The Surprising Hybrid Pedigree of Measures of Diversity and Economic Concentration

University of New South Wales
Center for Applied Economic Research
Economic Measurement Group
Sydney, Australia

Paolo M. Adajar and Ernst R. Berndt
November 27, 2020
Presentation is based in large part on a National Bureau of Economic Research Working Paper No. 26512, November 2019, having the same title, by Paolo M. Adajar\textsuperscript{1}, Ernst R. Berndt\textsuperscript{2}, and Rena M. Conti\textsuperscript{3}. This research has not been sponsored.

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\textsuperscript{1}Undergraduate, MIT Department of Economics
\textsuperscript{2}Professor Emeritus, MIT Sloan School of Management
\textsuperscript{3}Associate Professor, Boston University, Questrom School of Business
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Quantifying Competition

- Economists often want to examine how vigorous is the price competition faced by a firm or a set of firms in an industry, and to discern whether firms in an industry have market power.

- Traditionally, since in competition $P = MC$, we look to see how much of a divergence there is between $P$ and $MC$.

- Following Abba Lerner (1934), one can assume firms maximize profits, which yields the Lerner Index \( \frac{(P - MC)}{P} = \frac{1}{\varepsilon} \), where the term in brackets is variously called the margin or markup, and $\varepsilon$ is the absolute value of the own-price elasticity of demand.

- Obtaining reliable measures of $MC$ is often difficult, so instead one can infer the margin or markup indirectly by obtaining an estimate of the own-price elasticity of demand $\varepsilon$. 
In industries where fixed and sunk costs are substantial but marginal costs are relatively small (e.g., anything digital, or R&D intensive), margins or markups may be very large, despite it being a competitive industry, with $P = \text{average total cost} > MC$.

Thus, industry observers have used other measures to infer market power, such as the $k$-firm concentration index, or the Herfindahl-Hirschman Index ($HHI$), assuming firms in more concentrated industries have more market power to affect output price.

For both these metrics, revenue shares attained by the largest firms play a prominent role.
Among other tools and considerations, the DOJ and FTC use the HHI to evaluate whether proposed mergers will likely reduce competition, following 1982 and 2010 Horizontal Merger Guidelines.

However, as a recent FTC evaluation of the proposed Pfizer-Mylan acquisition reveals, increasingly US antitrust authorities are focusing on potential collusion across multiple products for multiproduct firms, rather than on concentration within single product markets.
Motivation

- Theoretical foundations of measures of concentration have not been developed extensively in the economics literature, despite their widespread use.
- The Summer 2019 issue of the *Journal of Economic Perspectives* has various articles questioning the usefulness of markups, margins, and concentration metrics in measuring market power and in enforcing antitrust laws.
- Notably, the size distribution of various outcomes (such as concentration based on revenue or quantity shares) is studied in many disciplines other than economics.
- We describe the history and foundation of various concentration measures as they link to other disciplines (ecology, inequality, physics, engineering), and then illustrate difficulties in implementation and interpretation with an empirical example in the U.S. pharmaceutical industry.
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• Concentration indexes are based on market shares, $S_i$, the fraction of revenue in the $N$-firm market held by a given firm $i$

• Alternatively measured in terms of quantity output, output capacity, value added, employment, etc.

• Indexes can be computed for an entire industry or for a specific product, depending on context
One of the earliest and simplest metrics

Defined as the sum of the total market share of the $k$ largest firms

$$CR_k := \sum_{i=1}^{k} S_i, \text{ where each } i \text{ is one of the } k \text{ largest firms} \quad (1)$$

$k$ often chosen as 4, 8, 20, or 50

Useful in its simplicity, ease of computation even without full market information

Drawbacks include sensitivity to arbitrary choice of $k$, not using any information on differences among the largest $k$ firms and among the smallest $N - k$ firms
Herfindahl-Hirschman Index (HHI)

- Introduced separately by Hirschman (1945) and Herfindahl (1950)

\[ HHI := \sum_{i=1}^{N} S_i^2 \]  \hspace{1cm} (2)

- Ranges from 0 to 1, concentrated markets have higher values
- Uses information from all firms, weighting larger firms more
- Reasonably accurate even without complete information on smallest firms
- Weights smaller firms less, so if small firms significantly impact large firms’ behavior, this is not captured in HHI
- But is the sum of squares term arbitrary? What are the economic or statistical theory foundations? Measurement without theory (Koopman critique)?
Theoretical foundation exists to a limited degree

HHI can be rewritten in the form

$$HHI = \frac{1}{N} + \sum_{i=1}^{N} (S_i - \overline{S_i})^2$$ \hspace{1cm} (3)

and so HHI decreases as the number of firms grows, and increases with higher variability among firms holding $N$ constant

Adelman (1969) introduced the idea of *numbers-equivalent* ($n_e$), the number of equal-sized firms that would generate the same HHI, i.e.,

$$n_e(HHI) = \frac{1}{HHI}$$ \hspace{1cm} (4)
Assume oligopoly of $N$ firms under Cournot competition.
Each produces quantity $q_i$ at marginal cost $c_i$, selling for a common unit price of $P$ with market price elasticity of demand $\varepsilon_d$.
Note in equilibrium, each firm’s FOC yields $\frac{P - c_i}{P} = \frac{q_i}{Q} \cdot \frac{1}{\varepsilon_d}$, the Lerner Index.
Industry-wide (variable) profits are then

$$\Pi = \sum_{i=1}^{N} (P - c_i)q_i = \frac{PQ}{\varepsilon_d} \sum_{i=1}^{N} S_i^2 = HHI \cdot \frac{PQ}{\varepsilon_d} \quad (5)$$

Thus, we have that

$$HHI = \frac{\Pi}{PQ\varepsilon_d} \quad (6)$$

so $HHI$ is positively related to variable profit share.
Herfindahl-Hirschman Index (HHI) (Concluded)

- First introduced by Albert O. Hirschman (1945) to analyze the composition of the United States’ balance in foreign trade accounts (using square root of modern $HHI$)
- Later used by Orris C. Herfindahl (1950) to analyze the US steel industry, developed independently
- Rosenbluth (1955) erroneously attributed original index to Herfindahl, leading to dispute about paternity of $HHI$
- Rosenbluth (1961) and Hirschman (1964) attempted to correct the record, but today it is typically called “Herfindahl-Hirschman Concentration Index” (in alphabetical rather than chronological order)
- Adelman (1969) respectfully and neutrally designated it as the $H$ concentration measure
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Ecologists have focused much attention on measuring biological diversity in habitats containing organisms belonging to different species.

Diversity is dependent on richness (number of species) and evenness (similarity of populations).

Habitats dominated by one or two species are considered to be less diverse (more concentrated) than are ones in which several different species have a similar abundance.
Simpson’s Diversity Index

- Created by Edward H. Simpson (1949) to combine richness and evenness into one metric
- If $S$ organisms are sampled and the $N$ species populations are $n_i$, the probability that two organisms are from the same species is

$$D = \sum_{i}^{N} \frac{n_i(n_i - 1)}{S(S - 1)}$$

(7)

- If $n$, $S$ are large, $D$ is identical to HHI

$$D \approx \sum_{i}^{N} \left( \frac{n_i}{S} \right)^2 = \sum_{i=1}^{N} S_i^2$$

(8)

- Simpson’s Diversity Index is defined as $1 - D$, the probability that two random organisms belong to different species, so that higher numbers refer to more diverse ecosystems
- Probability interpretation can readily be applied to HHI
In particular, if one is sampling products from various manufacturers in a given product market, what is the probability that two products belong to the same manufacturer?

\[ P(\cdot) = \sum_{i=1}^{N} S_i^2 = HHI \]  

(9)

• Similar interpretation holds for revenue shares (probability that two different dollars earned . . . )
Hannah-Kay Index ($HK$)

- Introduced by Hannah and Kay (1977)
- Generalized form of $HHI$, dependent on parameter $\alpha$

$$HK(\alpha) := \left[ \sum_{i=1}^{N} S_i^\alpha \right]^{\frac{1}{1-\alpha}}, \alpha > 0, \alpha \neq 1 \quad (10)$$

- As $\alpha \to 0$, $HK$ weights smaller firms more and tends toward $N$
- As $\alpha \to \infty$, $HK$ weights larger firms more and tends toward $\frac{1}{S_1}$, the reciprocal of the largest firm’s share
- Related to $HHI$, as $HK(2) = \frac{1}{HHI}$
- For HK, the numbers-equivalent is simply the index: $n_e(HK) = HK$
Entrophy ($E$)

- Has its roots in information theory, describing the frequency of characters in a data stream.
- Intuitively, more surprising to observe rarer characters precisely because they are rare.
- Information content ($-\ln(S_i)$) quantifies this rareness, where $S_i$ is the relative frequency a character is observed and $[-\ln(S_i)] > 0$.
- Entropy is the weighted average of these information contents:

$$E := -\sum_{i=1}^{N} S_i \ln(S_i)$$  (11)

- Origins in physics and engineering, and used in both economics and ecology, known as Shannon’s Diversity Index.
- Can also be derived by taking the limit of $HK$ as $\alpha \to 1$: $E = e^{HK(1)}$.
- Ranges from 0 to $\ln(N)$, and $n_e(E) = e^E$. 

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Rosenbluth/Hall-Tideman (RHT): Connections to Inequality

- Developed separately by Rosenbluth (1960) and Hall and Tideman (1967):

\[ RHT := \frac{1}{2 \sum_i S_i - 1} \]  

(12)

- Hall-Tideman developed index axiomatically, Rosenbluth graphically as \( RHT = \frac{1}{2K} \), where \( K \) is area above concentration curve

- Related to Gini coefficient \( G \), as

\[ RHT = \frac{1}{N(1 - G)} \]  

(13)

- The numbers-equivalent for \( RHT \) is \( n_e(RHT) = \frac{1}{RHT} \)

- See Adajar et al. (2019), Section V. for further discussion

Figure 1: Graphical Representation of \( RHT \)
Rate of Exploitation

- Alternative index of concentration related to buyer-side competition analogous to Lerner index, related to seller-side competition, and introduced by Joan Robinson
- Assume oligopoly of $N$ firms, each producing quantity $q_i$, selling at a fixed price of $P$. Production requires one input at average variable cost $C$, a good with market elasticity of supply $\varepsilon_s$, with marginal expenditure $ME$
- With monopsony power, firm’s $ME > C$, ‘exploiting’ input owner
- First order conditions yield $\frac{P-C}{C} = \frac{s_i}{\varepsilon_s}$, and as the firm chooses a production level so that $ME = P$, we have
  $$\frac{ME - C}{C} = \frac{S_i}{\varepsilon_s} \quad (14)$$
- The left side can be interpreted as the proportional decrease in input costs enjoyed by a monopsonist whose average costs are less than marginal input expenditures
Choosing Among Alternative Concentration Measures

- Hall and Tideman (1967): \textit{HHI} and \textit{RHT} measures satisfy six axioms, Gini coefficient and \textit{CR}_k do not. Empirically, correlations among \textit{HHI}, \textit{RHT} and \textit{CR}_k very high – above 0.9. Choice between \textit{HHI} and \textit{RHT} similar to choice among index number formulae – depends on weights used.

- Hart (1971): When number of firms is either large or small, classical statistical measures (e.g., means, variances, geomeans) are superior to entropy. “Consequently, there is little point in using the information theory measures to measure business concentration.”

- If one believes strength of competition increases with number of firms, one wants metrics that depend on both variability among and absolute number of firms, i.e., preferences favor \textit{HHI} and \textit{RHT}.
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A useful empirical illustration of concentration measures would ideally involve a market where a known structural break occurred, changing a monopoly to a market open to competition, with staggered entry and exit along with mergers and acquisitions, generating expected movements in concentration measures, but also some ambiguities.

Because of loss of exclusivity (LOE) due to patent expiration, along with statutes governing entry, as well as considerable consolidation among incumbent brand and generic entrants, the prescription pharmaceutical market offers an illuminating empirical illustration.

We focus on atorvastatin calcium, the US’s and world’s best selling branded drug, whose Lipitor™ brand experienced LOE in 2011.
Atorvastatin – Brand Name Lipitor (Pfizer)

- Statin drug developed by Pfizer’s Upjohn Division that reduces total cholesterol, low density lipoprotein cholesterol, triglycerides and increases high density lipoprotein cholesterol
- FDA approved Lipitor (Pfizer) in 1996, quickly became world’s largest selling drug and earning over $100B
- Lipitor LOE in November 2011, after which courts awarded Ranbaxy 180-day exclusivity. But FDA approval of Ranbaxy’s ANDA was uncertain because of data integrity issues. After Ranbaxy entered in November 2011, manufacturing problems limited its market penetration.
- Pfizer contracted with Watson (later acquired by Actavis) to produce an authorized generic
- After 180-day exclusivity expired in May 2012, three more ANDA holders entered (Apotex, Mylan, Sandoz)
Atorvastatin Data Sources

- Data from IQVIA National Sales Perspective™ (NSP), 2004Q4 – 2016Q3
- Data track invoiced direct sales from manufacturers to various distribution channels (e.g., hospitals), and invoiced indirect sales from wholesalers to retailers, long term care, clinics
- Data capture invoice-based discounts such as prompt payment, but do not capture rebates and discounts to third party payers such as health plans, government payers
- To the extent such rebates and discounts are excluded, as are wholesalers’ margins, IQVIA NSP unit price data overstates unit revenues received by manufacturers
- Price and revenue data also differ from dispensing pharmacy receipts
Figure 2: Revenue shares in the Atorvastatin Market, 2004Q4 - 2016Q3. Data from IQVIA’s National Sales Perspective.
After Pfizer’s Lipitor loss of exclusivity (LOE) in 2011Q4, Ranbaxy’s generic and Watson/Actavis’ authorized generic both gained market share rapidly until the triopoly ended in 2012Q2.

Afterwards, both of their market shares eroded from entry by Apotex, Mylan, and Dr. Reddy’s Laboratories, and Ranbaxy’s manufacturing problems.

Pfizer’s decline mitigated by Pfizer’s wholly-owned generic subsidiary Greenstone entrance in 2013Q1 - together, Pfizer and Greenstone had 47% market share eight quarters after LOE.

Five largest firms held 94% market share in 2013Q4, 98% in 2016Q3.

From 2013Q4 to 2016Q3, 17 distinct firms in market, but only 12 active by end.
Methodology

- Utilize data from IQVIA’s National Sales Perspective, 2004Q4 - 2016Q3
- Analyze post-LOE competition in the atorvastatin market using HHI and RHT, the two most supported indices in the literature
- Explore the sensitivity of indexes to combining subsidiaries with parent companies
Because Lipitor had so large a market pre-LOE, expect very substantial generic entry, with HHI/RHT dropping dramatically after LOE.

But speed of $HHI/RHT$ declines likely reduced due to 180-day exclusivity awarded Ranbaxy (troubled entry), and entry by Watson/Actavis authorized generic. Unclear what are net expectations during the 180-day exclusivity ending in May 2012, but expiration of exclusivity likely to result in change in trend of HHI/RHT metrics, with all metrics declining rapidly thereafter.

Pfizer’s market power affected not only by Lipitor brand loyalty and by its authorized generic agent Watson/Actavis, but also by entry by Pfizer’s generic subsidiary Greenstone, and prospectively, by its proposed July 2019 acquisition of generic titan Mylan. How will this potential market power be manifested in HHI/RHT metrics?
Finding, Atorvastatin Market Concentration: Revenue Shares

- Using revenue market shares, both HHI and RHT rapidly decline after LOE until the end of 2012, then are relatively stable, with RHT slightly greater than HHI.
- Indexes are remarkably similar, with a correlation of $r = .996$.

**Figure 3:** HHI and RHT for Atorvastatin Market Revenues. Data from IQVIA’s National Sales Perspective, 2011Q4 - 2016Q3.
Findings: Subsidiaries

- Analyze revenue shares in 2016Q3 using FTC-DOJ guidelines\(^4\)
- With Pfizer-Upjohn and Greenstone distinct, \(HHI = 2149.8\) \((n_e = 4.65)\), under the DOJ’s 2500 post-merger threshold for scrutinizing mergers. So, market appears quite competitive
- If Greenstone subsidiary is treated as a part of Pfizer, \(HHI\) increases by 775 to 2924.8 \((n_e = 3.42)\), possibly calling into question the competitiveness of the US atorvastatin market
- According to 2010 DOJ guidelines, mergers increasing \(HHI\) by over 200 points and resulting in post-merger \(HHI > 2500\) are “presumed to be likely to enhance market power” and invite close scrutiny from the DOJ/FTC

\(^4\)For this slide, we use the convention of the FTC and DOJ of multiplying \(HHI\) by 10,000, so that \(HHI\) ranges from 0 to 10,000.
On July 29, 2019, Pfizer announced proposed acquisition and merger with Mylan Pharmaceuticals.

If this merger had occurred in 2016Q3, Mylan would hold a 19.92% market share, second only to Pfizer's Lipitor share of 29.60%.

Treating Pfizer-Upjohn and Greenstone as one firm, we observe that merging with Mylan in 2016Q3 increases $HHI$ by 1701 from 2924 to 4625 (while $n_e$ decreases from 3.419 to 2.107).

As initial observation, this suggests the proposed merger will increase $HHI$ substantially and will likely be scrutinized closely by the DOJ/FTC.
• Whether the Mylan/Pfizer merger is anti-competitive given high post-merger HHI is beyond the scope of this research

• Shapiro (2019 JEP, p. 74) quotes 1990 DC Circuit Court ruling, “[e]vidence of market concentration simply provides a convenient starting point for a broader inquiry into future competitiveness”

• Many other factors besides concentration indexes important to consider, such as buyers’ market power, barriers to entry and exit, pricing actions following previous mergers and likely ones should this merger occur, implications for R&D, global trade matters, and cost implications from scale and scope economies facilitated by a merger
Recent Developments in Pfizer/Mylan Merger

- On October 30, 2020, FTC approved the Mylan/Pfizer merger under the condition that seven pharmaceuticals produced by Pfizer and Mylan be divested, including Caduet (a combination of ingredients in Lipitor and Norvasc)

- Suggests that FTC is less worried about concentration within the atorvastatin product market, and more worried about collusion across different product markets

- Two FTC Commissioners, in a dissent against this approval, were specifically concerned for the potential of “quid pro quo collusive arrangements” with “competitors on different drug products”
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Preliminary Conclusions

- Assessing competition is important and difficult within health markets and other complex product markets, especially when markets have high fixed/sunk and low marginal costs.
- $HHI$ and $RHT$ are highly correlated in the atorvastatin industry, and sensitive to definition of identity of competitors.
- Research offers support and encouragement for continued use of $HHI$, although quantifying market structure is just one factor in understanding competition.
- Regulators should carefully consider how firm boundaries are defined, as there are important implications for assessment of competition and enforcement of antitrust law.
Q+A
For further information, contact Paolo Adajar at padajar@mit.edu, Ernst Berndt at eberndt@mit.edu, or Rena Conti at rconti@bu.edu.
Appendix Slides