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A NEW WAY TO MEASURE COMPETITION*

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This article introduces a new way to measure competition based on firms' profits. Within a general model, we derive conditions under which this measure is monotone in competition, where competition can be intensified both through a fall in entry barriers and through more aggressive interaction between players. The measure is shown to be more robust theoretically than the price cost margin. This allows for an empirical test of the problems associated with the price cost margin as a measure of competition.

A question often asked in both economic policy and research is how the intensity of competition evolves over time in a certain sector. To illustrate, a competition authority may want to monitor an industry so that it can intervene when competition slackens. Alternatively, there may have been a policy change in an industry (e.g. abolishing a minimum price or breaking up a large incumbent firm) with the goal of intensifying competition in the industry. Afterwards policy makers want to check whether the policy change had the desired effect. In economic research, there are empirical papers trying to identify the effect of competition on firms' efficiency (Nickell, 1996), on firms' innovative activity (Aghion *et al.*, 2005 and references therein) and the effects of competition on wage levels (Nickell, 1999 for an overview) and wage inequality (Guadalupe, 2003). The question is how should competition be measured for these purposes.

The price cost margin (PCM) is widely used as a measure of competition. However, the theoretical foundations of PCM as a competition measure are not robust. Theoretical papers like Amir (2002), Bulow and Klemperer (1999), Rosentahl (1980) and Stiglitz (1989) present models where more intense competition leads to higher PCM instead of lower margins. We believe that there are two reasons why PCM is still such a popular empirical measure of competition. First, we do not know how important these theoretical counterexamples are in practice. Is it the case that in 20% of an economy's industries the structure is such that more competition would lead to higher PCM or is this only the case in 1% of the industries? In the former case there would be big problems for the empirical papers mentioned above which use PCM as a measure of competition. In the latter case, the theoretical counterexamples do not seem to pose acute problems for empirical research. As long as there is no evidence that the theoretical counterexamples are important empirically, one would expect that PCM remains a popular competition measure. The second reason for the popularity of PCM is that the data needed to get a reasonable estimate of PCM are available in most datasets.[1]

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[1] Sometimes PCM is defended as measure of competition with reference to its interpretation as a welfare measure (prices closer to marginal costs lead to higher welfare). However, as shown by Amir (2002) and Mankiw and Whinston (1986) there is, in general, no simple relation between PCM and welfare. The same is true for the measure introduced here: there is no simple relation with welfare. In this sense, the measures discussed here are positive, not normative.

The idea of the current article is to develop a competition measure that is both theoretically robust and does not pose more stringent data requirements than PCM. This new measure can then be estimated in the same datasets as where PCM is estimated. This allows a comparison between the new measure and PCM for a number of industries over time. If in 99% of the industries the two measures indicate the same development in intensity of competition over time, this would indicate that the theoretical counterexamples cited above are not particularly relevant in practice. However, if in 20% of the cases the two measures diverged then one should be more careful in using PCM as a measure of competition in empirical research and policy analysis.

The measure I introduce in this article is called relative profit differences (RPD). It is defined as follows. Let $\pi(n)$ denote the variable profit level of a firm with efficiency level $n \in \mathbb{R}_+$ where higher n denotes higher efficiency (more details follow below on how variable profits and efficiency are defined). Consider three firms with different efficiency levels, $n'' > n' > n$, and calculate the following variable $[\pi(n'') - \pi(n)]/[\pi(n') - \pi(n)]$. Then more intense competition (brought about by either lower entry costs or more aggressive interaction among existing firms) raises this variable for a broad set of models. More precisely, in any model where a rise in competition reallocates output from less efficient to more efficient firms it is the case that more intense competition raises $[\pi(n'') - \pi(n)]/[\pi(n') - \pi(n)]$. Since this output reallocation effect is a general feature of more intense competition, RPD is a robust measure of competition from a theoretical point of view. Moreover, I show that the output reallocation effect is a natural necessary condition for PCM to be decreasing in intensity of competition, but it is not sufficient.

The intuition for RPD is related to the relative profits measure ($\pi(n')/\pi(n)$ is increasing in intensity of competition for $n' > n$) introduced by Boone (forthcoming). The intuition for the relative profits measure is that in a more competitive industry, firms are punished more harshly for being inefficient. However, Boone (forthcoming) analyses the relative profits measure in a number of specific examples, not in a general framework as I use here.

The intuition why RPD is increasing in intensity of competition can be stated as follows. As the industry becomes more competitive, the most efficient firm n'' gains more relative to a less efficient firm n than firm n' does (with $n'' > n' > n$). Think, for instance, of a homogeneous good market where firms produce with constant marginal costs. If these firms compete in quantities (Cournot), one would find (if n is close enough to n'') that $\pi(n'') > \pi(n') > \pi(n) > 0$. If competition is intensified by a switch to Bertrand competition, the profit levels satisfy: $\pi(n'') > \pi(n') = \pi(n) = 0$. Hence the rise in competition raises $\pi(n'') - \pi(n)$ relative to $\pi(n') - \pi(n)$.

Recent papers measuring PCM include the following. First, Graddy (1995), Genesove and Mullin (1998) and Wolfram (1999) estimate the elasticity-adjusted PCM. This yields the conduct (or conjectural variation) parameter, which can be interpreted as a measure of competition. This approach has been criticised by Corts (1999) who shows that, in general, efficient collusion cannot be distinguished from Cournot competition using the elasticity-adjusted PCM. Second, Berry *et al.* (1995) and Goldberg (1995) estimate both the demand and cost side of the automobile market. Their models can be used to simulate the effects of trade or merger policies on the industry. Using their

estimates, one can also derive firms' PCMs. Nevo (2001) uses the same methods to estimate PCMs for firms in the ready-to-eat cereal industry. He does this under three different models of firm conduct and then compares the outcomes with (crude) direct observations of PCM. In this way he is able to identify the conduct model that explains the observed values of PCM best. As I argue below, in these papers one would also have been able to derive RPD, which has a more robust relation with intensity of competition.

This article is organised as follows. The next Section introduces the model and the way that more intense competition is identified in this general set up using the (generalised) output reallocation effect. Section 2 shows that RPD is increasing in competition and Section 3 discusses which type of data are needed to estimate RPD in practice. Section 4 compares RPD and PCM and argues that both require similar data to be estimated. Further, I show that whereas the output reallocation effect is sufficient for RPD to be monotone in competition, it is only a necessary condition for PCM to be decreasing in competition, which explains the theoretical counterexamples. Finally, Section 5 concludes. The proofs of results can be found in the Appendix.

1. The Model

The aim of this Section is to introduce a general model with I firms that can enter and compete in a market. Firms are ranked such that lower i implies higher efficiency: $n_1 \geq n_2 \geq \cdots \geq n_I$. To keep things general I do not impose a certain mode of competition like either Bertrand or Cournot competition. I simply assume that each firm i chooses a vector of strategic variables $a_i \in \mathbb{R}^K$. This choice leads to output vector $q(a_i, a_{-i}, \theta) \in \mathbb{R}^L_+$ for firm i where $a_{-i} = (a_1, \ldots, a_{i-1}, a_{i+1}, \ldots, a_I)$ and θ is a parameter that affects the aggressiveness of firms' conduct in the market. For instance, θ could be related to the substitution elasticity between goods from different producers or it could denote whether firms play Cournot or Bertrand competition. Further, the choices of the strategic variables also lead to a vector of prices $p(a_i, a_{-i}, \theta) \in \mathbb{R}^L_+$ for firm i's products.

Finally, we specify the costs of production for firm i as $C[q(a_i, a_{-i}, \theta), n_i]$. We say that $n_i \in \mathbb{R}_+$ measures a firm's efficiency level because of the following assumption.

ASSUMPTION 1 *For a given output vector $q \in \mathbb{R}^L_+$ we assume that*

$$\frac{\partial C(q,n)}{\partial q_l} > 0$$

$$\frac{\partial C(q,n)}{\partial n} \leq 0$$

$$\frac{\partial \left[\dfrac{\partial C(q,n)}{\partial q_l}\right]}{\partial n} \leq 0$$

for each $l \in \{1, 2, \ldots, L\}$, where the last inequality is strict for at least one combination of q and l.

That is, higher production levels lead to higher costs. Further, higher n firms produce the same output vector q with (weakly) lower costs C and (weakly) lower marginal costs for each product l. Although the efficiency levels $n_1, \ldots, n_I$ are exogenously given, the firms that are active in equilibrium are endogenously determined, as discussed below. The essential assumption here is that efficiency can be captured by a one dimensional variable n_i. This assumption is not innocuous and will be discussed further below.

Using this set up, consider the following two stage game. In the first stage, firms decide simultaneously and independently whether or not to enter. I normalise actions a_i in such a way that a firm i that does not enter has $a_i = 0$ (while firms that do enter have $a_i \neq 0$). If firm i enters it pays an entry cost γ_i. In the second stage, firms know which firms entered in the first stage and all firms that entered choose simultaneously and independently their action vectors a_i. I define an equilibrium of this game as follows.

Definition 1 *The set of actions $\{\hat{a}_1, \hat{a}_2, \ldots, \hat{a}_I\}$ denotes a pure strategy equilibrium if the following conditions are satisfied*

$$\max_{a_i}\{p(a_i, \hat{a}_{-i}, \theta)^T q(a_i, \hat{a}_{-i}, \theta) - C[q(a_i, \hat{a}_{-i}, \theta), n_i]\} - \gamma_i < 0 \text{ implies } \hat{a}_i = 0$$

where $p(\cdot)^T$ denotes the transpose of the column vector $p(\cdot)$ and

$$\{p(\hat{a}_i, \hat{a}_{-i}, \theta)^T q(\hat{a}_i, \hat{a}_{-i}, \theta) - C[q(\hat{a}_i, \hat{a}_{-i}, \theta), n_i]\} - \gamma_i \geq 0 \text{ for } \hat{a}_i \neq 0$$

further

$$\hat{a}_i = \arg\max_{a}\{p(a, \hat{a}_{-i}, \theta)^T q(a, \hat{a}_{-i}, \theta) - C[q(a, \hat{a}_{-i}, \theta), n_i]\}.$$

Thus firm i stays out of the market if it cannot recoup its entry cost γ_i. Firms that enter choose action a_i to maximise their (after entry) profits. In other words, I consider a subgame perfect equilibrium here. The zero profit condition is only used when competition is intensified by lowering entry costs. When changing conduct (for given number of firms) it is immaterial whether the zero profit condition holds or not.

I make the following symmetry assumption on the equilibrium outcome. This assumption can also be called a level playing field assumption or an exchangeability assumption (Athey and Schmutzler, 2001). As I discuss in Section 4, neither RPD nor PCM can deal with the asymmetric case. Since the main purpose of this article is to compare the two, I leave this case for future research and focus on the broad set of models where both measures perform reasonably well.

Assumption 2 *There exist vector valued functions $p(\cdot)$ and $q(\cdot)$ such that for a firm with efficiency n equilibrium price and output vectors can be written as*

$$p(n, N, \mathcal{I}, \theta) \tag{1}$$

$$q(n, N, \mathcal{I}, \theta) \tag{2}$$

where N is an aggregate efficiency index which is a function of the efficiency levels $n_1, \ldots, n_I$ and $\mathcal{I}$ is the set of firms that actually enter in equilibrium.

I first consider an example where this assumption is satisfied and then I discuss in what circumstances it is not satisfied.

EXAMPLE 1 *Consider an industry where each firm i produces only one product, faces a demand curve of the form*

$$p(q_i, q_{-i}) = a - bq_i - d\sum_{j\neq i} q_j$$

and has constant marginal costs $1/n_i$. *Then firm i chooses output* q_i *which solves*

$$\max_{q\geq 0}\left[\left(a - bq - d\sum_{j\neq i} q_j\right)q - \frac{1}{n_i}q\right]$$

where I assume that $a > 1/n_i > 0$ *and* $0 < d \leq b$. *Then the first order condition for a Cournot Nash equilibrium can be written as*

$$a - 2bq_i - d\sum_{j\neq i} q_j - \frac{1}{n_i} = 0. \tag{3}$$

Assuming I firms produce positive output levels, one can solve the I first order conditions (3). This yields

$$q(n_i) = \frac{\left(\frac{2b}{d} - 1\right)a - \left(\frac{2b}{d} + I - 1\right)\frac{1}{n_i} + \sum_{j=1}^{I}\frac{1}{n_j}}{[2b + d(I-1)]\left(\frac{2b}{d} - 1\right)}. \tag{4}$$

Defining the aggregate efficiency index as $N = \sum_{j=1}^{I} 1/n_j$, output can indeed be written as in Assumption 2 above. Prices can be written in a similar way as well.

Figure 1 illustrates a case that does not satisfy Assumption 2. It is an example of Salop's (1979) circle with 4 firms producing with constant marginal costs $1/n_i$. If the four firms do not have identical efficiency levels, the equilibrium output of a firm cannot be written as a function of just its own efficiency level and an aggregate efficiency index. The reason is that firms 1 and 3 face different environments. Firm 1 has a neighbour with efficiency level n_4 while firm 3 has a neighbour with efficiency

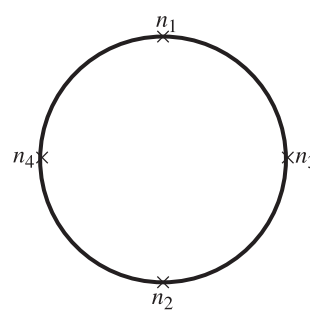

Fig. 1. *Circular Beach with Four Firms*

level n_2. As I discuss in Section 4 not only RPD but also PCM has problems in this case.

From now on I write firm i's equilibrium variable profits as

$$\pi(n_i, N, \mathcal{I}, \theta) \equiv p(n_i, N, \mathcal{I}, \theta)^T q(n_i, N, \mathcal{I}, \theta) - C[q(n_i, N, \mathcal{I}, \theta), n_i]. \tag{5}$$

Since I allow the entry cost γ_i to vary with a firm's identity i and hence with its efficiency level, it can be the case that more efficient firms face lower entry costs (γ_i increasing in i, while n_i is decreasing in i), because these firms are more efficient in both entry and production. But I also allow for the case where more efficient firms pay a higher entry cost to achieve their cost advantage (γ_i decreasing in i). For instance, this could reflect investments in R&D to develop a better production technology, investing more in capital or building a bigger factory to reap advantages of economies of scale. Thus an important distinction between $C(q, n_i)$ and γ_i is that $C(q, n_i)$ is weakly decreasing in n_i (for given q) while γ_i can both rise and fall with i.

In this framework I consider two ways in which competition can be intensified: a change in conduct and entry. The former, more aggressive interaction between players, is parameterised as $\mathrm{d}\theta > 0$. The latter is parameterised as a reduction in entry costs in the following way. Let $(\zeta_1, \ldots, \zeta_I) \in \mathbb{R}^I_+$ denote an arbitrary nonzero vector. Then we consider the following reduction in entry costs $\tilde{\gamma}_i = \gamma_i - \varepsilon\zeta_i$. The key to the analysis is the following way in which more intense competition is identified in this general framework. This is an assumption on how θ and ε affect the equilibrium outcome.

Definition 2 *We say that* $\mathrm{d}\theta > 0$ *and* $\mathrm{d}\varepsilon > 0$ *increase competition if the expression*

$$\frac{\mathrm{d}\ln\left\{-\left.\dfrac{\partial C[q(n_i, N, \mathcal{I}, \theta), n]}{\partial n}\right|_{n = n_i}\right\}}{\mathrm{d}\theta} \tag{6}$$

is increasing in n_i*, where the effect of* θ *is partial in the sense that the set of active firms* $\mathcal{I}$ *is taken as given; and the expression*

$$\frac{\mathrm{d}\ln\left\{-\left.\dfrac{\partial C[q(n_i, N, \mathcal{I}, \theta), n]}{\partial n}\right|_{n = n_i}\right\}}{\mathrm{d}\varepsilon} \tag{7}$$

is increasing in n_i*.*

Although these conditions do not look intuitive at first sight, we view them as a generalisation of the output reallocation effect to the case where $q(\cdot, n)$ is a vector.[2] In the case where firms produce homogenous goods, Boone (forthcoming) and Vickers (1995) identify a rise in competition as a parameter change that raises output of a firm relative to a less efficient firm. Put differently, a rise in θ (or ε) raises $q(n^*)/q(n)$ for $n^* > n$. In words, if more intense competition reduces (raises) firms' output levels, the

[2] As we will show below, these conditions are also natural candidates for necessary conditions to get the result that more intense competition leads to lower PCM. However, in that case the conditions are not sufficient.

fall (rise) in output is bigger (smaller) for less efficient firms. Alternatively, the *output reallocation effect* can be stated as:

$$\frac{\mathrm{d}\ln q(n,N,\mathcal{I},\theta)}{\mathrm{d}\theta} \text{ and } \frac{\mathrm{d}\ln q(n,N,\mathcal{I},\theta)}{\mathrm{d}\varepsilon} \text{ are increasing in } n. \tag{8}$$

Note that the output reallocation effect does not assume anything about the output levels of firms (only about relative output). This is important since a change from Cournot to Bertrand competition tends to raise output of efficient firms, while it reduces output for inefficient firms. Thus there is no direct relation between intensity of competition and a firm's output level. Also, entry by new firms (as a result of a reduction in entry barriers) can both reduce every incumbent firm's output level and increase firms' output levels. See Amir and Lambson (2000) for details.

The reason why I look at the partial effect of θ, for given set of active firms $\mathcal{I}$ that participate in the market, is the well known 'topsy turvy' result. In the case where firms produce differentiated goods, it may be the case that there are twenty firms under Cournot competition while there are sixteen firms under Bertrand competition. The reason is that Bertrand competition tends to lead to lower rents and hence fewer firms enter in equilibrium. To avoid having to resolve this ambiguity (more aggressive interaction but smaller number of players), I consider the change in θ for a given set of firms in the market. Only in this clear cut case do I require the reallocation effect to hold.

If goods are not perfect substitutes, $q(n^*)/q(n)$ is not well defined ('dividing apples by oranges'). Taking this into account and allowing each firm to produce a number of products, it becomes clear that the reallocation effect has to be expressed in money terms. In principle, there are two ways to do that: costs $C(q,n)$ and revenues $p^T q$. The disadvantage of using revenues is that prices p can be affected by θ as well as output q. To illustrate, intensifying competition by making goods closer substitutes directly affects firms' demand functions and prices irrespective of a change in firms' output levels. Hence costs $C(q,n)$ seem a more natural choice here as it allows for the isolation of the effect of competition intensity on output q.

To gain further intuition for definition 2, note that the conditions above can also be stated as follows. Consider two firms i,j with $n_i > n_j$. Then the reduction in costs due to a small rise in efficiency $\mathrm{d}n > 0$ for firm i relative to j is

$$\frac{-\left.\dfrac{\partial C[q(n_i,N,\mathcal{I},\theta),n]}{\partial n}\right|_{n=n_i}}{-\left.\dfrac{\partial C[q(n_j,N,\mathcal{I},\theta),n]}{\partial n}\right|_{n=n_j}}.$$

The conditions above say that a rise in competition raises this ratio. That is, more intense competition leads to a bigger fall in costs (due to the efficiency gain $\mathrm{d}n > 0$) for the high efficiency firm i as compared to the less efficient firm j.[3] This makes sense. More intense competition tends to marginalise inefficient firms by reducing

[3] In other words, if the model would allow for firms investing in R&D to improve their efficiency n, we would see the following effect. More intense competition raises R&D investments of firms relative to less efficient firms. This is in line with results found by Aghion *et al.* (2005).

their output levels. Therefore their costs become less dependent on their efficiency level.

2. New Measure of Competition

The innovation in this article is to measure intensity of competition using RPD defined as

$$\frac{\pi(n^{**}, N, \mathcal{I}, \theta) - \pi(n, N, \mathcal{I}, \theta)}{\pi(n^{*}, N, \mathcal{I}, \theta) - \pi(n, N, \mathcal{I}, \theta)} > 0 \tag{9}$$

for any three firms with $n^{**} > n^{*} > n$ with variable profits $\pi(\cdot)$ defined in (5). In theory there is a problem with this measure if all firms in an industry have the same efficiency level. Although a symmetry assumption is often convenient in modelling, in real world data sets there are no industries where all firms have the same efficiency level. Hence in practice this will not pose a problem. The following theorem shows that RPD is a robust measure of competition for both changes in conduct θ and entry ε.

THEOREM 1 *An increase in competition raises RPD for any three firms with $n^{**} > n^{*} > n$. That is,*

$$\frac{\mathrm{d}\left[\dfrac{\pi(n^{**}, N, \mathcal{I}, \theta) - \pi(n, N, \mathcal{I}, \theta)}{\pi(n^{*}, N, \mathcal{I}, \theta) - \pi(n, N, \mathcal{I}, \theta)}\right]}{\mathrm{d}\theta} > 0$$

where the effect of θ is partial, i.e. taking $\mathcal{I}$ as given, and

$$\frac{\mathrm{d}\left[\dfrac{\pi(n^{**}, N, \mathcal{I}, \theta) - \pi(n, N, \mathcal{I}, \theta)}{\pi(n^{*}, N, \mathcal{I}, \theta) - \pi(n, N, \mathcal{I}, \theta)}\right]}{\mathrm{d}\varepsilon} > 0.$$

To illustrate the RPD result, consider the example in Figure 2. This is based on example 1 with $a = 20$, $b = 2$, $N = 20$ and firm $i \in \{1,2,\ldots,20\}$ has constant marginal costs equal to $i/10$ (hence efficiency of i equals $n_i = 10/i$). Figure 2 has firm n's normalised efficiency level $(n - \underline{n})/(\bar{n} - \underline{n})$ on the horizontal axis and n's normalised

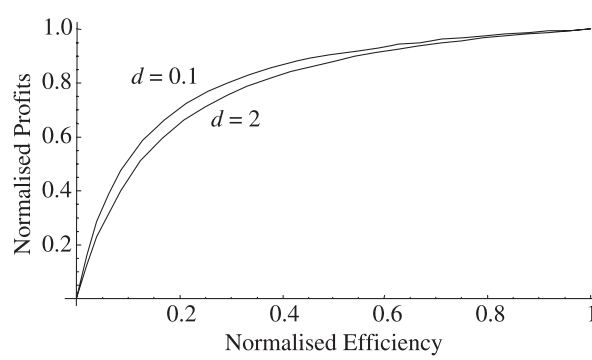

Fig. 2. *Firm n's Normalised Profits* $[\pi(n,\theta) - \pi(\underline{n},\theta)]/[\pi(\bar{n},\theta) - \pi(\underline{n},\theta)]$ *as a Function of n's Normalised Efficiency* $(n - \underline{n})/(\bar{n} - \underline{n})$

profits $[\pi(n,\theta) - \pi(\underline{n},\theta)]/[\pi(\bar{n},\theta) - \pi(\underline{n},\theta)]$ (note that this is the inverse of the expression in (9) to avoid dividing by zero for $n = \underline{n}$) on the vertical axis with $\underline{n} \leq n \leq \bar{n}$ ($\underline{n} = 1, \bar{n} = 10$) and where $\pi(n, \theta)$ is used as a shorthand for $\pi(n, N, \mathcal{I}, \theta)$. This relation is increasing (more efficient firms make higher profits π). The more competitive the industry, the more this curve is pulled into the corner at bottom-right. This is illustrated in the graph for the case where competition is intensified by making goods closer substitutes (d increases from 0.1 to 2). Further, with Bertrand competition, homogeneous goods and constant marginal costs one finds that the curve is flat and equal to zero for all $n \in [\underline{n}, \bar{n}\rangle$ and equal to 1 at $n = \bar{n}$. This corresponds to perfect competition.

How can RPD be used to measure competition in an industry? Since Theorem 1 shows that an increase in competition (either via conduct $\mathrm{d}\theta > 0$ or via entry $\mathrm{d}\varepsilon > 0$) raises RPD for *any three* firms, it follows that an increase in competition pulls down the curve in Figure 2. Suppose one follows an industry over time and observes that the estimated curve at time $t + 1$ lies below the curve at time t. Then one can conclude that competition has become more intense in this industry. The Theorem shows that this is a robust way to measure competition.

This ordering of curves (one lying below the other) is not necessarily complete in practice (although it is in theory). The situation here is comparable to the case where income inequality is measured using Lorenz curves. If the Lorenz curve for country A lies everywhere below the curve for country B, one can rank the two countries in terms of income inequality. If one curve intersects the other, the two countries cannot be ranked. One way to make the ordering of inequality complete again is to use the Gini coefficient. Similarly, if the curve in Figure 2 for an industry at time t intersects the curve at time $t + 1$, one can make the ordering complete (if one wants to) by calculating the area below the curves. This area then becomes the measure of competition. The smaller the area, the more competitive the industry is.[4] Because the Figure is normalised, the area lies between 0 and 1. In particular, in the Bertrand equilibrium with homogeneous goods and constant marginal costs, the area under the curve equals 0.

Note that this issue of completeness is also relevant for the PCM. Has competition intensified in an industry if PCM has fallen for 4 firms and risen for 2? Here the measure is often made complete by calculating the industry weighted average PCM (with firm i's weight equal to its market share). I come back to this industry average PCM below.

Note that one does not need to observe all firms in an industry to make a graph like the one in Figure 2. Indeed Figure 2 just uses a subset of the firms ($i \in \{1, \ldots, 10\}$). The reason is that the result in Theorem 1 holds for *any* three firms. Hence, increasing competition pulls down the whole curve. This property of RPD is useful as it allows for the use of RPD in data sets where not all firms in the industry are sampled. Examples are balanced panel data sets and data based on information from stock exchanges that do not cover privately held firms. In such data sets RPD can still be used as a measure of

[4] One loses information by making the ordering complete in this way but sometimes having a complete ordering is convenient enough to accept this information loss.

competition. This in contrast to concentration measures which are harder to interpret if not all firms in the industry are observed.

3. Identifying Variable Profits and Efficiency in the Data

Under which conditions can RPD be estimated using firm level panel data? Broadly speaking, the better one is able to separate fixed and variable costs in the data, the more robust the competition measure will be that one can estimate.

The data I have in mind for estimating the measure in (9) is firm or plant level data that specify per firm total revenues, total wage bill (or preferably wage costs split according to production workers (blue collar) and management (white collar), see below), costs of inputs used, energy etc. Data sets like this are available in more and more countries (usually at a country's statistical office where this data forms the basis of the national accounts). Examples of papers using such data are Aghion *et al.* (2005), Bloom and Van Reenen (2007), Klette (1999), Klette and Griliches (1999), Lindquist (2001) and Nickell (1996). Further, the data should be available at the four or five digit level such that the one dimensional efficiency assumption is a decent approximation. In particular, the more aggregated the data become, say at the two digit level, the more likely it is that one firm is more efficient in producing one good and another firm more efficient in producing another good within this two digit category. In that case, efficiency is no longer a one dimensional variable. As discussed below, this one dimensional efficiency assumption is also necessary for the price cost margin to be used as a measure of competition.

Equation (5) defining variable profits $\pi(\cdot)$, states that the costs $C(q, n_i)$ should be included in calculating firm i's profits while γ_i should not be included. Hence $\pi(\cdot)$ equals total revenue for a firm minus costs $C(q, n_i)$.

The following describes how to decide which cost categories in the data should be included in $C(q, n_i)$ and which in γ_i. First, any costs, like materials and energy, that are viewed as variable costs (i.e. varying with small changes in production) should be included in $C(q, n_i)$. Second, fixed costs that are seen as being positively correlated with a firm's efficiency level should be included in γ_i because only the costs γ_i are allowed to be increasing in efficiency n_i (see Assumption 1). Examples mentioned above are investments in R&D and capital stocks, where higher investments may lead to lower marginal costs and hence higher efficiency in production. For cost categories in the data that are seen as fixed costs that do not vary with efficiency, it is immaterial whether they are included under $C(q, n_i)$ or γ_i.[5] Finally, with fixed costs that fall with efficiency, one has a choice whether to incorporate them under $C(q, n_i)$ or γ_i. Here the decision should be based on Definition 2 and the equilibrium properties of the model one has in mind to describe the sector.

If the data allow the researcher to identify different cost categories, variable costs should be calculated as the sum of labour costs (if possible only the costs of (blue collar) production workers, since (white collar) managers tend to be viewed as fixed costs), material costs, intermediate inputs and energy expenditure.

[5] To see this, note that fixed costs that do not vary with n_i have no effect on the expression $-\partial C(q, n)/\partial n$ (in Definition 2) and such fixed costs drop out when considering profit differences $\pi(n^*) - \pi(n)$ (in (9)).

Depending on the data available, efficiency n can be measured in one of the following ways. If data on output are available, efficiency can be approximated as average variable costs defined as variable costs (discussed above) divided by the output index. If there is no information on production volumes but there is a price index, then revenue divided by the price index can be seen as an approximation of output. If there is information on the number of workers, labour productivity can be used as an approximation of efficiency. The more detailed information one has on firms' revenues, costs and output levels, the better one is able to measure competition using the approach in Figure 2.

If, in contrast, the only data one has, are based on income statements from publicly traded firms, detailed information on cost categories will be missing. Consider the example given in Table 1. These are income statements from Coca Cola for the years 2002–5.[6] Variable profits should in this case be defined as Total Revenues minus Costs of Sales. These costs of sales are the costs directly related to the sales such as costs of inputs, labour etc. One should not subtract fixed costs like Selling, General and Administrative expense which are overhead costs. One should also not subtract costs like Depreciation and Interest. Such costs do not tend to be variable. Hence in this type of standardised Income Statement variable profits are approximated by Gross Operating Profit. Note that it is an advantage that expenditures on or depreciation of R&D,

Table 1

Income Statement Coca Cola (All numbers in $ thousands)

	Period ending			
	12/2005	12/2004	12/2003	12/2002
Income Statement				
Operating Revenue (Revenue/Sales)	23,104,000	21,962,000	21,044,000	19,564,000
Total Revenues	23,104,000	21,962,000	21,044,000	19,564,000
Cost of Sales	7,263,000	6,745,000	6,912,000	6,299,000
Cost of Sales with Depreciation	8,195,000	7,638,000	7,762,000	7,105,000
Gross Margin	14,909,000	14,324,000	13,282,000	12,459,000
Gross Operating Profit	15,841,000	15,217,000	14,132,000	13,265,000
Selling, Gen. & Administrative Expense	8,824,000	8,626,000	8,061,000	7,001,000
Operating Income	6,085,000	5,698,000	5,221,000	5,458,000
Operating Income b/f Depreciation(EBITDA)	7,017,000	6,591,000	6,071,000	6,264,000
Depreciation	932,000	893,000	850,000	806,000
Operating Income After Depreciation	6,085,000	5,698,000	5,221,000	5,458,000
Interest Income	235,000	157,000	176,000	209,000
Earnings from Equity Interest	680,000	621,000	406,000	384,000
Other Income, Net	(93,000)	(82,000)	(138,000)	(353,000)
Other Special Charges	23,000	24,000	8,000	*
Special Income/Charges	23,000	24,000	8,000	*
Total Income Avail for Interest Expense (EBIT)	6,930,000	6,418,000	5,673,000	5,698,000
Interest Expense	240,000	196,000	178,000	199,000
Pre-tax Income (EBT)	6,690,000	6,222,000	5,495,000	5,499,000
Income Taxes	1,818,000	1,375,000	1,148,000	1,523,000
Income before Income Taxes	6,690,000	6,222,000	5,495,000	5,499,000
Net Income from Containing Operations	4,872,000	4,847,000	4,347,000	3,976,000
Net Income from Total Operations	4,872,000	4,847,000	4,347,000	3,976,000

[6] Taken from http://finapps.forbes.com/finapps/jsp/finance/compinfo/IncomeStatement.jsp?tkr=KO.

advertisement and capital should not be included in the variable costs. As noted by Fisher and McGowan (1983) and Fisher (1987), getting the costs of depreciation that are economically relevant (instead of advantageous for firms from a tax point of view) is usually impossible. As they argue, this invalidates the use of accounting rates of return and profits-sales ratios to infer market power. Since RPD does not need this type of depreciation information to calculate profits, this problem is circumvented.

Once variable profits π_{it} and efficiency or productivity n_{it} have been identified for firms $i \in \{1, \ldots, N_t\}$ in year t in a certain industry, one can calculate normalised profits and efficiency. Assuming (without loss of generality) that firms are ordered such that n_{it} is decreasing in i, normalised efficiency and profits are given by $(n_{it} - n_{N_t t})/(n_{1t} - n_{N_t t})$ and $(\pi_{it} - \pi_{N_t t})/(\pi_{1t} - \pi_{N_t t})$ respectively. Plotting normalised profits against normalised efficiency gives a graph like Figure 2. For year $t + 1$ a similar plot can be made. If the area under the curve is smaller in $t + 1$ than it is in t, we say that competition has become more intense in year $t + 1$.[7]

4. Discussion

This Section compares the RPD and PCM measures of competition. I show that the generalised output reallocation effect in Definition 2 is a natural necessary condition for PCM to be monotone in competition but it is not sufficient. This explains why RPD is a theoretically robust measure of competition while there are counterexamples where a rise in competition leads to higher PCM. I further argue that the data requirements for estimating these two measures and the assumptions needed to interpret them are similar.

First, I show that the generalised output reallocation effect in Definition 2 is not a sufficient for PCM to be monotone in competition. This is the sense in which RPD is a theoretically more robust measure of competition than PCM.

I write PCM as a function of efficiency n as follows

$$PCM(n, N, \mathcal{I}, \theta) = \frac{p(n, N, \mathcal{I}, \theta)^T q(n, N, \mathcal{I}, \theta) - C[q(n, N, \mathcal{I}, \theta), n]}{p(n, N, \mathcal{I}, \theta)^T q(n, N, \mathcal{I}, \theta)} = \frac{\pi(n, N, \mathcal{I}, \theta)}{\pi(n, N, \mathcal{I}, \theta) + C[q(n, N, \mathcal{I}, \theta), n]}.$$

In order to find the effect of conduct θ and entry ε on the PCM of a firm with efficiency n in a similar way as in the Proof of Theorem 1, I fix an (arbitrary) efficiency level $\underline{n} < n$ with $\pi(\underline{n}, N, \mathcal{I}, \theta) > 0$.[8] I write

$$\pi(n, N, \mathcal{I}, \theta) = \pi(\underline{n}, N, \mathcal{I}, \theta) + \int_{\underline{n}}^{n} -\frac{\partial C[q(v, N, \mathcal{I}, \theta), t]}{\partial t}\bigg|_{t=v} \mathrm{d}v.$$

[7] A spreadsheet can be found with an example data set at http://center.uvt.nl/staff/boone/. For these data both PCM and RPD are calculated.

[8] Instead of fixing an arbitrary $\underline{n}$, one can choose $\underline{n}$ such that $\pi(\underline{n}, \cdot) = \gamma$. In that case, however, there is an additional term when differentiating with respect to θ or ε because these parameters affect the level $\underline{n}$ for which $\pi(\underline{n}, \cdot) = \gamma$ is true. Note that by looking at profit differences, this level effect of θ and ε on $\pi(\underline{n}, \cdot)$ drops out. This also explains why it is easier to derive sufficient conditions for RPD to be monotone in competition than for relative profits, $\pi(n_i, \cdot)/\pi(n_j, \cdot)$, to be monotone.

LEMMA 1 *Fix an efficiency level $\underline{n}$, then the effect of θ on PCM can be written as*

$$\operatorname{sign}\left[\frac{\mathrm{d}PCM(n,N,\mathcal{I},\theta)}{\mathrm{d}\theta}\right] = \operatorname{sign}\left(\begin{array}{c}\dfrac{\dfrac{\mathrm{d}\pi(\underline{n},N,\mathcal{I},\theta)}{\mathrm{d}\theta}}{C[q(n,N,\mathcal{I},\theta),n]} - \dfrac{\pi(\underline{n},N,\mathcal{I},\theta)}{\{C[q(n,N,\mathcal{I},\theta),n]\}^2}\dfrac{\partial C(q,n)}{\partial q}\dfrac{\mathrm{d}q(n,N,\mathcal{I},\theta)}{\mathrm{d}\theta} + \\ \displaystyle\int_{\underline{n}}^{n}\frac{\mathrm{d}\left\{\dfrac{-\dfrac{\partial C[q(v,N,\mathcal{I},\theta),t]}{\partial t}\Big|_{t=v}}{C[q(n,N,\mathcal{I},\theta),n)]}\right\}}{\mathrm{d}\theta}\mathrm{d}v\end{array}\right)$$

where the effect of θ is partial (as above). A similar expression can be derived for a change in entry $d\varepsilon > 0$.

If n is high enough that $\underline{n}$ can be chosen substantially below n (and still satisfy $\pi(\underline{n}, N, \mathcal{I}, \theta) > 0$), the term with the integral will dominate the sign of $\mathrm{d}PCM/\mathrm{d}\theta$. A natural requirement for $\mathrm{d}PCM/\mathrm{d}\theta < 0$ in this case is $\mathrm{d}\{-\partial C[q(v,N,\mathcal{I},\theta),t]/\partial t|_{t=v}/C[q(n,N,\mathcal{I},\theta),n]\}/\mathrm{d}\theta < 0$ for $n > v$. For the class of cost functions where $C(q,n) = \omega(n)c(q)$ this condition boils down to the output reallocation effect in Definition 2. However, the condition in Definition 2 is not sufficient to get $\mathrm{d}PCM(n,N,\mathcal{I},\theta)/\mathrm{d}\theta < 0$ for all n because for low n we cannot exclude the case where more intense competition leads to lower output levels for inefficient firms. Hence $\mathrm{d}q(n,N,\mathcal{I},\theta)/\mathrm{d}\theta < 0$ and $\pi(\underline{n}, N, \mathcal{I}, \theta) > 0$ works in the direction of $\mathrm{d}PCM(n,N,\mathcal{I},\theta)/\mathrm{d}\theta > 0$ and the output reallocation effect is no longer sufficient. Also, if $\underline{n}$ is rather high, we cannot exclude the the case where $\mathrm{d}\pi(\underline{n},\cdot)/\mathrm{d}\theta > 0$.[9] This, again, works in the direction of $\mathrm{d}PCM(n,\cdot)/\mathrm{d}\theta > 0$.

Coming back to estimating the two measures. Broadly speaking, there are two ways in the literature to estimate price cost margins. One is to approximate firm i's price cost margin by an expression like; see, for instance, Scherer and Ross (1990, p. 418)

$$\frac{\textit{revenue } s_i - \textit{variable cost } s_i}{\textit{revenue } s_i}. \tag{10}$$

Using this to calculate PCM requires similar data as one needs to calculate profits $\pi(\cdot)$ in (5) as revenues minus variable costs. The other way to estimate price cost margins is to use a structural approach; see Reiss and Wolak (2005) for a survey. In this case, the researcher specifies what the demand function and the cost function $C(q,n_i)$ look like and what equilibrium is played by the firms. The data are then used to identify the specified demand and cost parameters. From this PCM can be derived.

[9] As an example consider a homogenous good duopoly with linear demand, $p = 1 - q_1 - q_2$ where firm i produces with constant marginal costs $1/n_i$. Then for n_1 substantially bigger than n_2, firm 1 has higher profits under Bertrand competition than under Cournot competition, where Bertrand competition is seen as more competitive.

Note that the RPD measure is a variable that can be estimated in both ways. As described above, one can estimate RPD in an analogous way as PCM is estimated in (10). But it is also possible to use a structural approach and be more specific about the functional forms of demand and costs $C(q,n_i)$. To illustrate, table VIII in Berry *et al.* (1995) contains all the information (efficiency n_i and variable profits π_i) needed to calculate RPD. My article just offers RPD as a complementary competition measure to PCM and does not take a position on how the measures should be estimated in practice.

When PCM is used as a measure of competition, the following three assumptions (which are needed for RPD to work) are not always explicitly made:

(*i*) efficiency is one dimensional,
(*ii*) a firm's efficiency level can be observed and
(*iii*) firms compete on a level playing field.

In the discussion paper version of this article (Boone, 2004), numerical examples are given to show that PCM can be higher with more intense competition if one of these conditions is not satisfied. Intuitively, if efficiency is, say, two dimensional, an increase in competition forces a firm to focus on the activity in which it is most productive. This may raise the firm-level price cost margin. If a firm's efficiency level is not observed, an increase in efficiency (*ceteris paribus* the intensity of competition) leads to a higher price cost margin which is then (incorrectly) interpreted as reduced competition. Finally, if firms compete on an uneven playing field, changes in competition can affect the 'uneveness' of the playing field, making it hard to interpret both RPD and PCM.

Finally, Lemma 1 considers the PCM of an individual firm. However, the question of the article concerns the measurement of industry competition. Aggregating from firm level PCM to industry PCM is usually done by calculating the weighted industry average PCM, where the weight of a firm equals its market share in the industry; see, for instance, Wolfram (1999). Boone (2004) gives an example where this industry average PCM increases after competition has become more intense due the following reallocation effect. An increase in competition reallocates market share from inefficient firms to efficient firms. Since efficient firms have a higher PCM than inefficient firms, the increase in competition raises the weight in the industry average PCM of firms with a high PCM. This can raise the industry average PCM.

5. Conclusion

This article started off with the observation that PCM is often used as a measure of competition in empirical research. From a theoretical point of view, however, it is not clear what the relation between PCM and competition actually is. There are a number of theoretical papers where more intense competition leads to higher PCM. At the moment it is not known how relevant these theoretical counterexamples are from an empirical point of view.

To answer this question I have developed a new measure of competition, RPD, which has two properties. First, RPD has a robust theoretical foundation as a measure of competition. It is monotone in competition both when competition becomes more intense through more aggressive interaction between firms and when entry barriers

are reduced. Second, the data requirements to estimate RPD are the same as the requirements to estimate PCM. That implies that any firm (or plant) level data set which allows a researcher to estimate PCM should also allow for the estimation of RPD. In this way we can see in which percentage of industries both measures point in the same direction. If it turns out that the measures are congruent for more than 95% of the industries, PCM can be used as a measure of competition in empirical research without much concern for the theoretical counterexamples.

Appendix. Proof of Results

This Appendix contains the proofs of the results in the main text.

A.1. Proof of Theorem 1

First note that for any differentiable function π of n it is the case that

$$\pi(n^*) - \pi(n) = \int_n^{n^*} \frac{\mathrm{d}\pi(t)}{\mathrm{d}t}\mathrm{d}t.$$

Next note that the envelop theorem applied to

$$\pi(n_i, N, \mathcal{I}, \theta) = \max_{a_i}\left\{p(a_i, \hat{a}_{-i}, \theta)^T q(a_i, \hat{a}_{-i}, \theta) - C[q(a_i, \hat{a}_{-i}, \theta), n_i]\right\}$$

implies that

$$\frac{\mathrm{d}\pi(n_i, N, \mathcal{I}, \theta)}{\mathrm{d}n_i} = -\frac{\partial C[q(n_i, N, \mathcal{I}, \theta), n]}{\partial n}\bigg|_{n=n_i},$$

where $q(n_i, N, \mathcal{I}, \theta) = q(\hat{a}_i, \hat{a}_{-i}, \theta)$ is the equilibrium output vector of a firm with efficiency level n_i. Hence for any two efficiency levels n^* and n it is the case that

$$\pi(n^*, N, \mathcal{I}, \theta) - \pi(n, N, \mathcal{I}, \theta) = \int_n^{n^*} -\frac{\partial C[q(t, N, \mathcal{I}, \theta), v]}{\partial v}\bigg|_{v=t}\mathrm{d}t.$$

Therefore we can write the effect of θ on the measure $(\pi^{**} - \pi)/(\pi^* - \pi)$ as

$$\frac{\mathrm{d}\left\{\dfrac{\displaystyle\int_n^{n^{**}} -\frac{\partial C[q(\cdot), t]}{\partial t}\mathrm{d}t}{\displaystyle\int_n^{n^*} -\frac{\partial C[q(\cdot), t]}{\partial t}\mathrm{d}t}\right\}}{\mathrm{d}\theta} = \frac{\mathrm{d}\left\{1 + \dfrac{\displaystyle\int_{n^*}^{n^{**}} \frac{-\frac{\partial C[q(\cdot), t]}{\partial t}}{-\frac{\partial C[q(\cdot), t]}{\partial t}\Big|_{t=n^*}}\mathrm{d}t}{\displaystyle\int_n^{n^*} \frac{-\frac{\partial C[q(\cdot), t]}{\partial t}}{-\frac{\partial C[q(\cdot), t]}{\partial t}\Big|_{t=n^*}}\mathrm{d}t}\right\}}{\mathrm{d}\theta} > 0$$

where $\partial C[q(\cdot), t]/\partial t$ is shorthand for $\partial C[q(t, N, \mathcal{I}, \theta), v]/\partial v|_{v=t}$. The inequality follows because definition 2 implies that

$$\frac{\mathrm{d}\left\{\dfrac{-\frac{\partial C[q(\cdot), t]}{\partial t}}{-\frac{\partial C[q(\cdot), t]}{\partial t}\Big|_{t=n^*}}\right\}}{\mathrm{d}\theta} > 0$$

for $t \in \langle n^*, n^{**}]$ and

$$\frac{\mathrm{d}\left\{\dfrac{-\dfrac{\partial C[q(\cdot),t]}{\partial t}}{-\dfrac{\partial C[q(\cdot),t]}{\partial t}\Big|_{t=n^*}}\right\}}{\mathrm{d}\theta} < 0$$

for $t \in [n, n^*\rangle$. To see this, note that

$$\operatorname{sign}\left(\frac{\mathrm{d}\left\{\dfrac{-\dfrac{\partial C[q(\cdot),t]}{\partial t}}{-\dfrac{\partial C[q(\cdot),t]}{\partial t}\Big|_{t=n^*}}\right\}}{\mathrm{d}\theta}\right) = \operatorname{sign}\left(\frac{\mathrm{d}\ln\left\{-\dfrac{\partial C[q(\cdot),t]}{\partial t}\right\}}{\mathrm{d}\theta} - \frac{\mathrm{d}\ln\left\{-\dfrac{\partial C[q(\cdot),t]}{\partial t}\Big|_{t=n^*}\right\}}{\mathrm{d}\theta}\right).$$

The same proof applies to the case with $\mathrm{d}\varepsilon > 0$.

A.2. Proof of Lemma 1

Writing PCM as follows

$$PCM(n, N, \mathcal{I}, \theta) = \frac{1}{1 + \dfrac{C[q(n, N, \mathcal{I}, \theta), n]}{\pi(n, N, \mathcal{I}, \theta)}}$$

we find that $\mathrm{d}PCM(n, N, \mathcal{I}, \theta)/\mathrm{d}\theta < 0$ if an only if

$$\frac{\mathrm{d}\left(\dfrac{\pi(\underline{n}, N, \mathcal{I}, \theta) + \int_{\underline{n}}^{n}\left\{-\dfrac{\partial C[q(v, N, \mathcal{I}, \theta), t]}{\partial t}\Big|_{t=v}\right\}\mathrm{d}v}{C[q(n, N, \mathcal{I}, \theta), n]}\right)}{\mathrm{d}\theta} < 0$$

where we have written $\pi(n, N, \mathcal{I}, \theta) = \pi(\underline{n}, N, \mathcal{I}, \theta) + \int_{\underline{n}}^{n}\{-\partial C[q(v, N, \mathcal{I}, \theta], t)/\partial t|_{t=v}\}\mathrm{d}v$. Differentiating $\pi(\underline{n}, N, \mathcal{I}, \theta) + \int_{\underline{n}}^{n}\{-\partial C[q(v, N, \mathcal{I}, \theta), t]/\partial t|_{t=v}\}\mathrm{d}v/C[q(n, N, \mathcal{I}, \theta), n]$ with respect to θ (taking $\underline{n}$ as given) we get the expression in the Lemma.

We can derive a similar expression for $\mathrm{d}\varepsilon > 0$.

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