahl.mines.edu\ demand.pdf

Figure 3:


Psr All Studies
Frequency
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100
80
60
40
20
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-1.45
-1.26
-1.07
-0.87
-0.68
-0.49
-0.30
-0.11
0.09
Psr 1990-2006 Studies
Frequency
80
70
60
50
40
30
20
10
0
-1.45
-1.26
-1.07
-0.87
-0.68
-0.49
-0.30
-0.11
0.09
Psr Studies Before 1990
Frequency
80
70
60
50
40
30
20
10
0
-1.45
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-1.07
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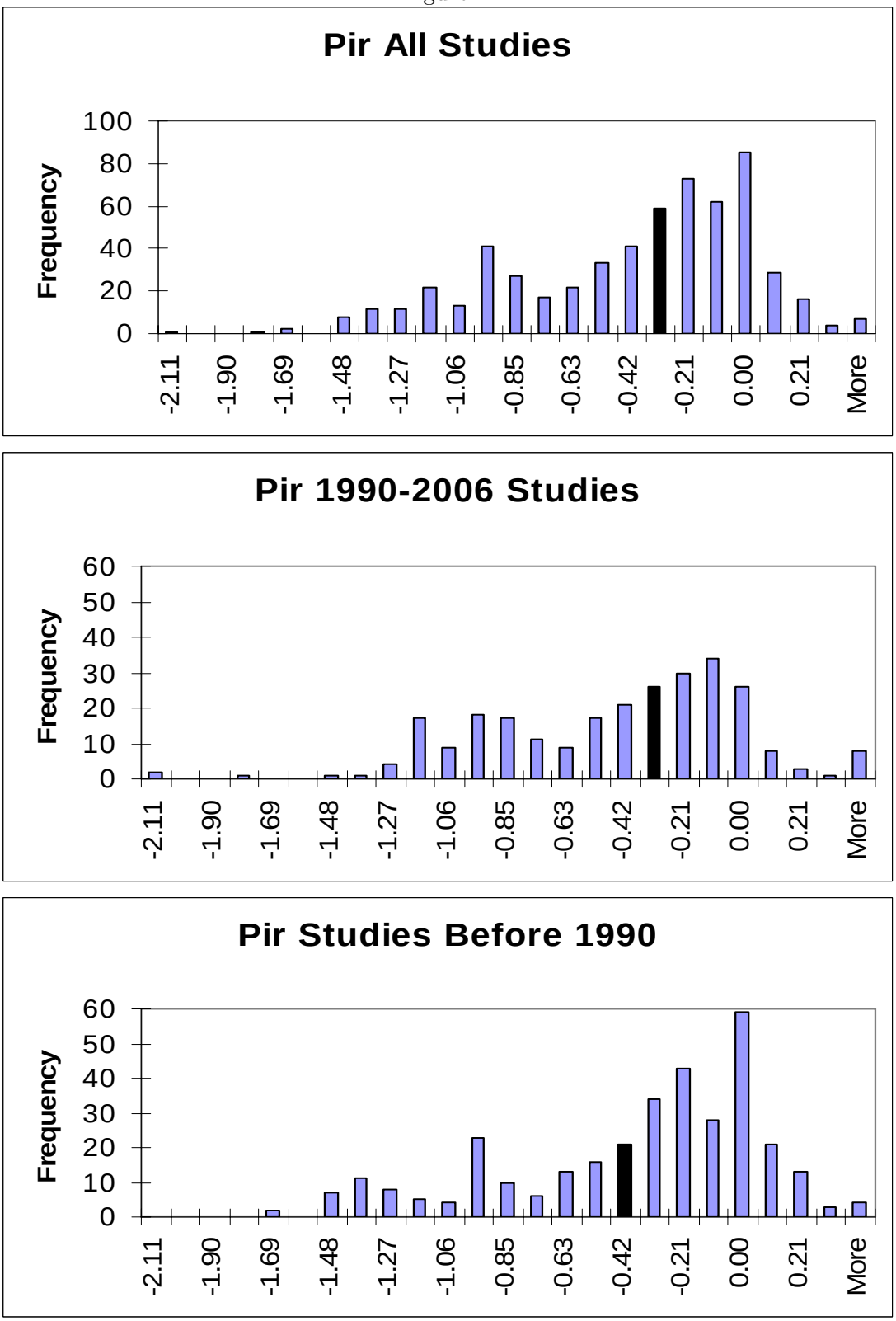
-0.68
-0.49
-0.30
-0.11
0.09

Figure 4: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-1.27
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-0.85
-0.63
-0.42
-0.21
0.00
0.21
More
Pir 1990-2006 Studies
Frequency
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50
40
30
20
10
0
-2.11
-1.90
-1.69
-1.48
-1.27
-1.06
-0.85
-0.63
-0.42
-0.21
0.00
0.21
More
Pir Studies Before 1990
Frequency
60
50
40
30
20
10
0
-2.11
-1.90
-1.69
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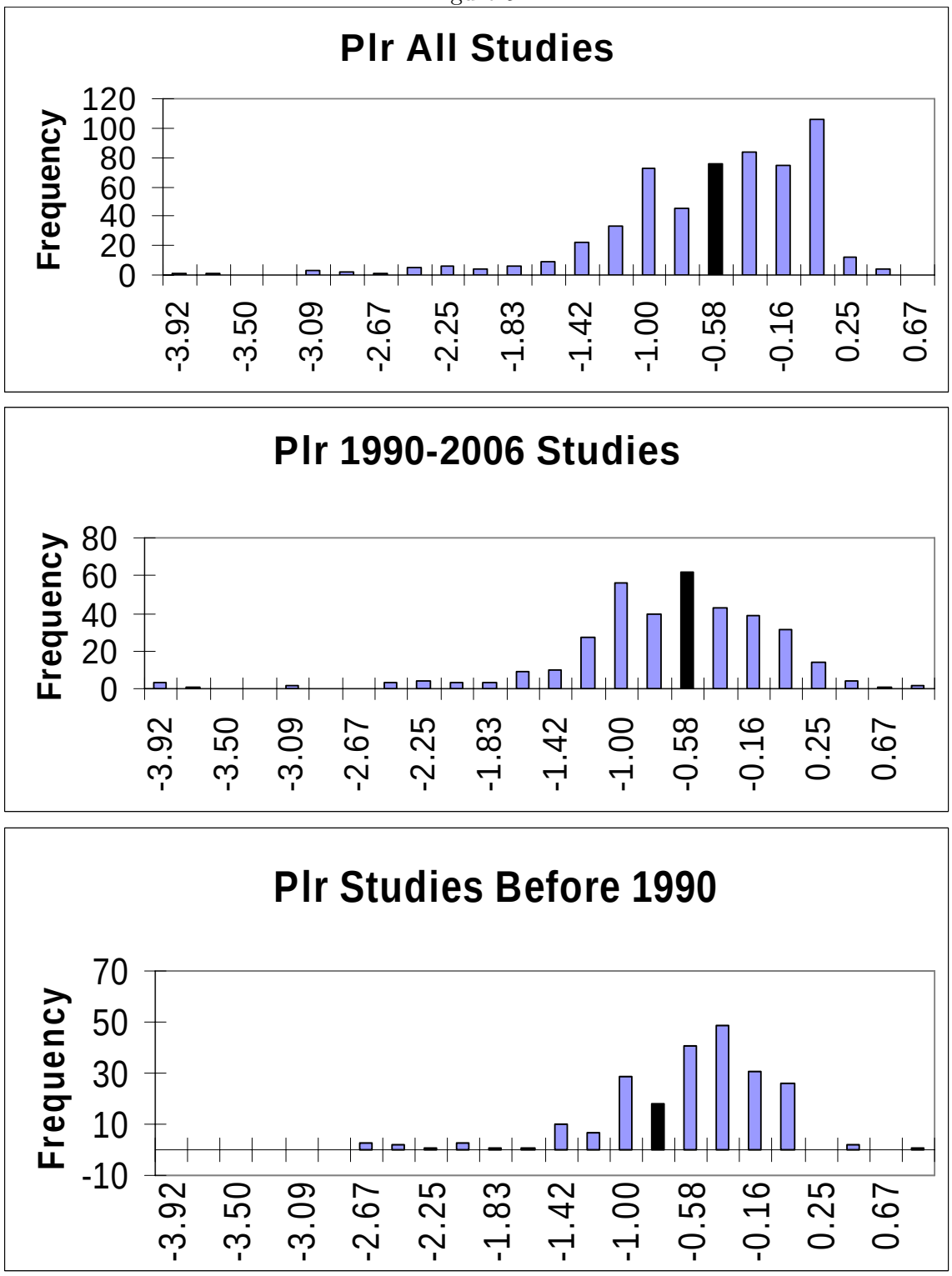
Figure 5: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Frequency
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-1.42
-1.00
-0.58
-0.16
0.25
0.67
Plr 1990-2006 Studies
Frequency
80
60
40
20
0
-3.92
-3.50
-3.09
-2.67
-2.25
-1.83
-1.42
-1.00
-0.58
-0.16
0.25
0.67
Plr Studies Before 1990
Frequency
70
50
30
10
-10
-3.92
-3.50
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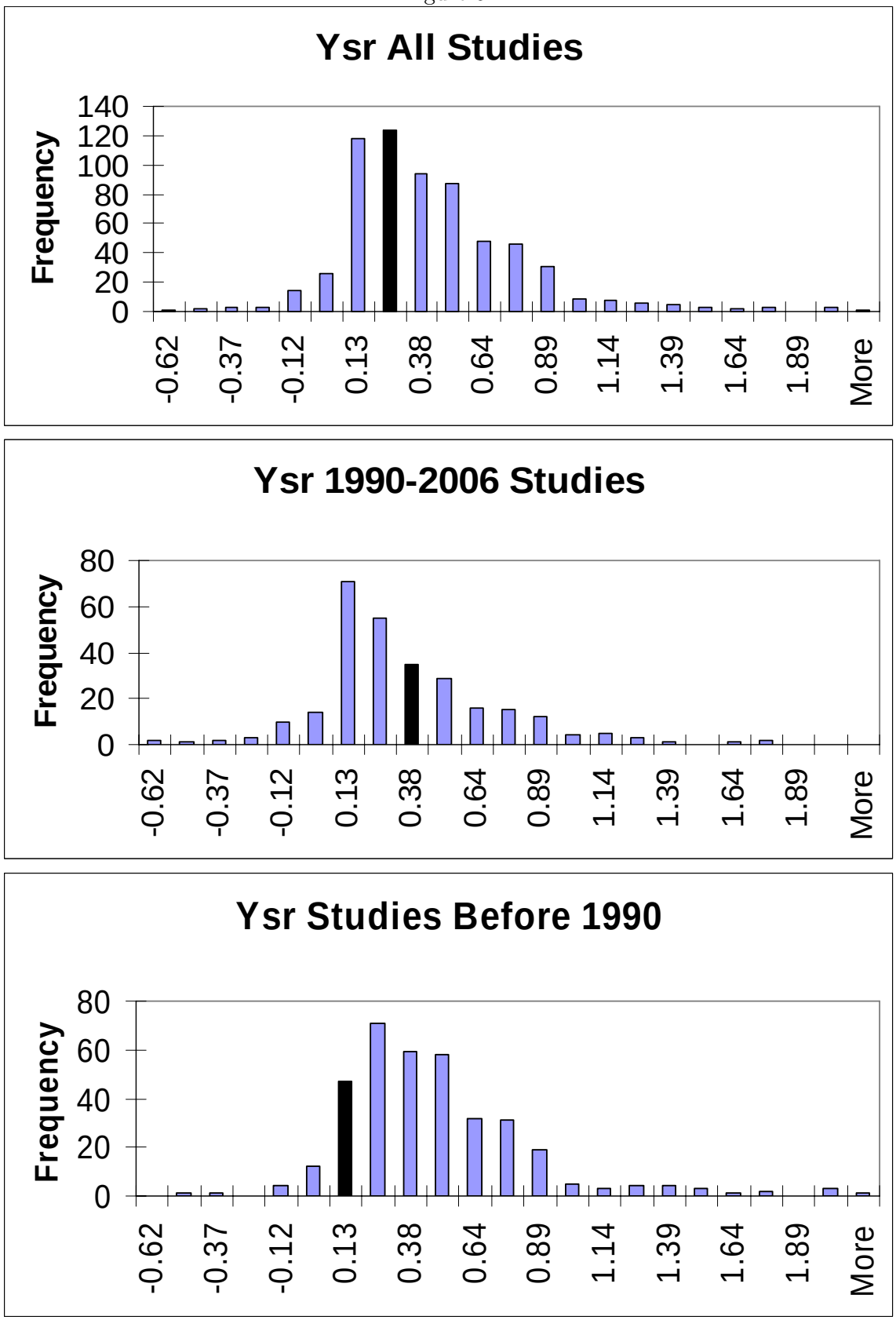
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1.39
1.64
1.89
More
Ysr 1990-2006 Studies
Frequency
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20
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More
Ysr Studies Before 1990
Frequency
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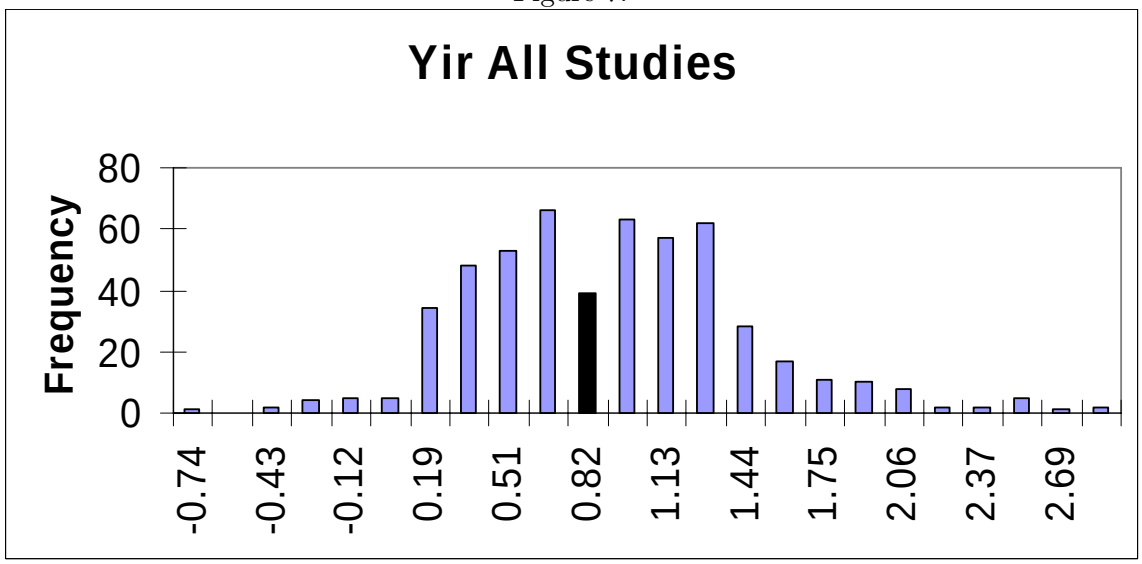
Figure 7: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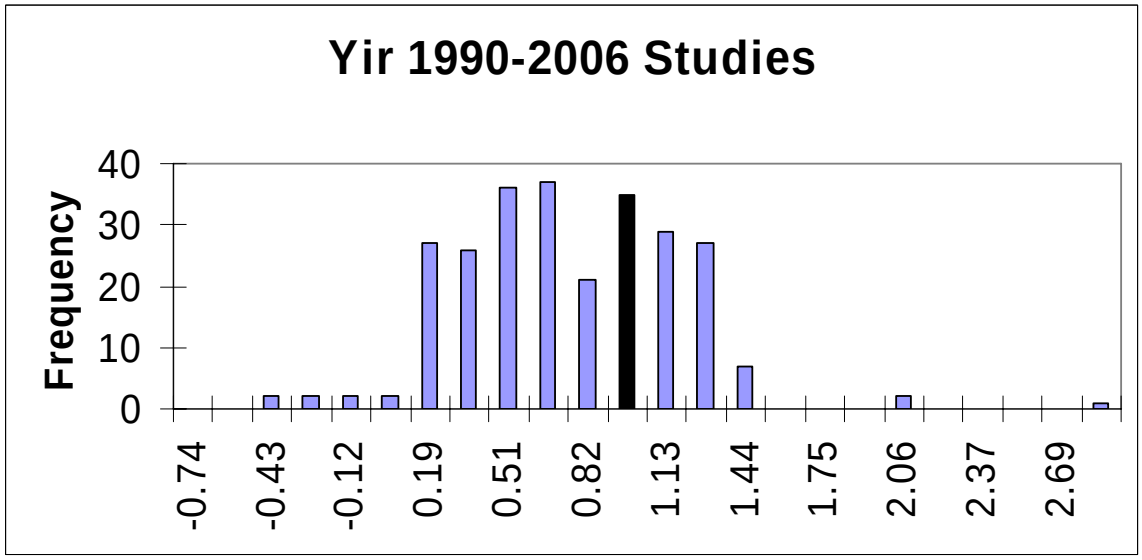
Yir 1990-2006 Studies
Frequency
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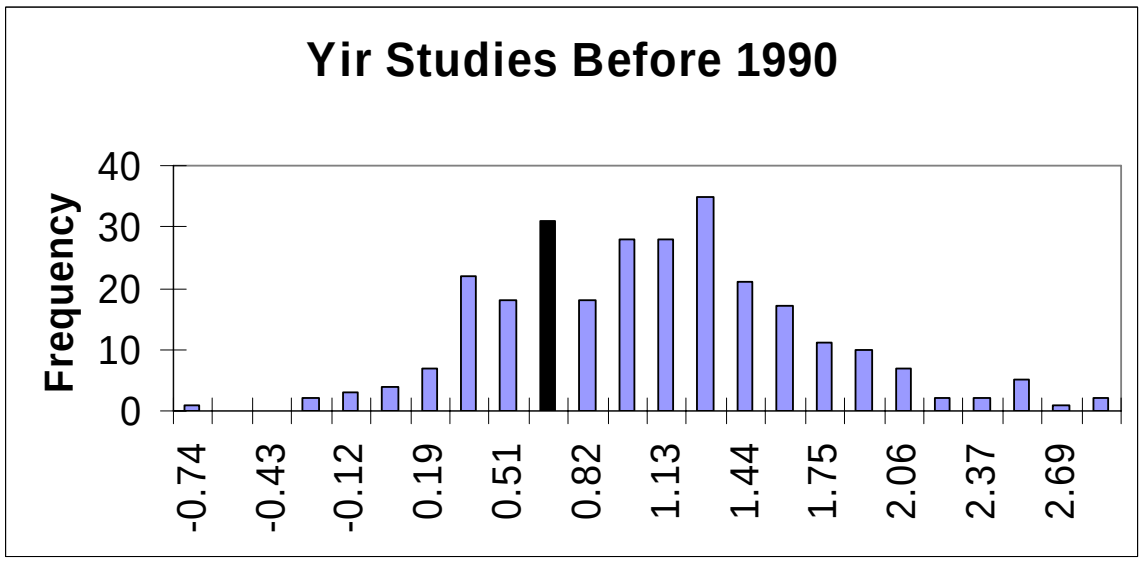
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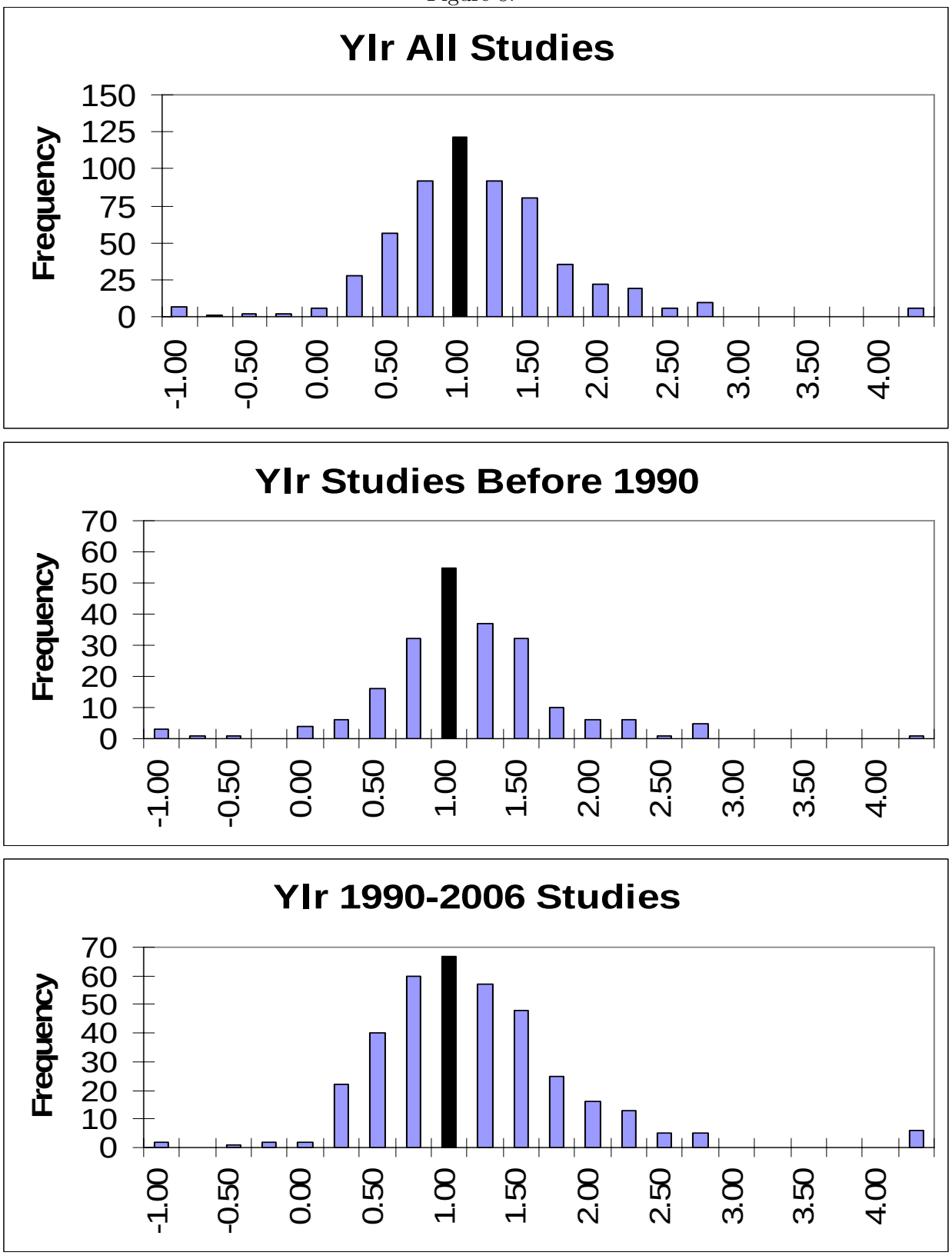
Figure 8: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Ylr 1990-2006 Studies
Frequency
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