1 Market power: competition among measures*

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1.1 CONCEPTUAL BACKGROUND AND MOTIVATION

Over the years, industrial organization theorists and game theorists have struggled to develop models that would predict a unique oligopoly equilibrium outcome, or even to limit the range of outcomes deemed consistent with rational behavior. While those efforts have immensely enriched our understanding of the possibilities for strategic behavior among firms, they have spectacularly (and informatively!) failed to attain their original goal. Oligopoly equilibrium concepts such as Cournot, Bertrand, Stackelberg, stable cartels, limit pricing, contestable markets, open-loop and closed-loop dynamic equilibria, consistent conjectures, and dynamic enforcement mechanisms such as trigger strategies, stick-and-carrot, optimal punishment, or Rotemberg-Saloner sustainable collusion all predict different outcomes, based on differing assumptions. Even the static Nash assumption of zero reaction (zero "conjecture") yields different predictions depending on whether firms choose price or quantity, and either model relies on an assumption of simultaneous choice in a static game which has been challenged by the endogenous role choice literature and by dynamic models. The notion of "consistent conjectures," originally thought to hold promise for predicting a unique rational outcome, was subsequently shown to predict virtually any outcome depending on functional forms, parameter values, and so on.

The grand lesson from these increasingly sophisticated theoretical tours-de-force is that firm conduct is, after all, an empirical question that cannot be reliably answered by theory alone. This fact is already tacitly acknowledged in the antitrust policies adopted by many countries. Unsurprisingly, therefore, a vast empirical literature of market power has developed to inform researchers, policymakers, and practitioners alike. But any such study requires some quantifiable measure of market power, and the choice of available measures has also proliferated substantially.

A valid measure of market power (or firm conduct, or competition) must first of all reflect some aspect that is relevant to economic welfare considerations. Why do policymakers care about market power and seek to suppress it? Quite simply because, from an economic perspective, market power results in higher prices and lower quantities, thus reducing consumer welfare and total welfare compared to what is attainable in a hypothetical perfectly competitive outcome.[1] While considerations of politics, special interests, and other dimensions may at times intrude into the reality of policy deliberations or enforcement, prices and quantities are the traditional kernel of an economist's attention to market power. Within this focus, a good empirical measure of market power must incorporate observable data in a manner that is robustly related to prices or quantities, and moreover must be able to compare observed data against the hypothetical competitive benchmark. For example, what is the "right" price or output level? Is a given price high or low? The theoretical competitive benchmark identifies an item's marginal cost of production as the

Table 1.1 Some empirical measures of market power from the literature[a]

Measure	Definition	References
Four-firm (or k-firm) concentration ratio	Sum of top k market shares	Saving (1970)
Herfindahl–Hirschman index	Sum of all squared market shares	Cowling and Waterson (1976)
Lerner index	1 − (marginal cost/price)	Lerner (1934)
Rothschild or Bresnahan conduct index (also known as the conduct parameter, as in Corts, 1999)	"Conjectural variation" elasticity (Shaffer, 1983); related to the product of market demand elasticity times the Lerner index (Cowling and Waterson, 1976; Genesove and Mullin, 1998; Corts, 1999; Wolfram, 1999)	Rothschild (1942); Bresnahan (1982); Lau (1982)[b]
Panzar–Rosse H-statistic	Sum of elasticities of total revenue with respect to each input price	Rosse and Panzar (1977); Panzar and Rosse (1987)
Hay–Liu–Boone index (also known as the performance–conduct–structure indicator)	Relative profit differences	Hay and Liu (1997); Boone (2008a, 2008b); Bikker and van Leuvensteijn (2015)

Notes:
[a] Other less formal indicators have been used, such as the frequency of rank turnover (Rhoades and Rutz, 1981), though Shaffer (1986) noted weaknesses in the conceptual underpinning or interpretation of that measure.
[b] Iwata (1974) and others have estimated similar models; see also Bresnahan (1989) for a general description. The same approach has been extended to multiproduct firms by Suominen (1994) and Shaffer (1996); the latter study shows that the correct multiproduct specification requires an additional cross-equation restriction overlooked by the former.

reference point against which to compare output prices, and the effect of higher prices on quantities sold will depend on the elasticity of demand by consumers (generally presumed to be exogenous, although a firm's investment in advertising or product differentiation may potentially influence both the level and the elasticity of demand).

These considerations provide a framework within which to evaluate and select among the various measures that have been used in the literature. Table 1.1 briefly lists some of the more commonly used measures.

The first two measures, based on market shares, are theoretically related to the equilibrium gap between price and marginal cost *in special cases* of oligopoly behavior under the assumption that firms attempt to maximize profits.[2] Unfortunately, these measures do not estimate or verify the assumed patterns of behavior, as required to interpret the competitive implications of any observed values of these statistics.[3] Moreover, if we could directly measure or confirm the pattern of conduct in a particular market or industry, such measures would render the market shares redundant or irrelevant, as we would already have our answer without having to look additionally at market shares. Finally, statistics based on market shares are subject to measurement error depending on how the "market" is defined, and do not address the policy-relevant question of causality (does one firm dominate the market because of barriers to entry that protect its monopoly position, implying strong market power to the detriment of consumers, or because it is producing high-quality products at lower prices than its competitors, which benefits consumers?). Thus, while they are convenient to measure, purely structure-based metrics fall short as a basis for reliable conclusions about market power.

The next two measures in the table are direct functions of prices and marginal cost, and thus satisfy the criterion of economic relevance. The familiar and long-established Lerner (1934) index directly quantifies the relative gap between price and marginal cost, and is thus monotonically associated with consumer welfare losses from market power for given cost and demand functions. Indeed, it has been shown to be the slope of a social welfare function (Dansby and Willig, 1979).[4] The Rothschild–Bresnahan index (Rothschild, 1942; Bresnahan, 1982) is sometimes called the "elasticity-adjusted Lerner index" (Genesove and Mullin, 1998) or the "elasticity-adjusted markup" (Wolfram, 1999).

While the economic meaning of the Lerner index and the Rothschild–Bresnahan index (or conduct parameter, as it is sometimes termed) is clear and well known, operational complexities may render their direct estimation difficult or unreliable (Hyde and Perloff, 1995). For both measures, accurate estimates of marginal cost are essential, but are typically hindered by limitations of functional form and measurement error. Corts (1999) demonstrates analytically and via simulations that differences between marginal and average measures may cause econometric estimates of the conduct parameter to diverge from values generated by particular underlying patterns of strategic interaction among firms, further undermining the robustness of the Rothschild–Bresnahan method. Empirical attempts to evaluate the robustness of standard measures of the Rothschild–Bresnahan index have yielded mixed findings, with Genesove and Mullin (1998) and Wolfram (1999) reporting favorable results in contrast to Hyde and Perloff (1995).

A theoretical advantage of the Rothschild–Bresnahan conduct index is that it can be mapped directly to explicit oligopoly equilibrium concepts, not only in static models but also in dynamic models (Worthington, 1990). Another advantage is that it will reflect any market power on the input side (monopsony power) as well as on the output side (Shaffer, 1999), and has been extended to decompose overall market power into its upstream and downstream components (Raper et al., 2000). Additionally, this index also corresponds algebraically to the relative deviation of aggregate *quantity* from the competitive ideal (Shaffer, 1993). Because of their rigorous theoretical underpinnings and clear economic interpretations, we shall focus on estimates of the Lerner index and the Rothschild–Bresnahan conduct index, discussing each in more detail below.

The Panzar–Rosse H-statistic is formally related to the observed response of profit-maximizing firms to exogenous changes in input prices, and has become increasingly popular in recent empirical literature owing in part to its parsimonious data requirements. The original theoretical analysis (Rosse and Panzar, 1977; Panzar and Rosse, 1987) derived equilibrium values of H for a small number of special cases, which empiricists subsequently applied under an implicit assumption that *all* oligopoly solution concepts would follow the simple pattern suggested by the original analysis ($H = 1$ for perfect competition, $H < 0$ for monopoly, $H < 1$ for monopolistic competition). Hence, subsequent studies interpreted $H < 0$ as "proving" market power, $H = 1$ as proving perfect competition, and $0 < H < 1$ as proving monopolist competition, even though Rosse and Panzar (1977) had already shown that monopolist competition could result in $H < 0$ and claimed less formally that oligopoly could cause $H > 0$.

More recently, a growing body of literature has identified increasingly many situations with contrasting patterns of association between H and market power (see for example Hyde and Perloff, 1995; Bikker et al., 2012; Molnar et al., 2013; Shaffer and Spierdijk, 2015). It is now known that neither the sign nor the magnitude of H can by itself distinguish between competitive and non-competitive situations without substantial auxiliary information, some of which (such as the timing or sequence of firms' choices) may be unobservable, and some of which could render H redundant by directly answering the policy-relevant research question. These problems are in addition to the standard impediments to econometric identification of the key parameter in a reduced-form model. Hence, H must be relegated to the same category as the concentration index and Herfindahl–Hirschman index, and deemed unfit for serious empirical work or public policy decisions.

We discuss the Hay–Liu–Boone index as a single concept, though its implementation varies somewhat from Hay and Liu (1997) to Boone (2008a). While Boone's model has gained rapid acceptance in the empirical literature (see for example Bikker and van Leuvensteijn, 2015), the earlier analysis by Hay and Liu has gone largely unrecognized thus far, despite embodying the same essential insight and intuition. Boone's measure interprets relative profitability across firms within a market according to the notion that higher-cost firms should theoretically suffer relatively greater losses of profitability in more competitive markets, whether competition stems from numbers of rivals or from patterns of conduct. Hay and Liu similarly note that firms' relative market shares respond to relative cost efficiency to a degree that is monotonically related to the strength of market competition, where competition in this sense can likewise reflect both entry barriers and strategic interaction among firms. The underlying conceptual framework also addresses relative incentives for managers to exert effort to enhance cost efficiency, either directly or via appropriate investment in R&D.

It is tempting to think that the Hay–Liu–Boone model operates in the same way whether cost inefficiency reflects X-inefficiency or scale inefficiency. However, further consideration suggests important nuances in that regard. For simplicity, the following discussion is cast in terms of the dependent variable of Hay and Liu (1997), though a similar argument can be made for that of Boone (2008a). Likewise, we focus here on simple average or marginal costs as measures of efficiency, as suggested in Boone (2008a), though a similar argument can be made for the frontier deviations proposed in Hay and Liu (1997).

Market share is in general positively correlated with firm size; indeed, that correlation is perfect for any sample drawn from a single market, or from a set of equal-sized markets. Therefore, the empirical association between market share and cost (either average cost or marginal cost) will reflect any association between scale and cost (average or marginal). If there are non-constant returns to scale, the empirical association between scale and cost will be nonzero – for any constant degree of competition – generating a nonzero value of the association between market share and cost that we wish to interpret as a measure of competition. (One may object that perfect competition requires all firms to operate at the point of minimum average cost, implying equal sizes of all firms and hence a zero association between scale and cost, but – even without measuring that association – we do not tend to observe equal-sized firms in practice; and, if we ever did, we could not apply the Hay–Liu measure to such a sample.) Thus, the dependent variable of Hay and Liu will be affected not only by the degree of competition, as they show, but also by the degree of economies or diseconomies of scale. Therefore, to map the observed value of their variable into a particular degree of competition, it is necessary to control for any deviation of the cost function from constant returns to scale. Because profits also respond to costs, which vary systematically with scale except in the special case of constant returns, the dependent variable of Boone (2008a) will also reflect both competition and economies or diseconomies of scale, implying a need to control for the shape of the cost function in that model as well.

Similarly, changes over time or across markets in both indices could result either from changes in actual competition or from changes in the cost function. Examples of factors shifting the cost function, potentially unrelated to the degree or change of competition, could include technological change, differentiated products, or a non-constant elasticity of cost with respect to scale combined with generally growing firms. Therefore, the Hay–Liu–Boone index cannot be unambiguously interpreted as reflecting either the degree or comparative levels of competition without controlling for economies or diseconomies of scale. Leuvensteijn et al. (2011) recognize this problem and attempt to address it using lagged marginal costs as instruments.

Finally, the Hay–Liu–Boone approach requires a sample of firms that exhibit adequate variation in cost efficiency, though empirical studies suggest that this requirement tends to be met in practice. Like any other empirical measure, this method is also potentially vulnerable to measurement error in the sample data, including that resulting from product differentiation or heterogeneous quality. As with most other methods, its findings are influenced by the market definition – both geographic and product markets – selected by the researcher (see footnote 9 below).

Turning our focus back to the Lerner and Rothschild–Bresnahan indices, we review more detail of each method in the following two sections and provide an empirical illustration in section 1.4.

1.2 THE LERNER INDEX

As indicated in Table 1.1 and discussed above, economists have used the term "competition" to denote several distinct properties, including such items as sheer numbers of firms, the price–cost margin, and the pattern of strategic interaction among firms. To the extent that public policy seeks to promote welfare, prices and quantities matter most directly (indeed, apart from quality, these are the only variables that affect consumer welfare), costs of production matter next (to the extent that producer welfare is part of the social objective), and all other considerations are relevant only to the extent that they help us infer how observed prices and quantities compare against a theoretical benchmark of perfect competition. For those economists accustomed to starting from a notion of market structure, entry and exit, or similar concepts, this perspective may require some adjustment.

As noted above, the Lerner index (which we denote L hereafter) is defined as the relative markup of an output price P over the associated marginal cost of production MC. As such, it reflects two of the economic variables that the previous paragraph proposes as among the most policy-relevant. Moreover, it can be solved for equilibrium values in theoretical models using various oligopoly solution concepts, providing some guidance on how to interpret its empirically observed values; alternatively, by comparing observed values against theoretically predicted ones, the Lerner index affords a means of testing theories of firm conduct.

Similarly, L is more or less related to a firm's unit profit (P − AC, or price minus average cost). In the special case of constant marginal cost with zero fixed cost, indeed, MC = AC and the two measures coincide. It is therefore tempting to hope that one could assess competition by comparing a firm's total profits against its level of output without further analysis, but it is well known that accounting profits are misleading for this purpose owing to a variety of complications (Fisher and McGowan, 1983). Accounting profits must always include a (required) financial return to shareholders, which is netted out of the "economic profits" that would theoretically be driven to zero in long-run competitive equilibrium; although financial economists have developed models to estimate a cost of financial capital, applying such models to calculate the appropriate adjustment in particular instances is neither simple nor precise. Accounting costs of producing a particular product include allocations of some components of overhead cost, and may omit other components; this problem can be more severe for a firm that produces more than one type of output, as is common. Accounting profits reflect, among other factors, depreciation that varies with the firm's mix of assets, the choice of depreciation schedule (which is sometimes constrained by the federal tax code), and asset vintage. Moreover, firms' managers have both discretion and incentive to adjust the timing of reported revenues and expenses to smooth the time path of accounting profits (Kang et al., 2010; Dechow et al., 2012), introducing time-varying discrepancies between economic and accounting profits. For these reasons and others, profit rates obtained from accounting data are unsuitable as a measure of competition.

Accurately estimating the Lerner index faces similar challenges. Sometimes it is not easy to observe the unit price of output, and simple proxies such as revenue divided by units of output can be distorted by two-part tariffs or other nonlinear pricing schedules, unobserved heterogeneity of output, reciprocal dealing, or other complications.[5] Nearly always, it is impossible to observe or directly calculate the true marginal cost of production, requiring instead an estimation process that may introduce error as discussed below.[6] Multiproduct firms further compound the difficulties of estimating both P and MC.

On the positive side, estimating the Lerner index does not depend on defining a geographic or product market for any firm in the sample. To see that, note that the Lerner index can be calculated for even a single firm, regardless of its true market, and the competitive benchmark value is also unaffected by the extent of the true market.[7] This feature simplifies the researcher's task, strengthens the robustness of empirical estimates, and affords greater flexibility in sample selection, since any set of firms (or even a single firm) will do. Another convenient feature of L is that its estimation typically does not pose problems of econometric identification of key parameters, unlike the Rothschild–Bresnahan conduct parameter or some other methods.

The standard empirical strategy of estimating L begins with either direct observation of P or calculating its proxy as the ratio of revenue from sales divided by the quantity of output, assuming those items can be observed. Some statistical ingenuity is generally required to estimate the firm's total cost function accurately and to derive a reliable marginal cost estimate as the partial derivative of the total cost function with respect to output quantity. Given the vast literature on empirical cost functions, we do not undertake to summarize or extend that aspect of analysis here. Suffice to say that, while the dedicated cost literature in recent years has moved toward the flexible Fourier form as one accepted standard, many empirical studies of competition still base their MC estimates on the simpler and more tractable translog form. One argument in support of this practice is that the translog form often provides an outstandingly good fit to real-world data, with R^2 values ranging between 0.95 and 0.99, while the Fourier form barely improves on these figures. Similarly, the Fourier form, with its many estimated parameters, might be susceptible to overfitting, which would undermine the research and policy goals of the empirical analysis of competition. On the other hand, the Fourier form has been shown to represent a global approximation to more general forms, unlike the translog. Other shortcomings of the translog form have also been noted, such as its tendency to impose a U-shape to the estimated average cost function even in cases where economies of scale are unbounded (Shaffer, 1998).

The Fourier form poses additional difficulties as well. For its trigonometric terms, the sample data must be normalized so that each term spans a fixed range, and the normalization must be subsequently reversed if the researcher wishes to interpret the estimates in terms of standard constructs such as the minimum efficient scale or the scale at which diseconomies set in. Moreover, when using the Fourier form, it is complicated to specify, impose, or test the parameter restrictions corresponding to standard theoretical requirements such as linear homogeneity in input prices and quasi-concavity. Unlike the case for most other functional forms, the actual number of parameters is not fixed a priori for the Fourier form, nor specified by any explicit optimization rule, but the literature has converged on a rule of thumb that relates the number of estimated parameters to the sample size (Gallant, 1982; Mitchell and Onvural, 1996). Even here, a subjective and ad hoc element remains in that there is no formal procedure for specifying in what sequence additional trigonometric terms are to be added to the empirical model as the number of estimated parameters is increased. Such issues have naturally prompted ongoing efforts to develop other approaches such as the nonparametric local-linear principal components cost function of Wheelock and Wilson (2012).

Another complication, alluded to above but seldom scrutinized or acknowledged, is whether standard assumptions underlying the neoclassical cost function are valid in a particular sample. The neoclassical cost relation is specified as a function of output quantities and prices of variable inputs, sometimes augmented by quantities of quasi-fixed inputs and other control variables. Underlying this specification is an assumption that firms are competitive price-takers in all input markets. But, when we have reason to test whether competition is strong or weak on the output side, we must also recognize the possibility of imperfect competition on the input side. In that case, input prices are not exogenous to the firm, but instead are systematic functions of the scale of production and exhibit observed values that reflect input-side market power (monopsony power). It is broadly documented that large firms tend to pay higher wages than smaller firms, and that large US banks tend to pay different interest rates on deposits than smaller banks. To the extent that any such differences reflect monopsony power, statistically holding these prices constant in the estimated cost function in the manner of the standard neoclassical specification may yield misleading estimates of the overall degree of market power. Such distortion is arguably innocuous when the research question is one of economies of scale or scope, or of productive efficiency; but it is central to the question of market power. Some samples might exhibit negligible sample variation in input prices, or some estimates might exhibit coefficients on input price terms that are statistically indistinguishable from zero, in which cases this question is moot. In all other cases, exploring this issue in more depth represents a potentially important improvement to empirical studies of market power.

Another point relevant to the appropriate treatment of input prices in empirical cost functions is that unobserved heterogeneity in either inputs or outputs can distort estimates of cost functions, and hence estimates of the Lerner index or similar measures of competition. For example, most empirical studies define a single measure of wages, despite the fact that each firm hires employees with diverse skills, tasks, seniority, and compensation. Cross-firm or time-series variation in the mix of employee types will cause intra-sample variation in the observed wage rate that does not represent variations either in monopsony power or in labor market conditions facing the firms. Similarly, unobserved heterogeneity in output characteristics can distort measures of output quantity and the interpretation of marginal cost. Whether such distortions are small, and whether they tend to cancel out across observations within a typical sample, may be difficult to determine and has been largely ignored in the literature. However, evidence of their importance may be inferred from the theoretical requirement that cost functions must be linearly homogeneous in input prices: in the rare cases where researchers have tested (rather than imposed) that condition, it is nearly always resoundingly rejected.[8]

Other regularity conditions should also be satisfied by empirical cost estimates, including positive marginal costs for every observation, quasi-concavity, and positive cost shares implied by Shephard's lemma. Time-series or panel data may incorporate the effects of technological change over time, requiring an empirical specification capable of accommodating or controlling for such change. While many empirical studies have ignored these details, formal rigor requires their consideration.

Once the Lerner index has been estimated, we then face the task of interpreting it – that is, of mapping it into a particular degree of competition, welfare, or other relevant outcome. This step is also tricky. For some purposes, it might suffice to rank subsamples according to the Lerner index, such as assessing competition before and after some regime change, whether regulatory, technological, or otherwise. For other purposes we may need to know the exact number; for example, we know that $L = 0$ under long-run competitive equilibrium, so any positive value of L would imply some degree of market power, implying some attendant welfare loss and likely motivating some policy response.

However, even a free-entry equilibrium would not attain $L = 0$ in the presence of fixed costs, as equilibrium profits must suffice to cover both fixed and variable costs of production. Conversely, and overlooked by most previous empirical studies of the Lerner index, actual market power could be empirically masked if firms exhibit expense preference (non-cost-minimizing) behavior by applying supracompetitive revenues to support supracompetitive levels of expense – as for instance on excess staffing, luxurious facilities, or inefficiently high investments in technology – rather than purely to generate supracompetitive profits (Edwards, 1977). Such behavior would raise marginal costs above competitive levels, reducing the observed price–cost margin.[9]

Even if all firms attempt to minimize costs, there is no unique value of L corresponding to monopoly, as the monopoly price (or Cournot, or Stackelberg, or any other particular oligopoly equilibrium price) varies with the elasticity of aggregate demand, which in turn varies across products, tastes, and other factors not necessarily under the control of the firm and not necessarily related to market power. Absent information about aggregate demand elasticity, we cannot even reliably rank different markets or samples according to market power using L alone, a point made in somewhat different form by Boone (2008a, 2008b). The Rothschild–Bresnahan index aims at overcoming this difficulty, and is discussed next.

1.3 THE ROTHSCHILD–BRESNAHAN CONDUCT PARAMETER

The Lerner index, while incorporating prices and marginal costs, sheds no light on equilibrium quantities produced or consumed, or on how those quantities would change as a function of prices or costs. As such, while useful, it is an incomplete measure from the perspective of conventional policy goals and associated economic outcomes. Therefore, while acknowledging its relevance, there are good reasons to supplement the Lerner index with one or more other measures.

The long history of theoretical and empirical research into patterns of strategic interaction among firms suggests that it is useful to explore some conduct variable or parameter that can be estimated empirically and that is also formally related to, or derived from, theoretical models of rational choices by firms. A natural candidate is the elasticity-adjusted Lerner index (Genesove and Mullin, 1998; Wolfram, 1999). While this parameter can be estimated in several versions, according to whether a firm's own impact on aggregate production is included or netted out, or distinguished by elasticity versus semi-elasticity forms, it is essentially the same measure as the Rothschild–Bresnahan conduct index (Rothschild, 1942; Bresnahan, 1982, 1989; Lau, 1982), as noted above, and is related to the product of the Lerner index times the market demand elasticity.

This parameter has also been interpreted as a conjectural variation (Iwata, 1974; Shaffer, 1983; see also Bowley, 1924; Cowling and Waterson, 1976), though nothing in its empirical estimation either requires or "proves" that firms have any particular expectation about rivals' actions. Rather, the conduct parameter quantifies the observed relationship among prices, marginal costs, and market demand elasticities in a way that maps directly into the spectrum of oligopoly solution concepts – not only static equilibria (a fact misunderstood by some authors)[10] but even explicitly dynamic equilibria (Worthington, 1990).[11]

This latter point cannot be overemphasized: whatever are the values of prices, marginal costs, and demand elasticity in a particular sample, they always exist and will perforce yield some corresponding value of the algebraic term that we call the conduct parameter.[12] Like the Lerner index, the conduct parameter faces complications in interpreting its value, as discussed below. In general, theoretical models indicate that the elasticity form of conduct parameter (as in Bresnahan, 1982) ranges from 0 for long-run competitive equilibrium to 1 for pure or joint monopoly, while taking intermediate values for other distinct oligopoly equilibrium concepts such as Cournot, Stackelberg, and so on. Non-elasticity forms of the parameter would take different but equally specific values (Corts, 1999). Some economists suggest interpreting the conduct parameter "as if" firms were following a particular conjecture, in the same manner as we commonly understand that observed patterns of demand suggest that consumers are behaving "as if" they were maximizing some particular utility function (Bresnahan, 1989, p. 1029).

Empirical estimation of conduct parameters involves challenges as well as some advantages. Because it involves the output price and marginal cost, among other variables, the conduct parameter is subject to the same difficulties as the Lerner index on the cost side (with one important exception noted below) as well as additional challenges on the demand side. Cost-side complications may arise particularly in cases where the price cannot be directly observed, where the marginal cost must be estimated from underlying data, or where firms may not be attempting to operate at the lowest feasible cost. We discuss demand-side complications below.

In addition, because its proper estimation requires a structural model incorporating both a supply equation and an aggregate demand equation, the conduct parameter requires more data than the Lerner index. Specifying an aggregate demand equation requires defining a geographic market and one or more product markets – unlike the Lerner index, which can be estimated for any individual firm or arbitrary set of firms. Misspecifying the market can bias the resulting estimates (Shaffer, 2001, footnote 7). Estimating the conduct parameter as derived in Bresnahan (1982) requires simultaneous estimation of a system of equations including at least one term that is nonlinear in the parameters, posing special software requirements; sequential estimation of the demand and supply equations would yield the wrong standard errors on key parameters, while purely linear equations do not match the theoretical basis for identifying the conduct parameter.

Misuse of linear forms here creates additional problems as well. Perloff and Shen (2012) show that conduct parameters cannot be estimated if the true model is linear in demand and marginal cost, and cannot be reliably estimated if the functions are linear with noise. This problem indeed drives Corts's (1999) Proposition 1, which he interprets as a weakness of the conduct parameter instead of recognizing that it is actually an artifact of a particular, very special functional form. However, linear marginal cost functions violate the well-known theoretical requirement that cost (and marginal cost) functions must be homogeneous of degree 1 in all input prices (e.g., loglinear), so a *properly specified* model would not exhibit the problem noted by Corts. Moreover, empirically, demand and marginal cost functions that are exactly linear would be expected to occur only on a set of measure zero, so that proper attention to empirically validated (and theoretically valid) functional forms should help an econometrician to circumvent this problem.

Corts (1999) identifies several other cases in which the empirically measured conduct parameter may not correspond in particular samples to unbiased estimates of the theoretical value. Such situations serve as a caution against drawing excessively narrow conclusions from estimated conduct parameters about absolute or relative degrees of market power, even though Corts also identified other conditions under which the estimated conduct parameter would be accurate. Fortunately, more can be said about this issue. First, it appears that the Corts critique does not apply in cases where the true conduct is perfectly competitive; in conjunction with Corts's finding that the empirical conduct parameter may equal zero despite a particular form of market power, this may suggest that the conduct parameter interpreted as a one-tail test of market power, at a minimum. In addition, Puller (2009) suggests one way around the problem in some of the cases Corts describes; this hopeful finding suggests that future theoretical work may continue to improve the potential reliability of the conduct parameter approach. Finally, several empirical studies that attempt to test the reliability of the conduct parameter approach against the Corts critique have all found that discrepancies between the structural estimates and independently ascertained "true" values, while nonzero, tend to be minor when applied to actual data (Genesove and Mullin, 1998; Wolfram, 1999; Clay and Troesken, 2003; Kim and Knittel, 2006).

Functional forms in the demand and supply equations should also satisfy specific theoretical requirements, including linear homogeneity of marginal cost in input prices. A similar requirement for demand functions, that they be homogeneous of degree zero in aggregate income and all prices (Kreps, 1990, p. 63), has typically been neglected in empirical conduct studies, but would require the estimation of a complete system of prices across the economy as well as particular functional forms. Neoclassical (inverse) demand schedules specify aggregate quantities as a function of the price of the output, demand shifters such as aggregate income, prices of other goods or services, and any other relevant regressors. Bresnahan (1982) provides useful information about the types of regressors and functional forms needed to identify the conduct parameter in this structural approach, which can be implemented using aggregate data alone, or (as in Iwata, 1974) using firm-specific data on the supply side.

Once the equations have been estimated, the fitted parameters should be checked for adherence to regularity conditions for both the demand function and the supply function. Demand functions should exhibit a negative own-price effect (downward-sloping aggregate demand) and, for normal goods (such as we believe would characterize banking services and most other items), a positive income effect. The previous section listed some common regularity conditions for cost functions such as positive marginal cost, quasi-concavity, and positive cost shares derived from Shephard's lemma. Any violation of these regularity conditions might suggest problems such as measurement error in the data or specification error regarding functional forms.

Recognizing that even the relatively modest data and estimation requirements of the structural conduct parameter model may sometimes prove problematic, Shaffer (2000) derives a simplified version of the test that involves only a correlation between two terms, which can be implemented in a nonparametric form if desired. An important benefit of this procedure is that it circumvents any need to estimate a cost function and determine an exact marginal cost, as long as the true marginal cost is uncorrelated with other variables in the test. This model is aimed at simply distinguishing between perfectly competitive conduct against a generic imperfectly competitive alternative, or in an alternative form whether the sample observations deviate from Cournot equilibrium, without attempting to quantify the exact degree of deviation from the respective benchmark. Additional assumptions are required to generate these results, including locally constant aggregate demand elasticity and, for some additional results, constant marginal cost. The analysis further proposes a first-differenced version of the test to accommodate inflation in nominal time-series data as well as intertemporal demand shifts.

1.4 EMPIRICAL ILLUSTRATION

This section extends the example of section 2.4 in Chapter 2 of this *Handbook*, where the Lerner index is estimated for the two banks operating in Dewey County. As explained by Weyl and Fabinger (2013), a firm's conduct parameter can generally not be estimated accurately as a simple parameter. Furthermore, our limited data sample makes it difficult to reliably estimate conduct parameters (Bresnahan, 1982, 1989) as done by, for example, Genesove and Mullin (1998), Shaffer (2004) and Uchida and Tsutsui (2005). We therefore apply the correlation test proposed by Shaffer (2000). The latter test uses only output price, output quantities, and marginal costs and does not impose any parametric assumptions (although estimated marginal costs are usually based on a parametric model). Based on the firms' first-order conditions for profit maximization as a function of competitive conditions, the procedure is able to compare the data against a null hypothesis of perfect competition. Applied to time-series data, the test evaluates whether a firm is behaving competitively on average during the sample period. To our best knowledge, we are the first to apply the competitive correlation test of Shaffer (2000) to bank data.

Following Shaffer (2000), the conduct parameter is derived from the first-order conditions for a profit-maximizing firm and equals, for bank $i = 1, 2$:

$$b_i = e(MC_i / P - 1)Q / Q_i - 1, \tag{1.1}$$

where e denotes the market elasticity of demand, MC_i the marginal costs of bank i, Q the aggregate output of both banks ($Q = Q_1 + Q_2$), and P the output price. Equation (1.1) implies that

$$eQ\,(MC_i / P - 1) = (1 + b_i)\,Q_i. \tag{1.2}$$

Consequently, $b_i = -1$ (perfect competition) implies zero correlation between Q_i and the left-hand side of equation (1.2) in a time-series sample, whereas $b_i > -1$ (imperfect competition) implies positive correlation. Shaffer (2000, prop. 1a) shows that zero correlation between Q_i and $Q\,(MC_i / P - 1)$ is both a necessary and a sufficient condition for competitive behavior for any form of the demand elasticity.[13]

In a time-series sample, demand shifts may induce spurious correlation between the two terms in equation (1.2), causing a bias towards rejection of the competitive hypothesis. This is the standard issue of econometric identification in reduced-form models. Shaffer (2000) proposes first-differencing to make the correlation test more robust for time-series samples with periods of fluctuating prices and market demand. Whenever the elasticity of demand is constant, imperfect competition implies a negative correlation between ΔQ_i and

$$\Delta Q\,(MC_i / P - 1) + Q\Delta MC_i / P - Q\,(MC_i / P^2)\Delta P, \tag{1.3}$$

whereas perfect competition implies zero correlation between these terms.

We run two versions of the test, with and without taking first differences. Applied to each of the two banks of Dewey County, we thus perform four tests in total. The null hypothesis of each test is perfect competition. In each version of the test we use the

Table 1.2 Spearman rank correlation test for for perfect competition

	Levels	Differences
Bank 1	−0.83	−0.65
	(0.000)	(0.000)
Bank 2	−0.36	−0.78
	(0.014)	(0.000)

Notes: The rank correlation based on level variables is in the column captioned "Levels"; the rank correlation based on first-differenced variables is in the column captioned "Differences." The *p*-values corresponding to the Spearman's rank correlation tests are within parentheses. The null hypothesis is that the rank correlation is zero (corresponding to perfect competition), while the alternative hypothesis is that the correlation is negative (corresponding with imperfect competition).

estimated marginal costs based on the translog cost function estimated in section 2.4 of Chapter 2 in this *Handbook*. In all cases, we test the sign of the correlation using a Spearman nonparametric rank correlation test. The test results are displayed in Table 1.2. All four tests reject the null hypothesis of zero correlation at each reasonable significance level, in favor of the alternative hypothesis of imperfect competition. Related correlation tests (Kendall and Pearson) reach the same conclusion. Hence, the correlation tests provide strong evidence against perfect competition, which is consistent with the results based on the Lerner index as reported in section 2.4 of Chapter 2.

1.5 SUMMARY

Decades of theoretical and empirical research have contributed numerous ways to measure competition and to compare the competitive impact of alternate regulatory policies and market environments. Several of the most convenient measures, unfortunately, are beset by very serious problems, while none are completely ideal. Faced with an ongoing and undiminished need to assess competition and market power nonetheless, we would advocate a focus on the scant handful of "least objectionable" measures. Among these, the Lerner index and the Rothschild–Bresnahan conduct index together provide complementary, well-established, easily understood measures that relate to policy-relevant aspects of market power according to formal underlying theoretical models of firms and industries. The latter approach is slightly more demanding with regard to data and estimation techniques, requiring nonlinear systems estimation except in a correlation version under additional assumptions; one tradeoff is that the correlation version yields only qualitative (rather than quantitative) conclusions about market power.

NOTES

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1. Some studies have shown that market power can also affect firms' choice of product quality, investment in R&D, and other dimensions, which additionally affect consumer welfare and total welfare. Our analysis in this chapter abstracts from these aspects.
2. The k-firm concentration ratio is relevant in a market featuring a k-firm cartel plus a competitive fringe (Saving, 1970); the HHI is algebraically related to the Lerner index for a static Cournot oligopoly (Cowling and Waterson, 1976). Previous studies have shown conditions under which either scenario could be sustained as a rational equilibrium, but theory alone has been unable to predict whether or when either of these scenarios will necessarily occur.
3. We commonly assume that a firm with 100 percent market share is a de facto monopoly and would price accordingly, but even that conclusion depends on an assumption that the extent of the geographic market and product market has been properly measured, as well as an assumption that the firm acts to maximize its profits without a strong threat of entry (potential competition) that would constrain its sustainable pricing (limit pricing). Alternative theoretical models offer contrasting predictions.
4. As noted by Amir and Lambson (2001) and Boone (2008a, 2008b), some alternate definitions of competition can produce nonmonotonic associations between "competition" and the Lerner index when firms face heterogeneous cost functions. An implication, not explored here, is that such other notions of competition need not be monotonically associated with consumer surplus, which could be construed as a conceptual or pragmatic shortcoming of such measures.
5. A common example of such a distortion in banking arises with the use of "compensating balance requirements," in which a borrowing firm is required to maintain a given minimum deposit balance at the lending bank, earning a below-market interest rate. This practice, while arguably grounded in mutual benefit (Davis and Guttentag, 1962), alters the accounting figures in a manner similar to reciprocal dealing, in that it reduces the effective interest rate on both the deposit and the loan.
6. A rare exception is Genesove and Mullin (1998), who were able to obtain direct or "engineering" measures of marginal cost in their sample. It was largely this empirical feature that enabled them to test the robustness of the Rothschild–Bresnahan method of inferring competition.
7. By contrast, at least three firms are needed to implement the Hay–Liu–Boone approach (Boone, 2008a, p. 1252), regardless of the true market. So, which three firms should be included? This requirement becomes problematic for markets containing a monopoly or duopoly as in Shaffer and DiSalvo (1994) or Shaffer (2002). Similarly, although Boone (2008a, p. 1253) claims that "one does not need to observe all firms in an industry" to apply his approach, the value of the index obtained will in general differ according to the particular set of firms included in the calculation, which in turn depends on the extent of the market recognized by the researcher.
8. For instance, Zardkoohi et al. (1986) note the failure of linear homogeneity in important prior literature, and the estimates of Shaffer and DiSalvo (1994) likewise violate the required condition. Some studies such as Suominen (1994) use a functional form that cannot satisfy linear homogeneity of marginal cost or total cost.
9. This problem is loosely related to that of variations in cost efficiency across firms due to managerial inefficiency, or to heterogeneous costs that may result from differential access to essential inputs. However, expense preference is distinct from these other concepts, and is more problematic for the empirical estimation of market power, by virtue of its intrinsic linkage with market power. While it is extremely difficult to distinguish actual costs from equilibrium competitive costs without imposing an assumption about strategic interaction among firms, Koetter et al. (2012) offer an insightful approach to this problem.
10. For example, Genesove and Mullin (1998, p. 357) claim that "the estimation of [the conduct parameter] rests upon a static conception of firm conduct."
11. The concept of a conjectural variation has drawn scorn from game theorists because it is incapable of predicting a unique rational oligopoly equilibrium on purely theoretical grounds. However, it is precisely this inability of pure theory to predict a unique equilibrium outcome that reduces the study of market power to an empirical question requiring some parameter that can be estimated to quantify the observed outcome; and it is precisely this flexibility of the conduct parameter that permits it to serve in that capacity (Tirole, 1988, p. 245; Bresnahan, 1989, p. 1029), subject to the caveats discussed above. Some empirical studies seek to avoid this controversy by omitting any mention of the conjectural variation terminology (Genesove and Mullin, 1998; Wolfram, 1999).
12. When estimating a single such parameter across a sample containing heterogeneous firms, the associated conduct parameter will correspond to some weighted or unweighted average value across the various observations, depending on how it is measured. Alternatively, as in Iwata (1974), firm-specific conduct parameters can be estimated.
13. Zero correlation is not a sufficient condition either if the market demand curve is horizontal or if $b_i = -1 + PP'Q\,/\,(QP'^2 - PP' - PP''Q)Q_i$, based on Lau (1982). Because these exceptions occur on a set of measure zero, there is sufficiency in practice.

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