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Assessing Competition with the Panzar-Rosse Model: The Role of Scale, Costs, and Equilibrium

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Abstract

The Panzar-Rosse model has been widely applied to assess competitive conduct, often in specifications controlling for firm scale or using a price equation. We show that neither a price equation nor a scaled revenue function yields a valid measure for competitive conduct. Moreover, even an unscaled revenue function generally requires additional information about costs and market equilibrium. Our theoretical findings are confirmed by an empirical analysis of competition in banking, using a sample covering more than 110,000 bank-year observations on almost 18,000 banks in 67 countries during 1986-2004.

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1 Introduction

The current financial and economic crisis has highlighted the crucial position of banks in the economy. Banks play a pivotal role in the provision of credit, the payment system, the transmission of monetary policy and maintaining financial stability. The vital role of banks in the economy makes the issue of banking competition extremely important. The relevance of banking competition is confirmed by several empirical studies that establish a strong relation between banking structure and economic growth (see e.g. Jayaratne and Strahan, 1996; Levine, Loayza and Beck, 2000; Collender and Shaffer, 2003). Also, an ongoing debate has emerged in the literature as to whether banking competition helps or harms welfare in terms of systemic stability (see e.g. Smith, 1998; Allen and Gale, 2004; De Jonghe and Vender Vennet, 2008; Schaeck et al., 2009) or productive efficiency (Berger and Hannan, 1998; Maudos and de Guevara, 2007).

Theory suggests that banking competition can be inferred directly from the markup of prices over marginal cost (Lerner, 1934). In practice, this measure is often hard or even impossible to implement due to a lack of detailed information on the costs and prices of bank products. The literature has proposed various indirect measurement techniques to assess the competitive climate in the banking sector. These methods can be divided into two main streams: structural and non-structural approaches (see e.g. Bikker, 2004). Structural methods are based on the structure-conduct-performance (SCP) paradigm of Mason (1939) and Bain (1951), which predicts that more concentrated markets are more collusive. Competition is proxied by measures of banking concentration, such as the Herfindahl-Hirschman index. However, the empirical banking literature has shown that concentration is generally a poor measure of competition; see e.g. Shaffer (1993, 1999, 2002), Shaffer and DiSalvo (1994), and Claessens and Laeven (2004). Some of these studies find conduct that is much more competitive than the market structure would suggest, while others find much more market power than the market structure would suggest. Since the mismatch can run in either direction, concentration is an extremely unreliable measure of performance.

The Panzar-Rosse approach (Rosse and Panzar, 1977; Panzar and Rosse, 1982, 1987) and the Bresnahan-Lau method (Bresnahan, 1982, 1989; Lau, 1982) are two non-structural methods that assess competition in the manner of the 'new empirical industrial organization' (NEIO) literature. Both methods can be formally derived from profit-maximizing equilibrium conditions, which is their main advantage relative to more heuristic approaches. As shown by Shaffer (1983a,b), their test statistics are systematically related to each other, as well as to alternative measures of competition such as the Lerner index (Lerner, 1934). In this paper we focus on the Panzar-Rosse (P-R) revenue test, which has been much more widely used in empirical bank studies. This approach estimates a reduced-form equation relating gross revenue to a vector of input prices and other control variables. The associated measure of competition – usually called the H statistic – is obtained as the sum of elasticities of gross revenue with respect to input prices. Rosse and Panzar (1977) show that H is negative for a neoclassical monopolist or collusive oligopolist, between 0 and 1 for a monopolistic competitor, and equal to unity for a competitive price-taking bank in long-run competitive equilibrium. Furthermore, Shaffer (1982a, 1983a) shows that H is negative for a conjectural variations oligopolist or short-run competitor and equal to unity for a natural monopoly in a contestable market or for a firm that maximizes sales subject to a breakeven constraint. As pointed out by Shaffer (2004a,b), the P-R method has certain shortcomings. However, it has attractive features too, which explains its continuing popularity in the empirical literature. The P-R revenue equation is easy to estimate by means of regression, with only few explanatory variables. Since the P-R model involves only firm-level data, it is robust to the geographic extent of the market.

There is a striking dichotomy between the reduced-form revenue relation derived in the seminal articles by Panzar and Rosse and the P-R model as estimated in the empirical literature. Many published P-R studies estimate a revenue function that includes total assets (or another proxy of bank size) as a control variable. Other articles estimate a price function instead of a revenue equation, in which the dependent variable is total revenue divided by total assets. In both cases, the choice to control for scale effects is neither explained nor justified. As far as we know, this inconsistency between the theoretical P-R model and its empirical translation has never been addressed in the economic literature.

The present paper fills this gap by exploring the consequences of controlling for firm scale in the P-R test. We prove that the properties of the price and revenue equations are identical in the case of long-run competitive equilibrium, but critically different in the case of monopoly or oligopoly. An important consequence of our findings is that a price equation and scaled revenue function – which both have been widely applied in the empirical literature – cannot identify imperfect competition in the same way that an unscaled revenue function can. This conclusion disqualifies several banking studies that apply a P-R test based on a price function or scaled revenue equation. See e.g. Shaffer (1982a, 2004a), Nathan and Neave (1989), Molyneux (1994, 1996), De Bandt and Davis (2000), Bikker and Haaf (2002), Claessens and Laeven (2004), Yildirim and Philippatos (2007), and Schaeck et al. (2009).

Furthermore, we show that the appropriate H statistic, based on an unscaled revenue equation, generally requires additional information about costs, market equilibrium and possibly market demand elasticity to allow meaningful interpretations. In particular, because competitive firms can exhibit $H < 0$ if the market is in structural disequilibrium (that is, if entry or exit is being induced by current conditions), it is important to recognize whether or not a given sample is drawn from a market or set of markets in equilibrium. We show that the widely applied equilibrium test (Shaffer, 1982a) is essentially a joint test for competitive conduct and long-run structural equilibrium, which substantially narrows its applicability. Our findings lead to the important conclusion that the P-R test is a *one-tail* test of conduct in a more general sense than shown in Shaffer and DiSalvo (1994). A positive value of H is inconsistent with any form of imperfect competition, but a negative value may arise under various conditions, including short-run competition. We illustrate our theoretical results with an empirical analysis of the competitive climate in the banking industry, based on a sample covering more than 110,000 bank-year observations on almost 18,000 banks in 67 countries during the period 1986-2004.

Although the P-R test has been applied more often to the banking industry than to any other sector, the applicability of the P-R model is much broader and not confined to banks only. See e.g. Rosse and Panzar (1977), Sullivan (1985), Ashenfelter and Sullivan

(1987), Wong (1996), Fischer and Kamerschen (2003), Tsutsui and Kamesaka (2005), who apply the P-R test to assess the competitive climate in the newspaper industry, the cigarette industry, the U.S. airline industry, a sample of physicians, and the Japanese securities industry, respectively. We emphasize that the aforementioned scale correction is also found in non-banking studies applying the P-R test to firms of different sizes; see e.g. Ashenfelter and Sullivan (1987) and Tsutsui and Kamesaka (2005). Hence, the scaling issue that we address in this paper is not confined to empirical banking studies, but applies to the entire competition literature. For this reason our theoretical analysis is formulated in terms of generic firms, and as such is not restricted to the special case of banks.

The setup of the remainder of this paper is as follows. Section 2 describes the original Panzar-Rosse model and the empirical translations found in the empirical competition literature. Next, Section 3 analyzes the consequences of controlling for firm size in the P-R test. Section 4 focuses on the correct P-R test (based on an unscaled revenue equation) and discusses the additional information about costs and equilibrium needed to infer the degree of competition. This section also shows that the widely applied equilibrium test is essentially a test for long-run competitive equilibrium. The bank data used for the empirical illustration of our theoretical findings are described in Section 5. The corresponding empirical results can also be found in this section. Finally, Section 6 concludes.

2 The Panzar-Rosse model

The Panzar-Rosse (P-R) revenue test is based on a reduced-form equation relating gross revenue to a vector of input prices and other control variables. Assuming an n-input single-output production function, the empirical reduced-form equation of the P-R model is written as

$$\log \mathrm{TR} = \alpha + \sum_{i=1}^{n} \beta_i \log w_i + \sum_{j} \gamma_j \log \mathrm{CF}_j + \text{error}, \tag{1}$$

where TR denotes total revenue, w_i the i-th input factor, and CF other firm-specific control factors. Panzar and Rosse (1977) show that the sum of input price elasticities,

$$H = \sum_{i=1}^{n} \beta_i, \tag{2}$$

reflects the competitive structure of the market. They prove that H is negative for a neoclassical monopolist or collusive oligopolist, between 0 and 1 for a monopolistic competitor, and equal to unity for a competitive price-taking firm in long-run competitive equilibrium. Shaffer (1982a, 1983a) shows that H is also negative for a conjectural variations oligopolist or short-run competitor.

The specification in Equation (1) is similar to what has been commonly used in the empirical literature, although the choice of dependent and firm-specific control variables varies. For example, the empirical banking literature often takes interest income as revenues to capture only the intermediation activities of banks (e.g. Bikker and Haaf, 2002). Larger firms earn more revenue, ceteris paribus, in ways unrelated to variations in input prices. Therefore, many studies include log total assets as a firm-specific control variable in Equation (1). Other studies take the log of revenues divided by total assets (TA) as the dependent variable in the P-R model, in which case not revenues but TR/TA – a proxy of the output price P – is explained from input prices and firm-specific factors. This results in a log-log price equation instead of a log-log revenue equation.

In sum, three alternative versions of the empirical P-R model have appeared in the empirical competition literature. The first one is the P-R revenue equation with log total assets as a control variable:

$$\log \mathrm{TR} = \alpha + \sum_{i=1}^{n} \beta_i \log w_i + \sum_{j} \gamma_j \log \mathrm{CF}_j + \delta \log \mathrm{TA} + \text{error}. \tag{3}$$

In the empirical banking literature this version of the P-R model has been used by e.g. Shaffer (1982a, 2004a), Nathan and Neave (1989) and Molyneux (1996). See also Ashenfelter and Sullivan (1987) and Tsutsui and Kamesaka (2005), who apply the P-R model to assess the competitive climate in the cigarette industry and the Japanese securities industry, respectively. Rosse and Panzar (1977) similarly control for scale in the newspaper industry, measured as daily circulation rather than assets. The second version is the P-R price equation without total assets as a control variable:

$$\log(\mathrm{TR}/\mathrm{TA}) = \alpha + \sum_{i=1}^{n} \beta_i \log w_i + \sum_j \gamma_j \log \mathrm{CF}_j + \text{error}, \tag{4}$$

yielding $H^p = \sum_{i=1}^{n} \beta_i$. See e.g. De Bandt and Davis (2000), Hempell (2002), Jiang et al. (2004), Koutsomanoli-Fillipaki and Staikouras (2005), Lee and Lee (2005), and Mamatzakis et al. (2005). The last version is the P-R price equation controlling for firm size:

$$\log(\mathrm{TR}/\mathrm{TA}) = \alpha + \sum_{i=1}^{n} \beta_i \log w_i + \sum_j \gamma_j \log \mathrm{CF}_j + \delta \log \mathrm{TA} + \text{error}. \tag{5}$$

This specification has been used by e.g. Molyneux (1994), Bikker and Groeneveld (2000), Bikker and Haaf (2002), Claessens and Laeven (2004), Yildirim and Philippatos (2007), and Schaeck et al. (2009). When log assets are included, the empirical estimates from a log-log price equation are equivalent to those of the corresponding log-log revenue equation, with the sole distinction that the coefficient on $\log \mathrm{TA}$ will differ by 1. The key issue addressed in this paper is the relation between the H statistics based on the scaled and unscaled versions of P-R price and revenue equation.

3 Controlling for scale in the P-R model

This section analyzes the consequences of controlling for firm scale in the P-R test. First, we address some implications of including $\log \mathrm{TA}$ as a regressor in the reduced-form revenue equation. Second, we derive some properties of the reduced-form price equation as compared with the P-R reduced-form revenue equation. This comparison requires a separate analysis of the effect of controlling for scale, and also requires a distinction between the case of U-shaped average costs and locally flat average costs.

Because elasticities are required to compute the value of H, and the coefficients in a log-log equation correspond directly to elasticities, virtually all empirical applications of the P-R test have relied on the log-log form discussed in Section 2. Accordingly, our analysis below will address this form exclusively. In addition, the original derivation of the

P-R result assumes that production technology remains unchanged across the sample, and we likewise maintain that assumption throughout.

3.1 Revenue equation

First, we address the common practice of including the log of total assets (or similar measure of scale) as a separate regressor in a reduced-form revenue equation such as Equation (3). This practice appears ubiquitous in the empirical P-R literature, even going back to the seminal study by Rosse and Panzar (1977), yet without explicit discussion or analysis. This point is important because the formal derivation of H does not include scale as a separate regressor, so it is necessary to rigorously explore the effects of such inclusion.

Intuitively, controlling for scale makes apparent sense because larger firms earn more revenue, ceteris paribus, in ways unrelated to variations in input prices. If we estimate a reduced-form revenue equation across firms of different sizes without controlling for scale, the standard measures of fit will be quite poor. Indeed, this fact has been used to justify the choice of $\log \text{P} = \log(\text{TR}/\text{TA})$ instead of $\log \text{TR}$ as the dependent variable, especially when scale has been omitted as a regressor in the price equation (see, for example, Mamatzakis et al., 2005).

The main problem arises in the case of imperfectly competitive firms. The standard proof that $H < 0$ for monopoly relies on the monopolist's quantity adjustment in response to changes in input prices. If a monopolist faced a perfectly inelastic demand curve, there would be no quantity adjustment and so TR would move in the same direction as P, which is the same direction as marginal costs (MC).[1] Hence, TR would move in the same direction as input prices, so we would observe $H > 0$.[2] The condition that rules this out is the firm's profit-maximizing condition $\text{MR} = \text{MC} > 0$ (where MR stands for marginal revenue), which implies elastic demand at equilibrium output levels. But if the regression statistically holds the output quantity constant by controlling for $\log \text{TA}$, then the coefficients that comprise H will represent the response of TR to input prices at a fixed output scale, which is just the change in price times the fixed output. Thus, the

[1] See, for example, Milgrom and Shannon, 1994, page 173; Chakravarty, 2002, page 352.

[2] The same result also occurs whenever the monopoly demand curve is inelastic, even if imperfectly so.

estimates will yield $H > 0$ for any monopoly when the revenue equation controls for scale. The same argument also applies to oligopoly and to the price equation. This leads to the following result.

Proposition 3.1 *Estimates of conduct for monopoly or oligopoly that control for scale, will yield $H > 0$.*

3.2 Price equation

As a preliminary step, we note the basic property that marginal cost MC, like total cost, is homogeneous of degree 1 in all input prices.[3] That is,

$$\sum_i \partial \log \mathrm{MC} / \partial \log w_i = 1 \tag{6}$$

for all inputs i and input prices w_i. Hence, the summed revenue elasticities of input prices must equal the elasticity of revenue with respect to marginal cost MC. That is, we have

$$\frac{\partial \mathrm{TR}}{\partial \log \mathrm{MC}} = \sum_i \frac{\partial \mathrm{TR} / \partial \log w_i}{\partial \log \mathrm{MC} / \partial \log w_i} = \sum_i \frac{\partial \log \mathrm{TR}}{\partial \log w_i} = H. \tag{7}$$

Thus, the P-R statistic H actually represents the elasticity of revenue with respect to marginal cost, under the assumption of a stable cost function so that all changes in marginal cost are driven by changes in one or more input prices. A similar property holds for H^p, the H statistic obtained from the P-R price equation. We shall make use of this result at various points below by referring interchangeably to H and $\partial \log \mathrm{TR} / \partial \log \mathrm{MC}$. In the following analysis, we define AC = average cost and x output quantity.

A few studies have used $\log \mathrm{P}$ as the dependent variable without controlling for $\log \mathrm{TA}$, and this is the case we address next. Note that

$$\begin{aligned} \partial \log \mathrm{P} / \partial \log w_i &= \partial \log (\mathrm{TR}/\mathrm{TA}) / \partial \log w_i \\ &= \partial \log \mathrm{TR} / \partial \log w_i - \partial \log \mathrm{TA} / \partial \log w_i. \end{aligned} \tag{8}$$

Under the standard assumptions of duality theory and the neoclassical theory of the firm, as used in the original proof of the parametric version of the P-R test (Rosse and Panzar,

[3] Rosse and Panzar (1977, page 7) provide a proof of this property.

1977), convexity of the production technology implies U-shaped average costs. Then, in long-run competitive equilibrium, we have $\partial \mathrm{TA}/\partial w_i = 0$ because the output scale at which average costs are minimized is not affected by input prices under the assumption of a stable production technology. Then $\partial \log \mathrm{TA}/\partial \log w_i = 0$ and so

$$\sum_i \partial \log \mathrm{P}/\partial \log w_i = \sum_i \partial \log \mathrm{TR}/\partial \log w_i = H. \quad (9)$$

Therefore, the price equation and the revenue equation both yield the same result ($H = H^p = 1$) in the case of long-run competition with U-shaped average costs, with or without $\log$ TA as a control variable. We thus obtain the following result.

Proposition 3.2 $H^p = 1$ *for firms in long-run competitive equilibrium with U-shaped costs, whether or not log TA is included as a separate regressor.*

Next, we address the sign and magnitude of H^p in the monopoly case. We know that the monopoly price is an increasing function of marginal cost (see, for example, Milgrom and Shannon, 1994, page 173; Chakravarty, 2002, page 352).[4] That is, $\partial \mathrm{P}/\partial \mathrm{MC} > 0$ and so $\partial \log \mathrm{P}/\partial \log \mathrm{MC} > 0$. By linear homogeneity of MC in input prices,

$$\partial \log \mathrm{P}/\partial \log \mathrm{MC} = \sum_i \partial \log \mathrm{P}/\partial \log w_i = H^p. \quad (10)$$

The conclusion here is that $H^p > 0$ for monopoly – a contrasting property to $H < 0$ if based on an unscaled revenue equation. That is, a price equation fitted to data from a monopoly sample in equilibrium should always yield a positive sum of input price elasticities. Because this result is also true for a competitive sample, by continuity it also holds for oligopoly. Clearly, this property holds whether or not log TA is included as a separate regressor. This yields the following result.[5]

Proposition 3.3 $H^p > 0$ *for monopoly or oligopoly, whether or not log TA is included as a separate regressor.*

[4]For either monopoly or oligopoly, the condition for profit maximization is MR = MC so we always have $\partial \mathrm{MR}/\partial \mathrm{MC} = 1$ in equilibrium.

[5]Interestingly, the same property also applies to the value of H in a reduced-form revenue equation if the estimated coefficient on log TA is unity (in which case the scaled revenue equation is equivalent to an unscaled price equation), as is often the case empirically. Possible explanations for a unit coefficient on log TA could include the law of one price when firms sell homogeneous outputs within the same market. Then all firms face the same output price, so TR is proportional to scale.

An important implication of Prop. 3.1 and 3.2 is that the sign of H^p cannot distinguish between perfect and imperfect competition and thus fails as a test for market power. Since the scaled price equation is equivalent to the scaled revenue equation, the same conclusion applies to H based on the scaled revenue equation.

Corollary 3.1 *$H > 0$ for monopoly or oligopoly if log TA is included as a separate regressor.*

3.3 The case of constant marginal and average costs

Next, we address the case of constant MC = AC. This case is important to consider separately for two reasons. First, in long-run competitive equilibrium, the firm's output quantity is indeterminate within the range over which the minimum average cost is constant, thus implying potentially different responses to exogenous shocks than assumed in the traditional P-R derivation. Second, substantial empirical and anecdotal evidence suggests that many firms are in fact characterized by significant ranges of constant marginal and average cost. Johnston (1960) reports evidence that many industries exhibit constant marginal cost. In banking, several decades of studies have yielded contrasting conclusions regarding economies or diseconomies of scale, but the market survival test suggests that marginal and average costs cannot deviate significantly with size, as banks have demonstrated long-term economic viability in direct competition over a range of scales on the order of 100,000:1 in terms of total assets.

In the case of monopoly or oligopoly, the imposition of constant AC will not change the properties of H or H^p. The reason is that the firm's output quantity is uniquely determined under imperfect competition (downward sloping firm demand) even when marginal cost is constant. Then the standard proof follows: MR = MC > 0 in equilibrium, an increase in input prices will drive up MC by linear homogeneity, the increase in MC will reduce the firm's equilibrium output quantity by the downward-sloping demand curve, and the reduction in output will reduce the firm's total revenue by the definition of positive MR. Thus $H < 0$. At the same time, however, the reduction in output quantity will increase the output price by the downward-sloping demand condition, so $H^p > 0$.

Proposition 3.4 *Constant MC does not alter the sign of H or H^p for monopoly or oligopoly, compared to the standard case of U-shaped average costs.*

Also the case of long-run competition yields the same results for H^p whether with constant AC or with U-shaped average costs. That is, P = MC in long-run competitive equilibrium, so ∂P/∂MC = 1 and thus, by linear homogeneity of MC in input prices, $H^p = 1$.

Proposition 3.5 *$H^p = 1$ in long-run competitive equilibrium with constant AC, whether or not log TA is included as a separate regressor.*

However, constant AC poses a problem for H (based on the unscaled revenue equation) in long-run competitive equilibrium. To see this, consider separately the cases of increasing and decreasing marginal cost. First, suppose input prices rise so that MC rises. Starting from an output price equal to the original MC, firms now find P < MC. But competitive firms are price takers and thus cannot unilaterally raise price to the new long-run equilibrium level. In the short run, firms will suffer losses until exit by some firms reduces aggregate production. Since market demand curves are downward-sloping, the reduction in aggregate production drives up the price. A new equilibrium is restored when exit has progressed to the point where the new P equals the new MC. The indeterminate aspect of firms' response here is the production quantity chosen by surviving firms. Since MC = AC = constant, firms can mitigate their losses by reducing output. In that case, a new equilibrium may be restored with little or no exit. Then each firm will be producing less at the new equilibrium, possibly to the point where total revenue is lower than before despite the higher output price. This scenario would yield an empirical measure of $H < 0$, which cannot be distinguished from the imperfectly competitive outcome.[6]

Now consider the other possibility, a decline in input prices causing a decline in MC. At the old output price, P > MC and positive profits will attract entry. However, with

[6] It is also possible that the reduction in output may be less severe, in which case H would lie between 0 and 1. Any reduction in the firm's output would cause $H < 1$.

constant MC = AC, incumbent firms are likely to expand production before entry occurs to take advantage of the incremental profits. Either way, aggregate output expands and the market price falls. At the new equilibrium (where P = MC), incumbent firms are producing more than before, but by an amount that is indeterminate. Again, it is possible to observe $H < 0$.[7]

In both cases, H will be less than unity if firms make any adjustment of production quantity in the transition to the new equilibrium. With constant MC, we should expect some output adjustment in general. Therefore, unless we can rule out constant MC as a separate hypothesis, a rejection of $H = 1$ does not reliably reject long-run competitive equilibrium, contrary to the standard results under the assumption of U-shaped average cost.

Proposition 3.6 *$H < 1$, or even $H < 0$, is possible for firms in long-run competitive equilibrium with constant AC in the P-R revenue test not controlling for scale.*

It should be noted that the standard functional forms employed in most empirical cost studies (such as translog, flexible Fourier, and minflex Laurent) are not very useful to testing for constant marginal cost. If MC and AC are constant, one could contemplate estimating the elasticity of market demand as a further input to properly interpreting H (Shaffer, 1982b). However, in that case an overall market must be defined, which is an extra step that is not necessary in a standard P-R test. We leave this as an important topic for future research.

3.4 The consequences of scaling

Table 1 summarizes the various conclusions about H and H^p. The case of monopolistic competition cannot arise with constant AC, while the zero-profit constraint implies $H^p > 0$ under monopolistic competition. The result that $0 < H < 1$ is possible for short-run competition is based on Rosse and Panzar (1977, page 14). They show that $H \leq 1$ (including the region between 0 and 1) for their 'Market Equilibrium Hypothesis', which

[7] A milder increase in output would cause H to lie between 0 and 1. Any increase in output by an individual firms would cause $H < 1$.

they define as firms trying maximize profits in the presence of market forces operating to eliminate excess profits (which includes short-run competition).[8] Because H^p is positive in the polar cases of long-run competition and monopoly (pages 8-9), it is also positive in intermediate cases, including short-run competition and monopolistic competition.

An important overall result is that the sign of H^p cannot yield reliable implications for the degree of competition, and various conditions can cause the sign of H^p to be reversed regardless of the degree of competition. Therefore, a reduced-form price equation cannot be used to infer the degree of competition. The same conclusion applies to H based on the scaled revenue equation. These conclusions disqualify several empirical studies that use a P-R test based on a price function or scaled revenue equation. See e.g. the banking studies by Shaffer (1982a, 2004a), Nathan and Neave (1989), Molyneux (1994, 1996), De Bandt and Davis (2000), Bikker and Groeneveld (2000), Bikker and Haaf (2002), Claessens and Laeven (2004), Mamatzakis et al. (2005), Yildirim and Philippatos (2007), and Schaeck et al. (2009) and the non-banking studies by Ashenfelter and Sullivan (1987) and Tsutsui and Kamesaka (2005).

4 Assessing competition with the unscaled P-R model

The previous section has made clear that a price function or scaled revenue equation cannot be used to infer the degree of competition. Only the unscaled revenue equation can yield a valid measure for competitive conduct. However, even if the competitive climate is assessed on the basis of the correct H statistic, there are still some caveats to consider.

4.1 Interpretation of the H statistic

Given an estimate of the H statistic based on the unscaled revenue equation, several situations may arise. A significantly positive value of H is inconsistent with any form of imperfect competition, whether the sample is in equilibrium or not. Hence, in this case

[8] More generally and intuitively, if $H < 0$ for any profit-maximizing firm facing a fixed demand curve (as shown in Shaffer 1983a) while $H = 1$ for any firm in long-run competitive equilibrium (after entry and exit have fully adjusted to any changes in input prices), then – by continuity – there must exist a phase of partial adjustment between short-run and long-run competition for which H lies between 0 and 1.

we do not need any additional information to reject imperfect competition. In particular, if we reject the null hypothesis $H < 0$, not controlling for scale, then no further tests are required to rule our the possibility of monopolistic, cartel, or profit-maximizing oligopoly conduct. Furthermore, $H = 1$ reflects either long-run competitive equilibrium, sales maximization subject to a breakeven constraint, or a sample of local natural monopolies under contestability (Rosse and Panzar, 1977; Shaffer, 1982a).[9] A negative value of H may arise under various conditions. Table 1 shows that, in addition to the correct H statistic, additional information about costs is generally needed to allow meaningful interpretations. A finding of $H < 0$, cannot by itself distinguish reliably between perfect and imperfect competition. Only when the hypothesis of constant AC is ruled out, can we be assured that long-run competition would generate $H > 0$; see Prop. 3.6. Similarly, if we reject $H = 1$, this does not mean that we reject long-run competitive equilibrium. Rather, independent information about the shape of the cost function is required in addition; see again Prop. 3.6. Since short-run competition may yield $H < 0$ as well, even under standard cost conditions (Shaffer, 1982a, 1983a; Shaffer and DiSalvo, 1994), we also need more information about long-run structural equilibrium to distinguish between perfect and imperfect competition. In sum, the P-R test boils down to a *one-tail* test of conduct, subject to additional caveats. A positive unscaled value of H is inconsistent with any form of imperfect competition, but a negative value may arise under various conditions, including long-run competition with constant average cost or short-run competition.

These findings also imply that the numerical value of H does not generally provide a reliable indicator of the strength of competition. In particular, smaller values of H do not necessarily imply greater market power, as also recognized in previous studies. Indeed, Shaffer (1983b) shows that $L = 1/(1 - H)$ at the firm level, where L is the firm's Lerner index. This implies $\partial L/\partial H = 1/(1 - H)^2 > 0$. Now take $H < 0$. A larger value of H is associated with a larger L, i.e a higher markup of price over marginal cost and hence more market power. Furthermore, Shaffer (1983a) shows that $E/(H - 1) = t$, with t the conjectural variation elasticity and E the market demand elasticity ($E < 0$). This implies

[9] Appendix A shows that H is not equal to unity under fixed markup pricing, in contrast to what is claimed in Rosse and Panzar (1977).

$\partial t/\partial H = -E/(H-1)^2 > 0$, so larger (negative) values of H are associated with larger t (more monopoly power). Both results imply a reverse ranking between negative values of H and degree of monopoly power, contrary to recent interpretations in the empirical literature. Because structural disequilibrium can disrupt these linkages, as noted above, H cannot be regarded as cardinal in general.

4.2 Further testing

Because it has been shown that even competitive firms can exhibit $H < 0$ if the market is in structural disequilibrium (that is, if entry or exit is being induced by current conditions), it is important to recognize whether or not a given sample is drawn from a market or set of markets in equilibrium. Empirical P-R studies have long applied a separate test for market equilibrium in which a firm's return on assets (ROA) replaces TR as the dependent variable in a reduced-form regression equation using the same explanatory variables as the standard P-R revenue equation (that is, input prices and usually other control variables). The argument is that, in a free-entry equilibrium among homogeneous firms, market forces should equalize ROA across firms, so that the level of ROA is independent of input prices (Shaffer, 1982a). That is, we define an H^{ROA} analogously to H and fail to reject the hypothesis of market equilibrium if we cannot reject the null hypothesis $H^{ROA} = 0$. Since its introduction, this test has been widely used, largely without further scrutiny (see e.g. Bikker and Haaf, 2002; Claessens and Laeven, 2004). Here we re-examine the conceptual underpinnings and properties of this test.

First, recall that long-run competitive equilibrium implies P = MC = AC with zero economic profits for any set of input prices. If accounting profits are sufficiently correlated with economic profits, then we should observe $H^{ROA} = 0$ in this case and the test would be valid, subject to similar caveats and critiques as the original H test discussed above. However, under imperfect competition, economic profits are positive and the observed accounting ROA may vary across firms or over time (think, for instance, of asymmetric Cournot oligopoly or a monopoly with blockaded entry). In particular, ROA may respond to input prices under imperfect competition, so H^{ROA} need not (and in general would not) equal zero even if the market is in structural equilibrium.

More specifically, we can show that $H^{ROA} < 0$ for monopoly facing any demand function that is not perfectly inelastic. If input prices rise, thus increasing MC, the monopolist reduces production and raises the price of its output in order to re-equilibrate at the new profit-maximizing condition MC = MR = P + $x\partial\text{P}/\partial x$. But, as market demand is not perfectly inelastic in general (and never perfectly inelastic at the point of monopoly equilibrium), the monopolist cannot pass along the entire increase in cost to its customers. That is, $\Delta\text{P} < \Delta\text{MC}$. Since the resulting margin P − MC is therefore lower after this adjustment, ROA is lower, and hence $H^{ROA} < 0$. This result does not depend on the specific form of demand or cost, and likewise generalizes to oligopoly. In the case of short-run competitive equilibrium, firms are output price takers and cannot pass along any increase in input prices in the short run, so that we would also observe $H^{ROA} < 0$. If input prices fall, firms in a competitive market may earn temporary profits until new entry occurs, again implying $H^{ROA} < 0$. In no case would we expect to observe $H^{ROA} > 0$.

Proposition 4.1 $H^{ROA} < 0$ *for monopoly, oligopoly, or short-run competitive equilibrium, whether or not log TA is included as a separate regressor.*

Therefore, we may think of H^{ROA} as a joint test of both competitive conduct and long-run structural equilibrium (i.e., a test of long-run competitive equilibrium). Whenever $H = 1$ and $H^{ROA} = 0$, both the revenue test and the ROA test provide results consistent with long-run competitive equilibrium. Where $H^{ROA} < 0$, this would be consistent with monopoly, oligopoly, or short-run (but not long-run) competition, all of which would also imply $H < 0$. Where $H^{ROA} < 0$ but $H > 0$, the conclusion would be that conduct is largely competitive but some degree of structural disequilibrium exists in the sample, though not enough to reverse a finding of $H > 0$.

5 Empirical results

The goal of this section is to provide an empirical illustration of the theoretical results obtained in Section 3 using bank data. We opt for the banking industry, as there is no other sector to which the P-R test has been applied so often, which facilitates comparison. For each country in our sample we estimate the H statistic using three different versions of the P-R model: H based on Equation (1), an unscaled revenue function, H^r based on Equation (3), a revenue function with total assets as explanatory variable; and H^p based on Equation (4), a price function with total revenue divided by total assets as the dependent variable. In line with the empirical banking literature, we estimate the P-R model separately for each country, yielding country-specific H statistics. Since some banks operate in multiple countries, our measure of competition in a particular country reflects the average level of competition on the markets where the banks of this country operate. As mentioned by Shaffer (2004a), the P-R model is robust to the geographic extent of the market. We emphasize that the goal of this empirical section is not fit the 'best' P-R model. Such a model would probably allow for changes in competition over time and could contain other extensions relative to the basic model of Section 2. The goal of this section is rather to illustrate our theoretical results by comparing the scaled and unscaled versions of the basic P-R model. Using more advanced versions of the basic P-R model would yield qualitatively similar results, so for the sake of exposition we confine this section to the basic version of the P-R model.

5.1 Dependent variable, input prices and control variables

To assess bank conduct by means of the P-R model, inputs and outputs need to be specified according to a banking firm model (Shaffer, 2004a). The model usually chosen for this purpose is the intermediation model (Klein, 1971; Monti, 1972; Sealey and Lindley, 1977), according to which a bank's production function uses labor and physical capital to attract deposits. The deposits are then used to fund loans and other earning assets. The wage rate is usually measured as the ratio of wage expenses and the number of employees, the deposit interest rate as the ratio of interest expense to total deposits, and the price of physical capital as total expenses on fixed assets (such as depreciation) divided by the dollar value of fixed assets. In practice, accurate measurement of input prices may be difficult. For example, the price of physical capital has been shown to be unreliable when based on accounting data (Fisher and McGowan, 1983a). Fortunately, Genesove and Mullin (1998) have demonstrated that NEIO measures of competition are empirically robust to measurement error of marginal cost and demand. As a robustness check, Shaffer (2004a) treats several of the inputs as quasi-fixed, omitting their prices in an alternative specification of the reduced revenue equation, and finds similar estimates as in the full long-run specifications.

In the unscaled P-R model the dependent variable is the natural logarithm of either interest income (II) or total income (TI), where the latter includes non-interest revenues. In the P-R price model the dependent variable is either II/TA (a proxy of the lending rate) or TI/TA. We use the ratio of interest expense to total funding (IE/FUN) as a proxy for the average funding rate (w_1), the ratio of annual personnel expenses to total assets (PE/TA) as an approximation of the wage rate (w_2), and the ratio of other non-interest expenses to fixed assets (ONIE/FA) as proxy for the price of physical capital (w_3). The ratio of annual personnel expenses to the number of fulltime employees may be a better measure of the unit price of labor, but reliable figures on employee numbers are only available for a limited number of banks. We therefore use total assets in the denominator instead, following other studies that use BankScope data; see e.g. Bikker and Haaf (2002). We include a number of bank-specific factors as control variables, mainly balance-sheet ratios that reflect bank behavior and risk profile. The ratio of customer loans to total assets (LNS/TA) represents credit risk. Generally, banks compensate themselves for this risk by means of a surcharge on the prime lending rate, which affects interest income. Furthermore, the ratio of other non-earning assets to total assets (ONEA/TA) reflects certain characteristics of the asset composition. The ratio of customer deposits to the sum of customer deposits and short term funding (DPS/F) captures important features of the funding mix. The ratio of equity to total assets (EQ/TA) accounts for the leverage, reflecting differences in the risk preferences across banks.

5.2 The data

The empirical part of this paper uses an unbalanced panel data set taken from BankScope, covering the period 1986 – 2004.[10] We focus on consolidated data from commercial, cooperative and savings banks and only consider countries for which we have at least 100 bank-year observations (a minimum number needed to obtain a sufficiently accurate estimate of a country's H statistic). Our sample consists of 112,557 bank-year observations on 17,913 different banks in 67 countries. As in most other such studies, the data have not been adjusted for bank mergers, which means that merged banks are treated as two separate entities until the point of merger, and thereafter as a single bank. As also noted by other authors (Kishan and Opiela, 2000; Hempell, 2002), our approach implicitly assumes that the merged banks' behavior in terms of their competitive stance and business mix does not deviate from their behavior before the merger and from that of the other banks. Since most mergers take place between small cooperative banks that have similar features, this assumption seems reasonable. We leave further testing of this assumption as a topic for further research, as it is clearly beyond the scope of this paper.

Table 2 provides relevant sample statistics for the dependent variables, input prices and control variables across the major countries. All figures are averaged over time, while interest income, total income, and total assets are expressed in units of millions of US dollars (at prices of the year 2000). The data present information on the banking market structure in terms of average balance-sheet sizes, levels of credit and deposit interest rates, relative sizes of other income and lending, type of funding, and bank solvency (or leverage), reflecting typical differences across the countries considered. The reported 5% and 95% quantiles demonstrate that all variables vary strongly across individual banks. In particular, bank size – as measured by total assets or revenues – exhibits substantial variation across banks, explaining the tendency in the economic literature to scale revenues.

[10] We confine our sample to the period preceding the International Financial Reporting Standards period.

5.3 Estimation results for H

In the unscaled P-R revenue equation the scale differences in revenues across banks of different sizes affect the error term, which becomes heteroskedastic with a relatively large standard deviation. This also inflates the standard errors of the model coefficients and of the resulting H statistic. Imprecise estimates of H reduce the power of statistical tests for the competitive structure of the market, which is clearly undesirable. Therefore, we estimate the P-R revenue equation by means of feasible generalized least squares (FGLS) instead of OLS to cope with the heteroskedasticity problem.[11] To deal with any remaining heteroskedasticity, we combine FGLS with White (1980a)'s heteroskedasticity robust standard errors. FGLS yields similar point estimates for H as OLS, but substantially smaller standard errors.

Tables 3 and 4 contain the estimation results for the 67 countries in our sample. For each country, we report H, H^r and H^p and corresponding standard errors. We first consider the P-R model with the dependent variable based on interest income. The average value of H over 67 countries equals 0.39 (with average standard error 0.03), versus 0.75 (0.05) for both H^r and H^p. With the dependent variable based on total income, the average values of H in the three versions of the P-R model equal 0.37 (0.04), 0.73 (0.05) and 0.73 (0.05), respectively. We emphasize that the cross-country averages are provided to illustrate the differences between the scaled and unscaled P-R models. As is explained in Section 4.1, these averages do not reflect the average level of competition, or the relative ranking of the strength of competition, in the countries under consideration. Several other summary statistics underscore the substantial differences between H on the one hand, and H^r and H^p on the other hand. For example, the correlation between H and H^r equals only 0.32. Similarly, the correlation between H and H^p is 0.33. By contrast, the correlation between H^r and H^p is 0.98. We apply a Wilcoxon signed rank test to the 67 differences between each country's H and H^r. This test rejects the null hypothesis that the median of the differences is zero at each reasonable significance level, confirming the difference between

[11] The FGLS estimator has the same properties as the GLS estimator, such as consistency and asymptotic normality (White, 1980b).

the two H statistics. We find the same test result for the differences between H and H^p. Throughout, the differences in H between the P-R models based on interest income and total income are negligible.

The significant differences in H between the unscaled revenue equation and the scaled P-R model confirm our theoretical results. H^r and H^p (based on the scaled P-R model) are positively biased relative to H (obtained from the unscaled revenue equation). To visualize the values of H in the three versions of the P-R model, Figure 1 depicts H in increasing order for all countries in the sample ('unscaled P-R'), together with the corresponding H^r ('scaled P-R'). H^p is not displayed since its values are very close to those of H^r. The H statistics based on the scaled P-R models are very similar and show substantially less variation across countries.[12] They generally take values in the interval $[0.5, 1]$. The cross-country dispersion in H is considerably larger. Figure 1 illustrates very clearly the positive bias in H^r and H^p relative to H.

5.4 Statistical tests for market structure

To assess how the bias in H^p and H^r impairs assessment of market structures, we follow the approach generally adopted in the existing banking literature. For each country we consider the H statistic based on either the price or scaled revenue equation. Subsequently, we draw conclusions about bank conduct on the basis of the theoretical values of H based on the unscaled revenue function. That is, we consider the null hypotheses $H < 0$ (corresponding to a neoclassical monopolist, collusive oligopolist, or conjectural-variations short-run oligopolist), $H = 1$ (competitive price-taking bank in long-run competitive equilibrium, sales maximization subject to a breakeven constraint, or a sample of local natural monopolies under contestability), and $0 < H < 1$ (monopolistic competitor). We apply t-tests to test each of the three null hypotheses. We compare the resulting test outcomes to the results based on H obtained from the unscaled revenue equation.

Table 5 summarizes the outcomes of the market structure tests for the scaled and unscaled P-R models. We only discuss the results for the P-R model in terms of inter-

[12]Since the coefficient of log TA in the revenue equation is virtually equal to 1 for all countries in our sample, the estimates for H^r and H^p turn out almost the identical.

est income, as we establish very similar outcomes for the P-R model with total income as dependent variable. According to the scaled P-R revenue function and the P-R price equation, $H < 0$ is rejected for all 67 countries. Based on the unscaled revenue function, $H < 0$ is rejected for 49 countries only. On the basis of H^r and H^p monopolistic competition is never rejected, whereas H rejects monopolistic competition for 27 countries. The three versions of the P-R model yield comparable results for the hypothesis $H = 1$. This hypothesis is rejected for 59 countries according to the scaled P-R revenue equation, and for 57 (of the same) countries on the basis of the price equation. According to the unscaled revenue equation, $H = 1$ is rejected for 51 countries. These tests for bank conduct confirm our main theoretical result, namely that scaling of the P-R equation results in substantially different estimates of H in case of imperfect competition, but not in case of perfect competition. Moreover, the positive bias in H^r and H^p becomes apparent from the fact that imperfect competition is rejected more often and monopolistic competition is rejected less often in the scaled P-R models than in the unscaled version.

5.5 Interpretation of test results

Finally, we turn to the interpretation of the test results based on H, corresponding to the unscaled revenue equation in terms of interest income. For the 40 countries for which $0 < H < 1$ is not rejected, we do not need any further information to conclude that banks behave as monopolistic competitors, or as competitive firms not quite in long-run structural equilibrium, or as long-run competitive firms having flat average cost curves. The competitive environment remains unclear for the 18 countries for which imperfect competition (i.e. $H < 0$) is not rejected, as $H < 0$ can arise under both perfect and imperfect competition. For 16 countries we do not reject $H = 1$, reflecting long-run competitive equilibrium, sales maximization subject to a breakeven constraint, or a sample of local natural monopolies under contestability.

Tables 6 and 7 provide the outcomes of the ROA test as discussed in Section 4.2. For 9 countries we cannot reject $H^{ROA} = 0$ and $H = 1$, providing strong evidence for long-run competitive equilibrium. For 9 other countries we reject $H^{ROA} = 0$ in favor of $H^{ROA} < 0$

but cannot reject $H < 0$, both consistent with monopoly, oligopoly, or short-run (but not long-run) competition. For 21 countries we reject $H^{ROA} = 0$ in favor of $H^{ROA} < 0$ and reject $H < 0$ in favor of $H \geq 0$, suggesting that there is generally competitive conduct but some structural disequilibrium in these countries. For the remaining 28 countries we cannot reject $H^{ROA} = 0$, although we reject $H < 0$ in favor of $H \geq 0$. Failure to reject $H^{ROA} = 0$ could result from large standard errors without 'proving' long-run competition (this interpretation, of course, holds for any hypothesis that we cannot reject). On the other hand, $H < 1$ can also occur in a competitive market and the ROA test may be an additional indication for this.

6 Conclusions

This paper has shown that a Panzar-Rosse price function or scaled revenue equation – which have both been widely applied in the empirical competition literature – cannot be used to infer the degree of competition. Only an unscaled revenue equation yields a valid measure for competitive conduct. Our theoretical findings have been confirmed by an empirical analysis of competition in the banking industry, based on a sample covering more than 110,000 bank-year observations on almost 18,000 banks in 67 countries during the 1986-2004 period.

Even if the competitive climate is assessed on the basis of an unscaled revenue equation, there are still some caveats that must be considered. In particular, the Panzar-Rosse H statistic generally requires additional information about costs, market equilibrium and possibly market demand elasticity to allow meaningful interpretations. However, it is not a straightforward exercise to obtain such additional information.

The coexistence of firms of different sizes within the same market is strong evidence either of disequilibrium or of locally constant average cost. Since constant average cost and disequilibrium undermine the reliability of the P-R test, a sample of firms of widely differing sizes within a single market may be intrinsically unsuitable for application of the P-R test. Samples of firms from multiple markets, by contrast, could exhibit a wide range of sizes without apparent problems in the P-R test, although then a separate test for market boundaries (which is not otherwise important in the P-R framework) may be required to rule out a single market for such a sample. If a single market is found for a sample of different-sized firms, then one should test further for evidence of a flat average cost curve before estimating a P-R model. We leave this as an important topic for future research.

Our findings lead to the important overall conclusion that the unscaled P-R test is a *one-tail* test of conduct. A positive value of H is inconsistent with any form of imperfect competition, but a negative value may arise under various conditions, including short-run or even long-run competition. In this way, the Panzar-Rosse revenue test results in a non-cardinal statistic for bank conduct that is less informative than prior literature has suggested. This may plead in favor of alternative measures of competitive conduct, such as the Bresnahan-Lau approach.

Appendix A The Administered Pricing Hypothesis

Rosse and Panzar (1977, page 15-16) erroneously claim that $H = 1$ in case of constant markup pricing (referred to as the Administered Pricing Hypothesis, APH). We first provide a counterexample to $H = 1$ under APH, in the special case of constant marginal and average cost, or $C(q) = cq$, also using the fact that marginal cost is homogeneous of degree 1 in input prices (or we can think of a single input and constant returns, so c is the input price). Then APH implies $R = aC$ for some constant $a > 1$. But in the usual case of linear pricing, $R = pq$ where p is the output price and $q = q(p)$ with $q'(p) < 0$ (downward sloping demand). As we are showing a counterexample, it suffices to look at the case of linear pricing. Hence, under APH, $pq = acq$ and $p = ac$. Now

$$H = (c/R)(\partial R/\partial c) = (c/pq)(\partial R/\partial c) = (c/acq)(\partial R/\partial c) = (1/aq)(\partial R/\partial c) \tag{A.1}$$

and

$$\partial R/\partial c = a(\partial C/\partial c) = a[q + c(\partial q/\partial p)(\partial p/\partial c)] = a[q + ca(\partial q/\partial p)]. \tag{A.2}$$

So $H = 1 + [ac/q(p)](\partial q/\partial p) < 1$ since $a > 0$, $c > 0$, $q > 0$, and $\partial q/\partial p < 0$.

Next, we consider U-shaped AC and prove that $H < 1$ under APH. Again, as we are showing a counterexample, it suffices to look at the case of log-quadratic cost (not quadratic because linear homogeneity must be satisfied). Let

$$\log C(x) = a + b \log x + (c/2)(\log x)^2 + \log w, \tag{A.3}$$

for output quantity x and a single input price w. Note that linear homogeneity in w requires the unitary coefficient on $\log w$ and forbids terms in $(\log w)^2$ and $\log x \times \log w$. This form corresponds to a standard translog cost function with a single input. The associated marginal cost is not constant unless $b = 1$ and $c = 0$. For appropriate combinations of parameter values, this function represents U-shaped average cost. APH implies $px = \alpha C(x)$ for some fixed $\alpha > 1$, so $p = \alpha C(x)/x$. Then

$$\log p = \log \alpha + a + b \log x + (x/2)(\log x)^2 + \log w - \log x, \tag{A.4}$$

under APH, so $\partial\log p/\partial\log w = 1$. Now under linear pricing

$$H = \partial\log R/\partial\log w = \partial\log(px)/\partial\log w. \tag{A.5}$$

Moreover, under APH

$$\begin{aligned}
\partial\log(px)/\partial\log w &= \partial[\log p + \log x]/\partial \log w \\
&= \partial \log p/\partial \log w + \partial \log x/\partial \log w = 1 + \partial \log x/\partial \log w \\
&= 1 + (w/x)(\partial x(p)/\partial w) = 1 + (w/x)x'(p)(\partial p/\partial w) \\
&= 1 + (w/x)x'(p)(p/w)(\partial \log p/\partial \log w) = 1 + px'(p)/x.
\end{aligned}$$

Finally, we observe that $1 + px'(p)/x < 1$ since $p > 0$, $x > 0$, and $x'(p) < 0$.

Our counterexamples for both constant and U-shaped AC demonstrate that the result $H = 1$ under APH as claimed by Rosse and Panzar (1977) does not hold true.

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Table 1: **Summary of properties of the H-statistic under alternative cost conditions**

		H **based on**		
market power	**AC function**	**unscaled rev. eq.**	**scaled rev. eq.**	**price eq.**
long-run competition	U-shaped	Rosse and Panzar (1977): $H = 1$	Prop. 3.2: $H = 1$	Prop. 3.2: $H = 1$
long-run competition	flat	Prop. 3.6: $H < 0$ or $0 < H < 1$ possible	Prop. 3.5: $H = 1$	Prop. 3.5: $H = 1$
short-run competition	U-shaped	Shaffer (1982a, 1983a): $H < 0$ possible Rosse and Panzar (1977): $0 < H < 1$ possible	by continuity: $H > 0$	by continuity: $H > 0$
monopoly	U-shaped	Rosse and Panzar (1977): $H < 0$	Prop. 3.1 & Cor. 3.1: $H > 0$	Prop. 3.3: $H > 0$
monopoly	flat	Prop. 3.4: $H < 0$	Prop. 3.4: $H > 0$	Prop. 3.4: $H > 0$
oligopoly	U-shaped	Rosse and Panzar (1977): $H < 0$	Prop. 3.1 & Cor. 3.1: $H > 0$	Prop. 3.1: $H > 0$
oligopoly	flat	Prop. 3.4: $H < 0$	Prop. 3.4: $H > 0$	Prop. 3.4: $H > 0$
monopolistic competition	U-shaped	Rosse and Panzar(1977): $0 < H < 1$ under conditions, but $H < 0$ possible	by continuity: $H > 0$	by continuity: $H > 0$

Table 2: **Sample statistics for BankScope data**

This table reports some sample statistics for interest income, total income, total assets, proxies of lending rate, output price and input prices, as well as for various correction variables. Interest income, total income and total assets are in real terms and reported in units of 1 million dollars (in year-200 prices). The sample period covers the 1986 – 2004 period.

									all countries (weighted)		
	France	**Germany**	**Italy**	**Japan**	**Spain**	**Switzerland**	**UK**	**US**	**world-wide mean**	**5% quantile**	**95% quantile**
TI	870.9	98.8	260.2	879.2	760.6	191.3	1047.9	58.6	255.3	11.5	937.5
II	698.0	84.5	212.8	712.7	644.6	129.2	892.9	44.9	212.8	6.7	782.1
TA	11779.9	1572.3	3279.2	19446.4	8848.6	3330.3	12614.5	784.7	3262.1	71.5	13209.0
II/TA	0.069	0.062	0.065	0.024	0.070	0.041	0.066	0.062	0.090	0.049	0.181
TI/TA	0.086	0.072	0.077	0.028	0.082	0.069	0.077	0.070	0.115	0.058	0.212
IE/FUN	0.051	0.038	0.037	0.006	0.045	0.031	0.049	0.029	0.064	0.029	0.123
PE/TA	0.016	0.015	0.017	0.010	0.015	0.015	0.012	0.016	0.018	0.006	0.035
ONIE/FA	1.168	0.797	1.132	0.945	1.046	0.802	1.510	0.885	1.731	0.632	3.782
LNS/TA	0.524	0.598	0.516	0.589	0.562	0.656	0.409	0.622	0.499	0.243	0.689
ONEA/TA	0.050	0.007	0.047	0.010	0.024	0.019	0.042	0.022	0.043	0.015	0.086
DPS/F	0.308	0.434	0.427	0.473	0.403	0.397	0.390	0.489	0.415	0.307	0.478
EQ/TA	7.336	5.204	11.437	5.145	8.898	11.340	11.100	10.426	11.211	5.430	17.686

Table 3: **Estimation results for P-R models**

This table reports estimated values of H and corresponding standard errors for unscaled and scaled versions of the P-R model. The unscaled P-R model is estimated using FGLS, whereas the scaled models are estimated by means of OLS. The reported standard errors are based on White (1980a)'s heteroskedasticity robust covariance matrix. The models denoted by 'log II (+ log TA)' and 'log TI (+ log TA)' refer to the revenue equation with, respectively, log II and log TI as the dependent variable and log TA as the scaling variable.

			log **II**		log **TI**		log **II** (+log **TA**)		log **TI** (+log **TA**)		log(**II**/**TA**)		log(**TI**/**TA**)	
country	**# banks**	**# obs.**	H	$\sigma(H)$	H	$\sigma(H)$	H^r	$\sigma(H^r)$	H^r	$\sigma(H^r)$	H^p	$\sigma(H^p)$	H^p	$\sigma(H^p)$
United Arab Emirates	17	120	-0.704	0.024	-0.752	0.034	0.605	0.057	0.598	0.064	0.653	0.059	0.622	0.061
Argentina	122	470	0.122	0.018	0.082	0.015	0.762	0.042	0.736	0.046	0.801	0.042	0.755	0.042
Australia	41	244	1.222	0.068	1.262	0.075	0.854	0.024	0.881	0.029	0.862	0.024	0.887	0.030
Austria	205	1343	0.657	0.005	0.764	0.007	0.683	0.020	0.805	0.018	0.684	0.019	0.805	0.018
Bahrain	12	117	-0.134	0.022	0.066	0.071	0.597	0.086	0.744	0.062	0.615	0.087	0.774	0.065
Bangladesh	33	273	1.064	0.056	1.119	0.086	1.018	0.080	0.975	0.066	1.020	0.082	0.976	0.066
Belgium	92	615	0.781	0.026	0.697	0.018	0.890	0.032	0.819	0.034	0.892	0.031	0.822	0.033
Bolivia	16	136	0.939	0.043	0.895	0.051	0.968	0.055	0.850	0.049	0.967	0.059	0.850	0.049
Brazil	176	900	1.056	0.007	1.109	0.010	0.766	0.031	0.829	0.027	0.750	0.032	0.817	0.029
Canada	68	542	0.610	0.016	0.644	0.015	0.776	0.030	0.820	0.029	0.775	0.030	0.817	0.029
Chile	36	232	1.151	0.013	1.032	0.032	0.981	0.086	0.769	0.029	0.970	0.090	0.766	0.029
Colombia	40	295	0.100	0.026	0.124	0.018	0.799	0.046	0.754	0.055	0.787	0.047	0.759	0.053
Costa Rica	52	156	0.689	0.010	0.765	0.019	0.826	0.041	0.869	0.026	0.823	0.046	0.867	0.027
Croatia	58	280	-0.698	0.022	-0.830	0.030	0.565	0.046	0.477	0.088	0.589	0.043	0.499	0.082
Czech Republic	35	210	0.981	0.033	0.769	0.040	0.862	0.048	0.734	0.054	0.863	0.050	0.734	0.053
Denmark	103	1068	-0.396	0.007	-0.390	0.009	0.713	0.022	0.746	0.029	0.738	0.023	0.754	0.027
Dominican Republic	31	184	-0.474	0.082	-0.442	0.065	0.761	0.300	0.770	0.094	0.690	0.300	0.754	0.092
Ecuador	29	121	0.683	0.025	1.144	0.058	0.384	0.091	0.871	0.063	0.386	0.088	0.861	0.066
Finland	14	112	0.113	0.043	0.027	0.054	0.797	0.053	0.742	0.077	0.795	0.054	0.751	0.072
France	440	3745	0.237	0.001	0.132	0.001	0.746	0.020	0.652	0.022	0.774	0.020	0.675	0.022
Germany	2327	19190	0.877	0.000	0.909	0.001	0.781	0.008	0.802	0.008	0.780	0.008	0.801	0.008
Greece	28	165	-0.271	0.046	-0.196	0.030	0.720	0.045	0.784	0.047	0.702	0.044	0.778	0.043
Hong Kong	44	331	-0.800	0.022	-0.842	0.017	0.581	0.040	0.572	0.050	0.570	0.037	0.576	0.046
Hungary	31	139	-0.371	0.036	-0.476	0.048	0.831	0.059	0.756	0.052	0.800	0.062	0.755	0.051
Iceland	29	101	-1.046	0.084	-1.109	0.125	0.867	0.042	0.714	0.044	0.930	0.051	0.777	0.046
India	78	650	0.165	0.043	0.176	0.044	0.744	0.054	0.698	0.033	0.745	0.055	0.705	0.034
Indonesia	106	713	0.447	0.006	0.382	0.019	0.741	0.024	0.667	0.029	0.745	0.024	0.672	0.029
Ireland	40	207	1.119	0.040	1.148	0.040	0.885	0.075	0.846	0.061	0.893	0.077	0.853	0.063
Israel	18	145	-0.120	0.040	-0.131	0.028	0.809	0.068	0.721	0.067	0.801	0.071	0.711	0.070
Italy	829	6238	1.108	0.001	1.131	0.001	0.746	0.009	0.763	0.009	0.735	0.010	0.758	0.009
Japan	781	3277	-0.401	0.003	-0.335	0.005	0.518	0.042	0.601	0.018	0.519	0.040	0.592	0.017
Jordan	11	115	-1.797	0.058	-1.875	0.047	0.686	0.064	0.494	0.065	0.698	0.059	0.549	0.062

Table 4: **Estimation results for P-R models (continued)**

			log **II**		log **TI**		log **II** (+ log **TA**)		log **TI** (+ log **TA**)		log(**II**/**TA**)		log(**TI**/**TA**)	
country	**# banks**	**# obs.**	H	$\sigma(H)$	H	$\sigma(H)$	H^r	$\sigma(H^r)$	H^r	$\sigma(H^r)$	H^p	$\sigma(H^p)$	H^p	$\sigma(H^p)$
Kazakhstan	27	115	-0.139	0.069	-0.102	0.064	0.578	0.079	0.601	0.054	0.602	0.072	0.622	0.057
Kenya	49	188	0.959	0.036	0.996	0.049	0.611	0.067	0.598	0.066	0.632	0.073	0.633	0.078
Latvia	29	145	0.160	0.030	0.118	0.022	0.859	0.102	0.870	0.106	0.865	0.098	0.872	0.109
Lebanon	63	494	-0.204	0.015	-0.253	0.012	0.775	0.037	0.707	0.039	0.788	0.034	0.732	0.037
Luxembourg	140	1381	0.506	0.003	0.453	0.003	0.869	0.018	0.810	0.019	0.868	0.018	0.811	0.019
Malaysia	46	342	0.484	0.032	0.462	0.021	0.912	0.033	0.899	0.051	0.903	0.033	0.891	0.050
Mexico	49	112	1.590	0.039	1.534	0.028	0.893	0.094	0.841	0.067	0.857	0.077	0.830	0.059
Monaco	14	135	0.427	0.116	0.406	0.113	0.828	0.047	0.841	0.056	0.813	0.052	0.843	0.060
Netherlands	63	384	1.165	0.029	1.188	0.027	0.833	0.021	0.853	0.027	0.830	0.021	0.843	0.028
Nigeria	72	323	0.425	0.026	0.407	0.010	0.773	0.062	0.725	0.039	0.771	0.061	0.740	0.039
Norway	68	420	0.358	0.020	0.364	0.036	0.822	0.032	0.823	0.037	0.836	0.034	0.834	0.038
Pakistan	25	211	1.253	0.040	1.194	0.035	0.796	0.069	0.678	0.082	0.777	0.066	0.665	0.081
Panama	94	134	0.158	0.035	0.148	0.039	0.627	0.034	0.636	0.048	0.625	0.034	0.624	0.053
Paraguay	26	194	-0.308	0.027	-0.247	0.011	0.652	0.044	0.714	0.056	0.672	0.035	0.732	0.047
Peru	26	188	0.041	0.020	0.022	0.029	0.906	0.043	0.854	0.057	0.935	0.039	0.879	0.051
Philippines	49	371	0.251	0.036	0.360	0.056	0.733	0.035	0.745	0.038	0.741	0.035	0.747	0.039
Poland	59	265	-0.028	0.040	-0.221	0.024	0.893	0.041	0.757	0.040	0.890	0.037	0.741	0.039
Portugal	33	293	0.361	0.034	0.062	0.025	0.806	0.026	0.479	0.074	0.802	0.027	0.480	0.073
Romania	34	138	1.135	0.042	1.114	0.063	0.728	0.082	0.759	0.081	0.740	0.083	0.758	0.080
Russian Federation	233	645	0.487	0.008	0.546	0.006	0.604	0.037	0.650	0.023	0.606	0.037	0.657	0.024
Saudi Arabia	11	142	0.667	0.040	0.485	0.070	0.565	0.062	0.400	0.061	0.570	0.064	0.406	0.063
Slovakia	24	107	0.347	0.041	0.279	0.108	0.652	0.083	0.514	0.146	0.642	0.082	0.516	0.144
Slovenia	28	109	0.075	0.114	0.058	0.120	0.659	0.080	0.633	0.072	0.646	0.089	0.649	0.064
South Africa	39	162	1.260	0.062	1.167	0.123	0.709	0.108	0.693	0.070	0.678	0.113	0.679	0.071
Spain	171	1376	0.950	0.007	0.971	0.007	0.745	0.018	0.736	0.013	0.744	0.018	0.735	0.013
Sweden	93	422	0.893	0.014	0.933	0.018	0.691	0.039	0.708	0.038	0.687	0.040	0.709	0.038
Switzerland	433	2975	1.046	0.003	1.084	0.004	0.616	0.027	0.656	0.023	0.612	0.026	0.642	0.022
Thailand	19	157	-0.357	0.026	-0.543	0.016	0.656	0.066	0.594	0.062	0.610	0.065	0.545	0.062
Turkey	54	210	0.693	0.041	0.759	0.034	0.670	0.071	0.701	0.045	0.670	0.070	0.701	0.044
Ukraine	47	184	0.602	0.009	0.599	0.023	0.644	0.058	0.608	0.049	0.646	0.058	0.610	0.050
United Kingdom	194	454	0.733	0.014	0.769	0.004	0.796	0.037	0.831	0.028	0.796	0.037	0.831	0.028
United States	9534	56796	0.248	0.000	0.342	0.000	0.558	0.006	0.657	0.006	0.561	0.006	0.655	0.006
Uruguay	44	120	1.077	0.028	0.933	0.049	0.942	0.037	0.817	0.051	0.945	0.039	0.814	0.052
Venezuela	57	295	0.848	0.022	0.801	0.022	0.748	0.070	0.741	0.057	0.746	0.068	0.742	0.056
Vietnam	24	136	0.899	0.044	0.877	0.064	0.810	0.059	0.750	0.058	0.809	0.059	0.745	0.059
average			0.39	0.03	0.37	0.04	0.75	0.05	0.73	0.05	0.75	0.05	0.73	0.05

Table 5: **Comparison of scaled and unscaled P-R models**

For each of the six model specifications, this table provides the cross-country averages of the H statistic and the corresponding average standard errors. Furthermore, it contains the results of market structure hypothesis testing and reports the number of times the unscaled P-R model and each of the scaled models reject a null hypothesis (at a 5% significance level) regarding the market structure.

			# rejection of null hypothesis		
dependent variable	**scaling variable**	**avg. H (avg. std. error)**	$H < 0$	$0 < H < 1$	$H = 1$
log II	none	0.39 (0.03)	49	27	51
log II	log TA	0.75 (0.05)	67	0	59
log(II/TA)	none	0.75 (0.05)	67	0	57
log TI	none	0.37 (0.04)	47	24	51
log TI	log TA	0.73 (0.05)	67	0	64
log(TI/TA)	none	0.73 (0.05)	67	0	65

Table 6: **Outcomes of ROA test**

This table reports estimated values of H^{ROA} and corresponding standard errors. The reported standard errors are based on White (1980a)'s heteroskedasticity robust covariance matrix. The last column provides the outcomes of a t-test for the null hypothesis $H_0 : H^{ROA} = 0$ versus the alternative $H^{ROA} < 0$. The value 'R' in the last column indicates that the null hypothesis of long-run structural equilibrium is rejected, whereas an 'A' indicates that the null hypothesis is not rejected.

country	H^{ROA}	$\sigma(H^{ROA})$	$H_0 : H^{ROA} = 0$
United Arab Emirates	-0.752	0.622	A
Argentina	-5.469	1.094	R
Australia	-0.454	0.127	R
Austria	0.170	0.276	A
Bahrain	0.020	0.348	A
Bangladesh	-0.143	0.114	A
Belgium	-1.807	0.969	A
Bolivia	-1.910	0.783	R
Brazil	-0.355	0.325	A
Canada	-0.500	0.241	R
Chile	-0.077	0.154	A
Colombia	-0.249	0.315	A
Costa Rica	-7.176	3.962	A
Croatia	-0.400	0.729	A
Czech Republic	-2.656	1.200	R
Denmark	-0.061	0.042	A
Dominican Republic	-1.323	0.271	R
Ecuador	-1.569	1.547	A
Finland	-0.244	1.090	A
France	-0.126	0.075	A
Germany	-0.509	0.197	R
Greece	-0.596	0.079	R
Hong Kong	-0.008	0.174	A
Hungary	0.067	0.371	A
Iceland	-1.315	0.302	R
India	-1.818	0.676	R
Indonesia	-0.716	0.509	A
Ireland	0.389	0.639	A
Israel	0.182	0.084	A
Italy	-1.357	0.633	R
Japan	-0.131	0.425	A
Jordan	-1.105	0.368	R
Kazakhstan	-0.348	0.049	R
Kenya	-1.425	0.302	R

Table 7: **Outcomes of ROA test (continued)**

country	H^{ROA}	$\sigma(H^{ROA})$	$H_0 : H^{ROA} = 0$
Latvia	-0.407	0.127	R
Lebanon	-0.791	1.007	A
Luxembourg	0.897	1.257	A
Malaysia	0.454	1.156	A
Mexico	-0.117	0.069	A
Monaco	-1.179	0.511	R
Netherlands	-0.613	0.436	A
Nigeria	-3.016	0.980	R
Norway	-0.011	0.291	A
Pakistan	-2.305	0.741	R
Panama	0.098	0.106	A
Paraguay	0.249	0.206	A
Peru	-0.257	0.389	A
Philippines	-0.689	0.615	A
Poland	-0.783	0.487	A
Portugal	-0.986	0.431	R
Romania	-0.037	0.338	A
Russian Federation	-0.885	0.256	R
Saudi Arabia	-3.259	0.712	R
Slovakia	-3.075	1.056	R
Slovenia	0.441	0.512	A
South Africa	-2.319	0.494	R
Spain	-0.745	0.191	R
Sweden	-0.115	0.895	A
Switzerland	-0.783	0.733	A
Thailand	-5.000	1.692	R
Turkey	-2.363	1.179	R
Ukraine	-1.879	0.657	R
United Kingdom	-0.594	0.024	R
United States	-1.249	0.514	R
Uruguay	-1.578	0.760	R
Venezuela	0.127	0.323	A
Vietnam	-1.244	0.945	A

Figure 1: **Values of the H statistic**

This figure displays H in increasing order for all countries in the sample ('unscaled P-R') and the corresponding H^r based on the P-R revenue equation with total assets as covariate ('scaled P-R'). The dashed lines around the point estimates constitute a 95% pointwise confidence interval.