OFFICE OF FINANCIAL RESEARCH

A Systemwide Stress Testing of the Credit Default Swaps Market

Jill Cetina, Mark Paddrik, Sriram Rajan
Office of Financial Research

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Motivation

- In 2015 the Federal Reserve introduced a *counterparty default scenario* in CCAR's trading shock which assumes the default of a bank's single largest counterparty.
- In 2008, financial interconnectedness threatened financial stability. Yet, its incorporation and evaluation in stress tests is inadequate.
- Management of the largest counterparty may be insufficient. Does information on the full counterparty network provide critical insights on stress tests?

US Supervisory Stress Testing

- 2009: Supervisory Capital Assessment Program (SCAP)
- 2011: Comprehensive Capital Analysis and Review; featured a Global Market Shock that took into account
  - Counterparty Valuation Adjustment (CVA): adjustments to account for changes in counterparty risk against trading risk.
  - Incremental Default Risk (IDR): counterparty credit loss adjustments that vary against portfolio credit risk.
  - Both IDR and CVA are computed relative to banks' internal models.
- 2015: Introduction of counterparty default scenario. Default of largest counterparty across derivatives, repo, and sec-lending activities on a *stressed P&L basis*.

This Paper

- We assess full information on the counterparty network by:
  - using the CDS market as a microcosm of banks' trading books;
  - building the network of counterparty exposures based on confidential contractual data;
  - imposing the 2013, 2014, and 2015 CCAR stress test scenario on each BHC's network of counterparties.
- We compute 1. largest, 2. systemic, and 3. indirect measures of counterparty concentration risk to benchmark against current supervisory practices.
- Insights:
  - Evidence: stress testing approaches which consider only direct counterparty exposures may understate or mis-specify risk.
  - Critique: though macroprudential by design, the implementation of stress-testing has a microprudential bias.

Contributions

1. Comprehensive evaluation of total economic, as opposed to notional, impact on CDS market of CCAR stress scenario.
2. Stressed losses are concentrated: top sources of counterparty loss are concentrated for each BHC and across BHCs.
3. The network effects of large counterparty losses are material and are suggestive of significant second-order impacts.
4. This paper provides an agenda for using networks in supervisory stress-testing.

Outline

1. Literature Review
2. Data
3. Methodology
4. Results
5. Conclusions

Literature Review

- **Portfolio stress-testing**: describe impact of macroeconomic factors on the full loss distribution.
  - Carling et al (2003), Misina et al (2006)
- **Network propagation**: evaluate feedback mechanism of institutions, given structural features. Few approaches have been applied to empirical data because of data limitations.
  - Martinez-Jaramillo et al (2010), Battiston et al (2012), Glasserman et al (2015)
- **Supervisory application of network models**: describe implementation of network models for regulatory and policymaking purposes.
  - Bank of Canada (2010), Lee, S. (2013), Bank of Korea (2012), ECB (2013)

Data

- Transaction- and position- level data provided by Depository Trust Clearing Corporation (DTCC). Features:
  - OFR observes data wherein either counterparty and/or position is US-domiciled.
- Content used for this paper:
  - Position-level counterparty exposures.
  - Transaction-level notional amounts, recovery, reference entity, upfront payments, maturity.
  - Credit spread term stucture from Markit.

Summary statistics

As-of-date	# Counterparties	# Positions	# Reference Entities
9/28/2012	1060	6,282,128	4297
9/27/2013	985	7,273,913	3651
9/26/2014	959	6,389,129	3173

Computing Losses Under Stresses

How do we arrive at economic loss under stress for each BHC, across its portfolios of CDS positions? Background:

- CCAR stresses are applied on CCAR *as-of-dates*
- Index positions are disaggregated to single-name equivalents. Tranches are ignored.
- Contracts are revalued to the stress scenario.

Apply the following steps:

1. Bootstrap credit curves to market spreads for all contracts.
2. Mark positions to market and to systemic stresses.
3. Aggregate mark-to-market changes under stress to firm level.

Bootstrapping Credit Curves

Portfolio credit survival and default rates are central to pricing CDS contracts. We infer these rates from market information through a bootstrap technique.

- Premia are received so long as a credit survives. CDS payments are made upon a credit's default.
- Bootstrap establishes *hazard rates* (h_i)– which, in turn, imply survival and default probabilities– through all tenors upon a valuation date.

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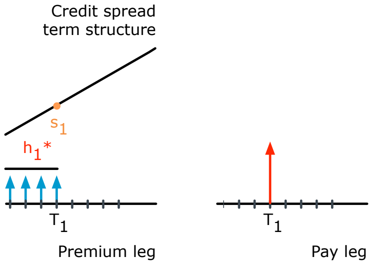

Bootstrap through T_1

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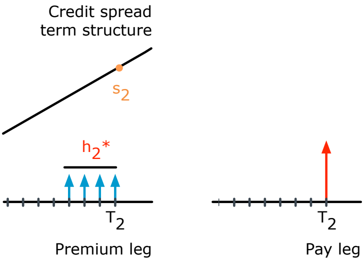

Bootstrap through T_2

Bootstrapping Credit Curves

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- Premia are received so long as a credit survives. CDS payments are made upon a credit's default.
- Bootstrap establishes *hazard rates* (h_i)– which, in turn, imply survival and default probabilities– through all tenors upon a valuation date.

$$V_{premia} = s\mathbb{E}\Big[\sum_{i=0}^{N} \Delta_i e^{-\int_{t_0}^{t_i} r(v)dv} (\mathbb{I}_{\tau<t_i} + \alpha \mathbb{I}_{t_{i-1}<\tau<t_i})\Big] \tag{1}$$

$$V_{pay} = \mathbb{E}\Big[e^{-\int_{t_0}^{\tau} r(v)dv} (1-R)\mathbb{I}_{\tau<T_N}\Big] \tag{2}$$

- Using $\mathbb{E}\Big[\mathbb{I}_{\tau<T_{N_i}}\Big] = 1 - e^{-\int_0^{T_{N_i}} h_i(v)dv}$, we bootstrap credit curve over all traded tenors $T_{N_1}, T_{N_2}, T_{N_3}$ to generate a schedule $\Big\{(0,T_1] : h_1^*, (T_1,T_2] : h_2^*, (T_2,T_3] : h_3^*, ...(T_{n-1},T_n] : h_n^*\Big\}$. Bootstrap Procedure

Marking to Market

1. At time t_0 party x sells $\$N$ notional protection to counterparty y. The coupon spread of c basis points may generally not equal the market spread, s_0.

$$NPV^{x \to y}(N, c, t_0, s_0) = N(V^x_{prem}(T, c, h^*(s_0)) - V^y_{pay}(T, h^*(s_0))) \tag{3}$$

2. The MtM of the position is then the difference between the as-of-date and initial mark:

$$MtM^{x \to y}(N, c, t_n, s_n) = NPV^{x \to y}(N, c, t_n, s_n) - \frac{1}{B(t_0, t_n)} NPV^{x \to y}(N, c, t_0, s_0) \tag{4}$$

3. This allows us to compute the change in MtM as a result of stress:

$$\Delta MtM^{x \to y}(N, c, t_n, s_n^{stress}, s_n) = MtM^{x \to y}(N, c, t_n, s_n^{stress}) - MtM^{x \to y}(N, c, t_n, s_n) \tag{5}$$

Global Market Shock

Aggregate Losses Across all Contracts

CCAR Stress Tests 2013-2015: Gross Shocks by Market Sector

Corporate Investment Grade: Advanced Economies			
Year	Base	Stressed	Change
2013	$233,412,328,185	($437,113,392,049)	($670,525,720,234)
2014	$350,044,213,151	($339,960,701,463)	($690,004,914,613)
2015	$297,398,438,077	($88,376,662,712)	($385,775,100,789)

Corporate Investment Grade: Emerging Markets			
Year	Base	Stressed	Change
2013	$20,209,565,003	($36,292,089,453)	($56,501,654,456)
2014	$36,669,194,712	($26,696,426,057)	($63,365,620,769)
2015	$32,675,603,486	($18,244,410,582)	($50,920,014,069)

Corporate Sub Investment Grade: Advanced Economies			
Year	Base	Stressed	Change
2013	($67,586,764,190)	($455,875,225,985)	($388,288,461,795)
2014	$81,313,258,240	($166,219,997,620)	($247,533,255,860)
2015	$79,443,260,157	($155,667,949,009)	($235,111,209,165)

Corporate Sub Investment Grade: Emerging Markets			
Year	Base	Stressed	Change
2013	($311,287,315)	($31,832,968,561)	($31,521,681,246)
2014	$12,717,316,699	($33,228,237,980)	($45,945,554,679)
2015	$7,450,820,588	($38,170,334,042)	($45,621,154,630)

Sovereign			
Year	Base	Stressed	Change
2013	($59,120,885,142)	($116,368,112,056)	($57,247,226,914)
2014	($43,969,617,788)	($288,397,541,751)	($244,427,923,963)
2015	($8,335,380,612)	($79,073,465,837)	($70,738,085,225)

US Financials			
Year	Base	Stressed	Change
2013	($124,673,484,815)	($487,740,868,019)	($363,067,383,204)
2014	$114,367,229,436	($39,249,914,107)	($153,617,143,543)
2015	$106,361,688,259	($6,863,682,549)	($113,225,370,808)

Non-US Financials			
Year	Base	Stressed	Change
2013	($131,458,836,283)	($701,825,146,410)	($570,366,310,127)
2014	$41,220,494,707	($277,084,172,623)	($318,304,667,330)
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Aggregate Portfolio Changes at Firm Level

- Market participant loss sizes for the 5th through 95th percentiles are not significant.
- Although focus of stress changed, distribution is comparable. Are stress-tests predictable?

Distribution of Market Participant Stress, 2013-2015

Percentile	CCAR 2013	CCAR 2014	CCAR 2015
5	($64,189,324)	($65,819,980)	($48,153,408)
10	($16,949,089)	($16,932,003)	($13,412,053)
20	($2,331,211)	($1,899,843)	($1,892,131)
30	($205,848)	($24,676)	($220,546)
40	$109,212	$159,683	$51,562
50	$601,580	$868,390	$464,928
60	$1,954,869	$2,502,310	$1,713,934
70	$5,831,175	$6,054,297	$4,870,313
80	$17,548,872	$18,169,501	$13,690,226
90	$54,744,625	$58,557,167	$50,185,309
95	$128,106,889	$139,706,949	$132,492,911

Source: authors' calculations, data provided by DTCC

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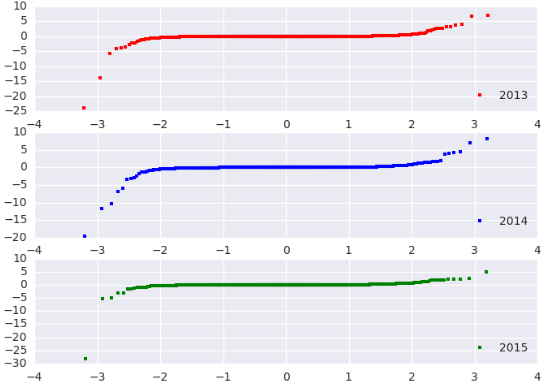
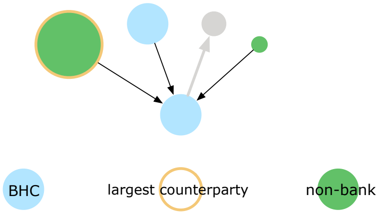


Largest Counterparty Default Loss Concentration

How do we determine the largest counterparty loss?



Largest Counterparty Default Loss Concentration

How do we determine the largest counterparty loss?
For a BHC we compute the change in position value for any counterparty:

$$\Delta V_p^{bhc} = \sum_{\substack{j \in \\ Sales}} \Delta MtM_j^{bhc \to p} + \sum_{\substack{k \in \\ Purchases}} \Delta MtM_k^{p \to bhc} \tag{6}$$

The counterparty default scenario is focused on *gains* to the BHC foregone upon a counterparty's default:

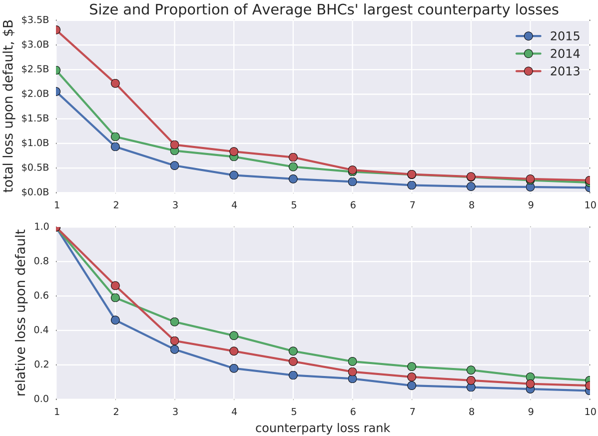
$$\begin{gathered} (p_1, p_2, ..., p_n) \\ where\ \Delta V_{p_1}^{bhc} >= \Delta V_{p_2}^{bhc} >= ... >= \Delta V_{p_n}^{bhc} \\ and\ \Delta V_{p_i}^{bhc} > 0 \end{gathered} \tag{7}$$

A BHC's loss ratio is given as

$$BHC\ loss(p_i) = \Delta V_{p_i}^{bhc} / \Delta V_{p_1}^{bhc} \tag{8}$$

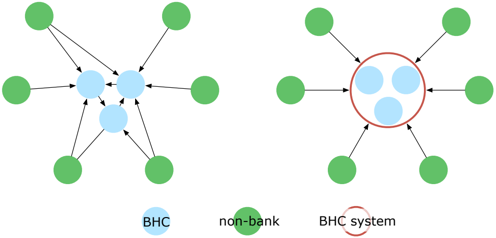
Largest Counterparty Default Loss Concentration

- Granularity: the largest counterparties are larger than all others.
- Magnitude of loss (sources of gain) falls with rank and over time.



Systemic Concentration Risks

- Top counterparties are shared across BHCs.
- Raises questions of systemic impact when any of the largest counterparties fail.



- For each BHC:

$$H_{BHC} = \sum_{i=1}^{N} s_{i,BHC}^2 \tag{9}$$

- For the system (BHC_1 thru BHC_6):

$$H_{system} = \sum_{i=1}^{M} s_{i,system}^2 \tag{10}$$

Systemic Concentration Risks

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Table: Portfolio Herfindahl Measures: 2013 CCAR

	BHC_1	BHC_2	BHC_3	BHC_4	BHC_5	Mean BHC	System
HHI	351	926	583	524	434	564	284
HHI ex 1st largest CP	243	812	368	462	236	424	334
HHI ex 1st, 2nd largest CPs	208	186	328	296	192	242	253
HHI ex $\cdots$, 3rd largest CPs	184	172	319	279	189	229	248
HHI ex $\cdots$, 4th largest CPs	178	158	299	248	186	214	223
HHI ex $\cdots$, 5th largest CPs	166	148	246	196	181	187	219

2014 and 2015

Systemic Concentration Risks

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- Raises questions of systemic impact when any of the largest counterparties fail.

Table: Mean BHC versus systemic BHC herfindahl measures

	2013		2014		2015	
	Mean BHC	System	Mean BHC	System	Mean BHC	System
HHI	564	284	520	248	816	550
HHI ex 1st largest CP	424	334	353	226	508	187
HHI ex 1st, 2nd largest CPs	242	253	317	214	380	167
HHI ex $\cdots$, 3rd largest CPs	229	248	286	204	303	154
HHI ex $\cdots$, 4th largest CPs	214	223	246	193	258	147
HHI ex $\cdots$, 5th largest CPs	187	219	229	181	221	140

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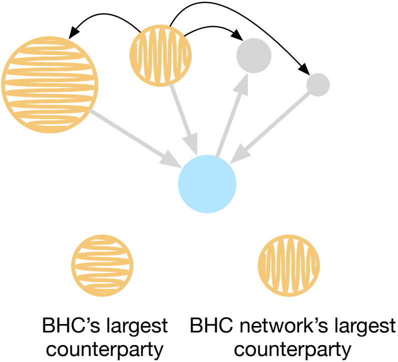
- Concentration has risen **within** BHCs and **across** in the most recent CCAR.

Indirect Concentration Risks

- What are the implications of a BHC's counterparty failure on that BHC's other counterparties?
- Are there concerns for collateral flow and ability to meet margin calls?
- Recall AIG in 2008 and concerns over contagion.



Indirect Concentration Risks

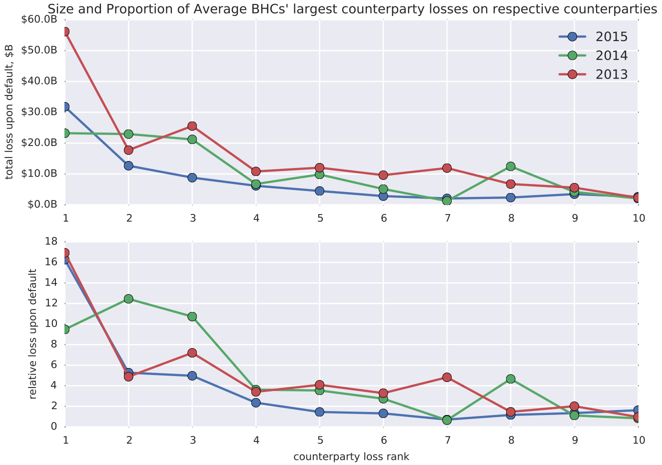
For all BHC counterparties, we compute the change in position value for a specific counterparty's failure (p):

$$\Delta V_p^{CP(bhc)} = \sum_{\substack{q \in \\ CP(bhc), q \neq p}} max\left(\Delta V_p^q, 0\right) \tag{9}$$

where $CP(bhc)$ is the set of all counterparties to a BHC and ΔV_p^q is defined as before. The BHC counterparty loss ratio is given as

$$BHC\ counterparty\ loss(p_i) = \Delta V_{p_i}^{CP(bhc)} / \Delta V_{p_1}^{bhc} \tag{10}$$

Indirect Concentration Risks



Indirect Concentration Risks

- Are there hidden concentration risks in the network?
- Indirect losses exceed direct losses, in several instances by an order of magnitude.
- Smaller counterparties can be larger sources of indirect loss. Evidence from 2015:

ith largest CP default	Ratio	BHC_1	BHC_2	BHC_3	BHC_4	BHC_5
	BHC Loss(b,1):	1.00	1.00	1.00	1.00	1.00
1	BHC CPs' Losses(b,1):	17.41	7.25	6.07	0.00	16.68
	BHC Loss(b,2):	0.71	0.52	0.20	0.62	0.91
2	BHC CPs' Losses(b,2):	25.49	8.60	3.67	6.95	17.56
	BHC Loss(b,3):	0.65	0.33	0.16	0.50	0.61
3	BHC CPs' Losses(b,3):	3.06	4.18	4.82	15.48	26.13
	BHC Loss(b,4):	0.39	0.31	0.15	0.39	0.61
4	BHC CPs' Losses(b,4):	8.87	0.75	1.22	3.52	3.71

Source: Authors calculations, which use data provided to the OFR by The Depository Trust & Clearing Corporation

Conclusion

- Regulators should broaden the focus beyond single largest counterparty stressed loss.
  - Microprudential focus on the largest counterparty may not take into account systemic concentration risks.
  - Indirect losses from a BHC's counterparty failure on the BHC's counterparty network can be large relative to the BHC's direct losses to that counterparty. This could be understood as a channel for contagion.
- This paper presents a case for using networks in supervisory stress testing.

Future Work

- Consider the impact of initial margin buffers.
- Assess potential for contagion through network shock propagation.
- Evaluate stress tests from the perspective of non-banks and central counterparties.

Bootstrapping Credit Curves

1. The first stage is calculation of the initial hazard rate, h_1.

$$V_{premia}(h_1) = s_1 \sum_{i=1}^{N_1} F(t_i)\Delta_i \left(e^{-h_1 t_i} + \alpha \frac{e^{-h_1 t_i} - e^{-h_1 t_{i-1}}}{2} \right) \tag{11}$$

$$V_{pay}(h_1) = (1-R) \sum_{i=1}^{N_1} F(t_i) \left[e^{-h_1 t_{i-1}} - e^{-h_1 t_i} \right] \tag{12}$$

$$h_1 * = \underset{h_1}{\text{argmin}} \left[\left(V_{premia}(h_1) - V_{pay}(h_1) \right)^2 \right] \tag{13}$$

2. The second stage is to compute h_2*, given h_1*.

$$V_{premia}(h_2|h_1) = s_2 \left\{ C(h_1) - \sum_{i=N_1+1}^{N_2} F(t_i)\Delta_i \left[P(t_i) - P(t_{N_1}) - \alpha \frac{P(t_i) - P(t_{i-1})}{2} \right] \right\} \tag{14}$$

$$V_{pay}(h_2|h_1) = A(h_1) + \sum_{i=N_1+1}^{N_2} F(t_i)(P(t_i) - P(t_{i-1})) \tag{15}$$

where $P(t_i) = 1 - e^{-h_2 t_i} \; \forall \; i <= N_1$ and $P(t_i) = 1 - e^{-h_1 t_i}$ otherwise. $A(h_1)$ and $C(h_1)$ are known. h_2* is the solution over $(N_1, N_2]$ for

$$\underset{h_2}{\text{argmin}} \left[\left(V_{premia}(h_2|h_1) - V_{pay}(h_2|h_1) \right)^2 \right] \tag{16}$$

Bootstrapping Credit Curves (continued)

3. In this manner, we can compute a term structure of default intensities for each reference entity, over possible CDS payment dates:

$$\Big\{(0, N_1] : h_1^*, (N_1, N_2] : h_2^*, (N_2, N_3] : h_3^*, ...(N_{n-1}, N_n] : h_n^*\Big\} \tag{17}$$

or alternatively stated, over time increments:

$$\Big\{(0, T_1] : h_1^*, (T_1, T_2] : h_2^*, (T_2, T_3] : h_3^*, ...(T_{n-1}, T_n] : h_n^*\Big\} \tag{18}$$

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2015 CCAR Global Market Shock

Corporate Credit							
Advanced Economies							
	AAA	AA	A	BBB	BB	B	<B or Not Rated
Spread Widening (%)	130.0	133.0	110.2	201.7	269.0	265.1	265.1
Emerging Markets							
	AAA	AA	A	BBB	BB	B	<B or Not Rated
Spread Widening (%)	191.6	217.2	242.8	277.5	401.9	436.4	465.8

Loan							
Advanced Economies							
	AAA	AA	A	BBB	BB	B	<B or Not Rated
Relative MV Shock (%)	-6.2	-6.7	-13.4	-22.6	-26.9	-30.5	-39.8
Emerging Markets							
	AAA	AA	A	BBB	BB	B	<B or Not Rated
Relative MV Shock (%)	-23.2	-27.6	-32.0	-36.4	-61.3	-66.7	-72.2

State & Municipal Credit							
	AAA	AA	A	BBB	BB	B	<B or Not Rated
Spread Widening (bps)	12	17	37	158	236	315	393

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Concentrated Sources of Counterparty Default

Table: Portfolio Herfindahl Measures: 2014 CCAR

	BHC_1	BHC_2	BHC_3	BHC_4	BHC_5	Mean BHC	Systemwide
HHI	427	706	743	444	279	520	248
HHI ex 1st largest CP	381	513	244	365	264	353	226
HHI ex 1st, 2nd largest CPs	354	431	230	331	239	317	214
HHI ex $\cdots$, 3rd largest CPs	287	395	222	293	234	286	204
HHI ex $\cdots$, 4th largest CPs	266	282	206	257	220	246	193
HHI ex $\cdots$, 5th largest CPs	248	252	205	245	197	229	181

Table: Portfolio Herfindahl Measures: 2015 CCAR

	BHC_1	BHC_2	BHC_3	BHC_4	BHC_5	Mean BHC	Systemwide
HHI	841	749	632	1093	763	816	550
HHI ex 1st largest CP	594	611	377	457	502	508	187
HHI ex 1st, 2nd largest CPs	499	346	344	239	471	380	167
HHI ex $\cdots$, 3rd largest CPs	435	282	306	194	296	303	154
HHI ex $\cdots$, 4th largest CPs	267	270	288	184	280	258	147
HHI ex $\cdots$, 5th largest CPs	167	239	255	181	261	221	140

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