# toward an empirical network macro-economics

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CAIDA

**Sixth Annual CAIDA-WIDE Conference**
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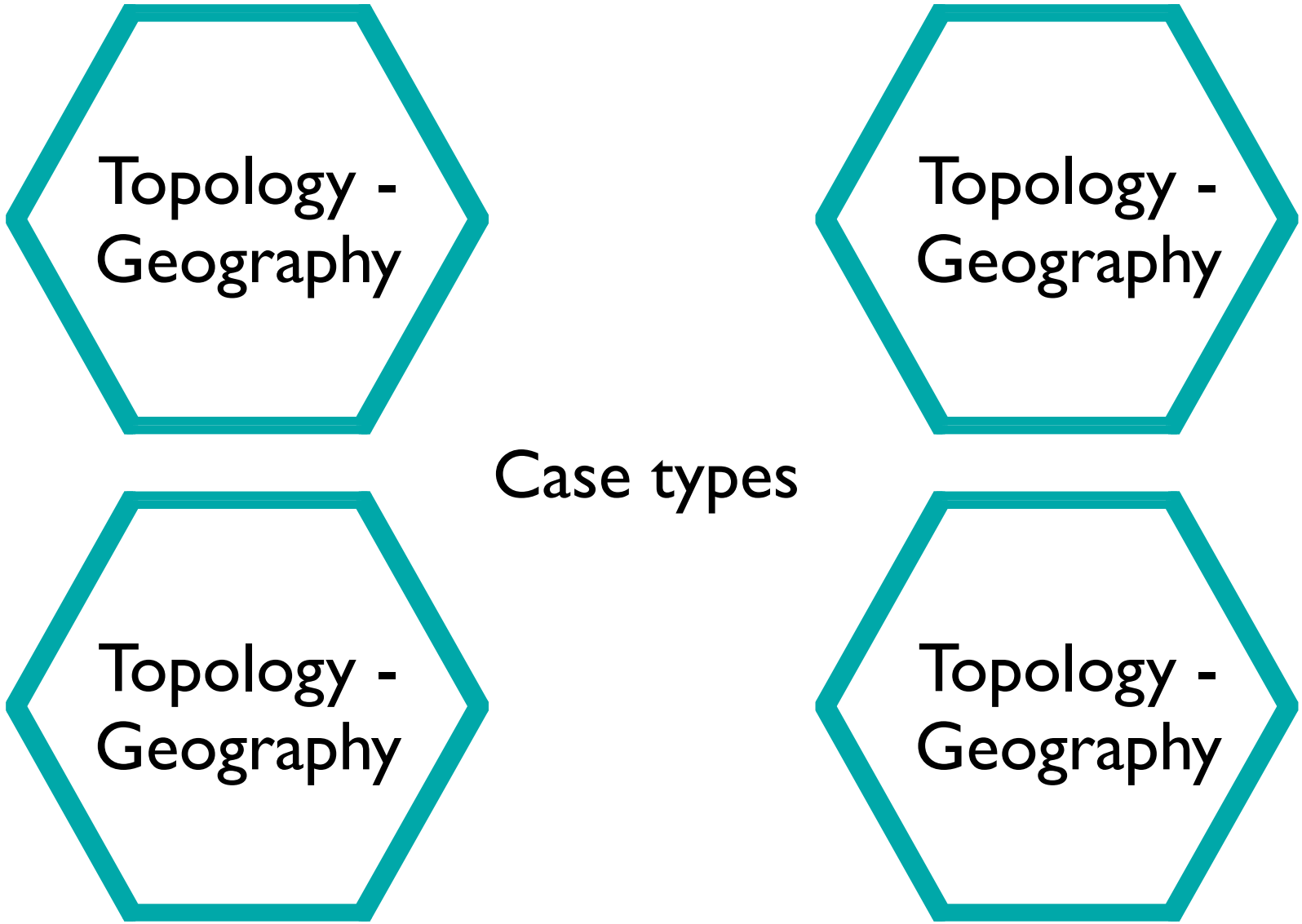
# research agenda

- Internet public interests?
- How are we doing? Getting better or worse over time, by what measure?
- Underperforming, or over -- by what standard?
- Why? What are the causes of change in relevant measures?

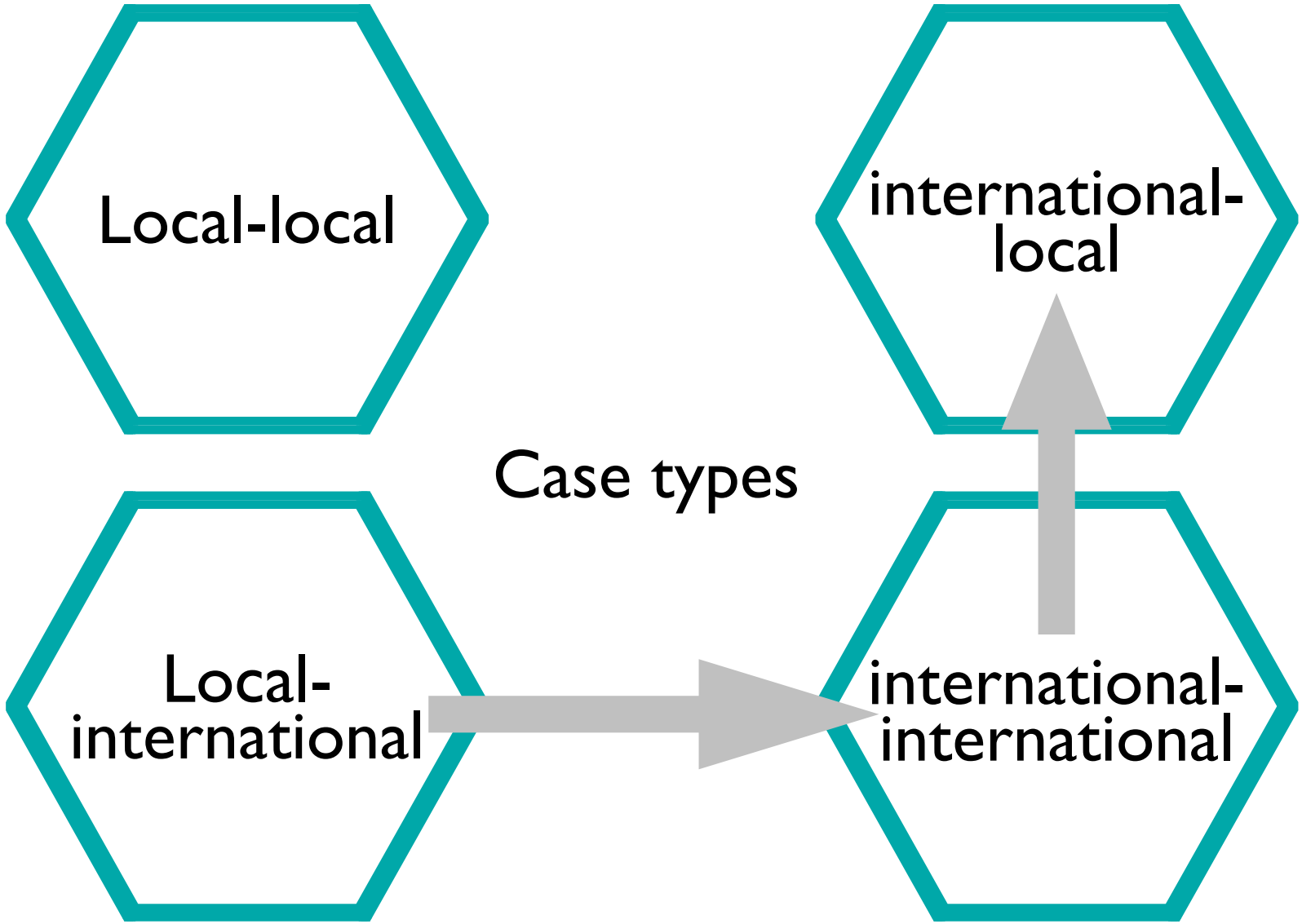
# (current) unit of analysis

- **Countries**: vertical silos that influence or directly control all sorts of relevant factors
- Control many levers to change conditions, for good or ill
- Because higher level of analysis not meaningful, lower levels of analysis not sustainable, or sportsmanlike
- "National network economies"

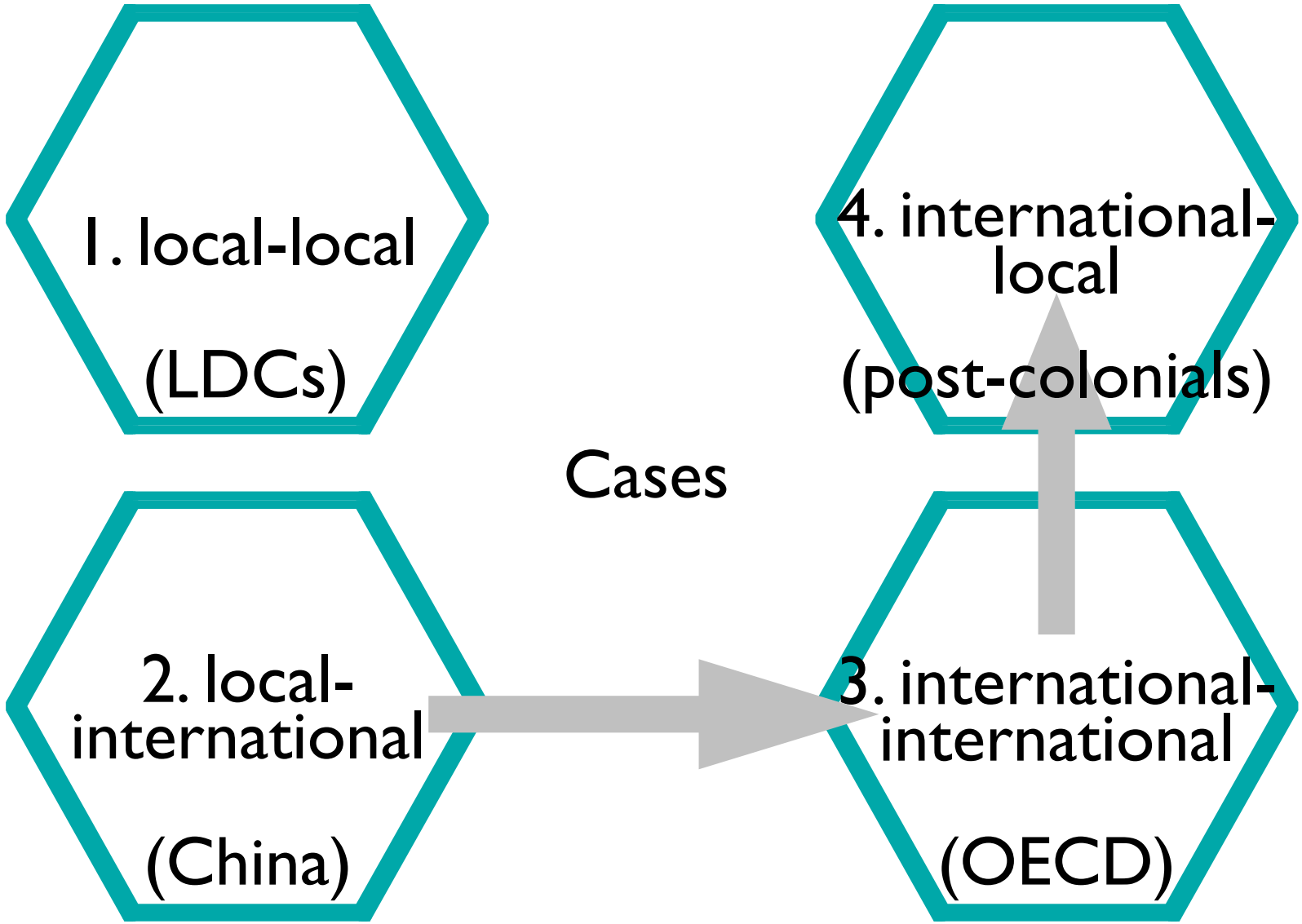
# The Internet "relatively insensitive to national borders"...



# ...but only relatively, and kinds of insensitivities are few and identifiable



# Cross-border production



# metric

- **“Internet production”** aka unique public routed IP
- Represents promises fulfilled to deliver more “users, usage, uses” -- why? Because that’s what we tell the RIRs in order to justify the allocations
- Modulated by sensitivity to policy era (pre-RIR, changing RIR policies), scale (HD ratio), bias in favor of diversity, public interoperability...
- “Naive institutional realism” (tm)
  + law of large numbers
  = plausible ~~deniability~~ assertability

# measurement device

- **Autonomous Systems**: point of attachment for new users, usage, uses -- things that policy makers care about
- Running an AS has a cost-point that has some relationship to size/scale of operation
- Below that point, network outsourcing: operations/growth differentially accrue to someone else's AS. Afterward, network insourcing: more benefits internalized.

# measurement device

- **Micro-dynamics**: Each AS represents a (different) solution to a (different) problem, combining different technology inputs, target missions/markets, pricing strategies, external relationships (Maltz, Xie, Zhan, Zhang)
- Some "work" and survive or even grow; others stagnate, disappear, or are assimilated into other ASes. 300 +/- new ones appear every month, 100 +/- disappear, (mostly) forever (Uijterwaal, Wilhelm)
- Familiar-looking industrial dynamics

# measurement device

- **Macro-dynamics**: AS break-even point varies relative to cost of critical inputs for running an AS -- infrastructure, interconnection etc. -- many of which are determined at national level.
- Some NNEs may be attractive for Internet production, but inhospitable to new independent network creation, resulting in few, large ASNs -- should NNE constituents (or trade partners) care?
- In some cases, better terms to be had elsewhere, leading to offshoring and/or cross-border outsourcing: divergent NNE growth rates... again, should this matter to anyone?

# accounting conventions

- "Internet production" attributed to origin AS, regardless of actual location
- Origin AS attributed to self-provided ISO 3166 country code
- Arguably more "accurate" (definitely more complete) than any other dimension of whois
- Inconsistent semantics maybe (UBO, admin, legacy, chauvinism, etc. etc.) -- but similar to MNCs in other sectors, and susceptible to improvement over time

# benchmarks

- How well is a NNE doing now/over time, relative to the past, since milestone (x), compared to other NNEs, *all things remaining equal*?
- Other measured phenomena often benchmarked against GDP, population, etc.
- Old benchmark for comms was "main lines" i.e., DS0s connected to end user premises; proxy for sunk investment by incumbents -- still the family jewels for PSTNs (i.e, Powerful STNs)
- Together with coax infrastructures (also measurable), still the layer one access platform for 99.9% of Internet users

# testable hypotheses one

- Industry structure as an independent variable explaining differential NNE growth rates
- Is the presence of significant market power (SMP) associated with faster/slower NNE growth, all things remaining equal?
- Null hypothesis: Presence/absence has no effect, or measurement ambiguities preclude answer, or national-level treatment invalidates the question

# Theory behind H.1

- "Logical multiplexing" -- systems-level version of statmux; multiple ASes operating across common communications facilities (i.e., "infrastructure-based competition") delivers more/faster Internet growth for any given set of inputs.
- Alternately: Cost and complexity of multiple operators makes provider diversity less efficient than monopoly service provision
- Null hypothesis: Neither clearly better, or measurement ambiguities preclude answer, or national-level analysis

# methodology 1:
## The Herfindahl-Hirschman Index (HHI)

- HHI provides a single value measure of the number and size of firms in relationship to a given industry, and and suggests the mix of competition/market power that characterizes the industry overall.
- Calculated by summing the squared market shares of each individual firm in a given market. Can range from 1 (1:1 firm / market share ratio) to 10,000 (single monopoly provider).
- Decreases in the HHI generally indicate a loss of pricing power and an increase in competition, whereas increases imply the opposite

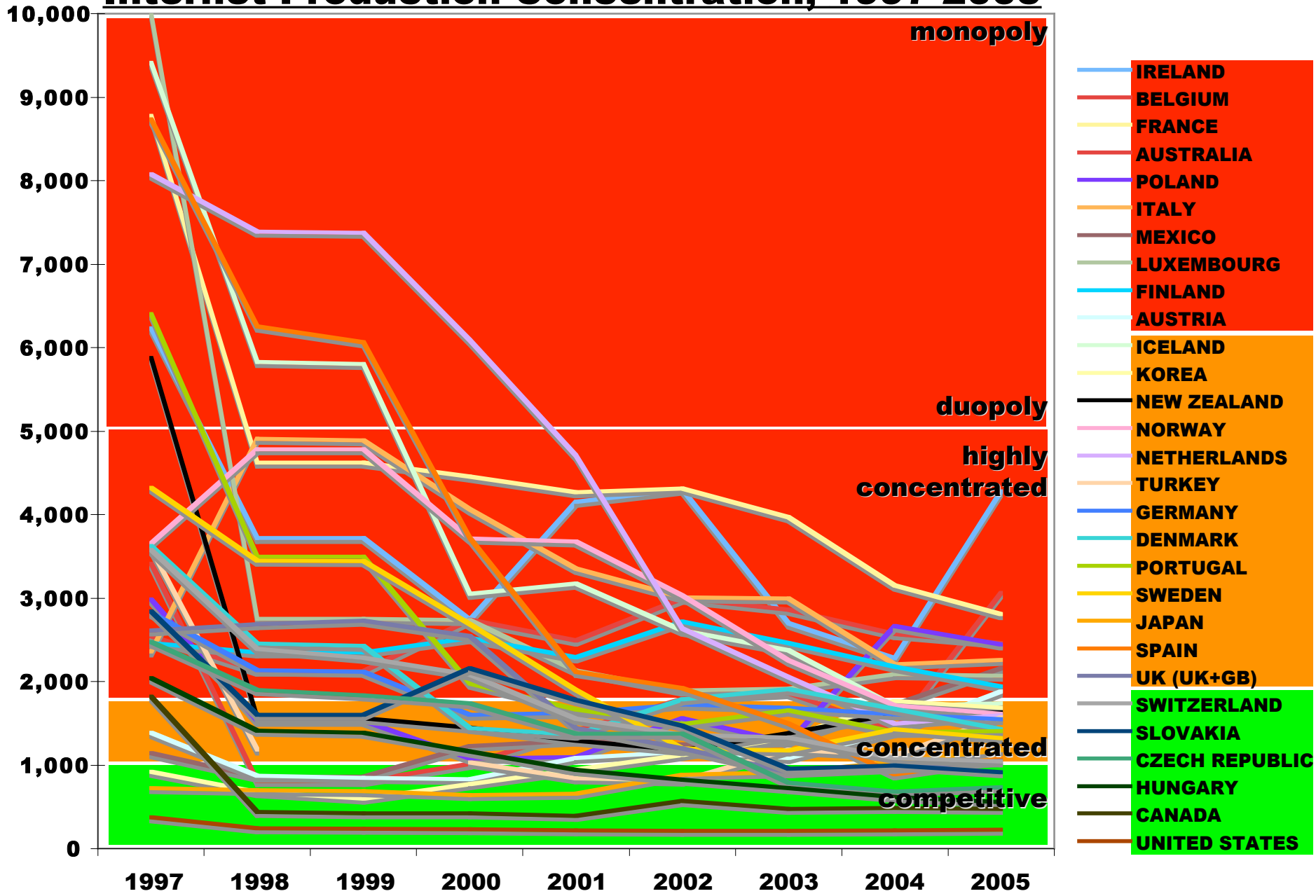
# HHI policy interpretations

| Market Structure & Interpretation | Current HHI | Dynamic Change |
|---|---|---|
| Conditions/environments that are less likely to have anti-competitive effects. | <1000<br>1000-1800<br>>1800 | Any<br><100<br><50 |
| Conditions that "may raise significant competitive concerns." | 1000-1800<br>>1800 | >100<br>50 – 100 |
| Conditions that "exist in already highly concentrated markets" and are "more likely to raise significant competitive concerns." | >1800 | >100 |

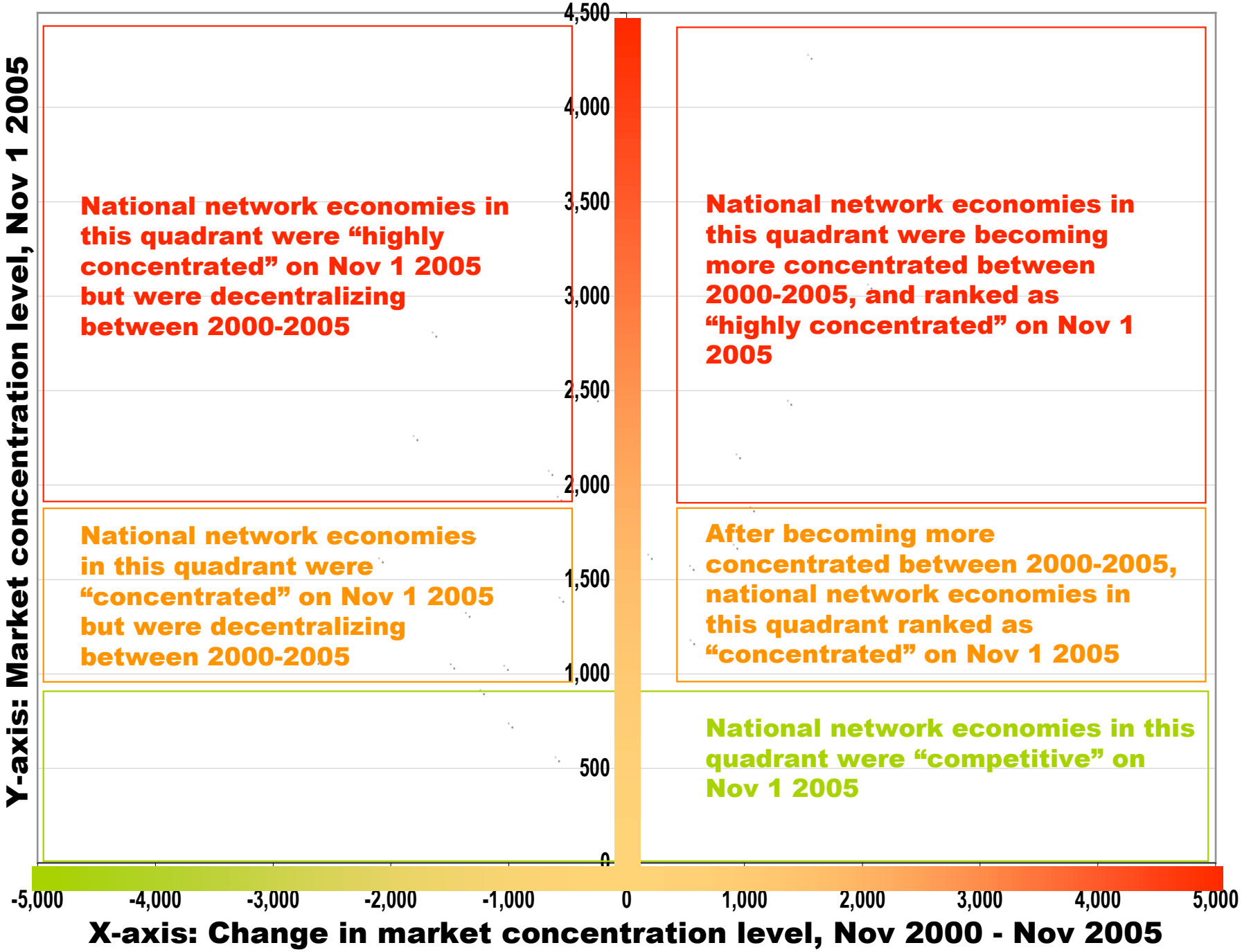
# methodology 1:
## The Herfindahl-Hirschman Index (HHI)

- Firms == routed Autonomous System Numbers (ASNs) grouped by whois country code of ASN(s) allocation
- Industry == "national Internet production" == sum of unique public IP addresses originated by ASNs with country code of ASN(s) allocation
- Market share == ratio of individual:total unique IP address originated by ASNs grouped by country code of ASN(s) allocation
- National HHI == sum of squared (public IP originated by ASN) grouped by country code of ASN(s) allocation
- Data taken from Univ. Oregon Route Views Project, first RIB capture for each November 1, 1997-2005

# Evolving OECD Market Structures:
# Internet Production Concentration, 1997-2005



# Production Concentration



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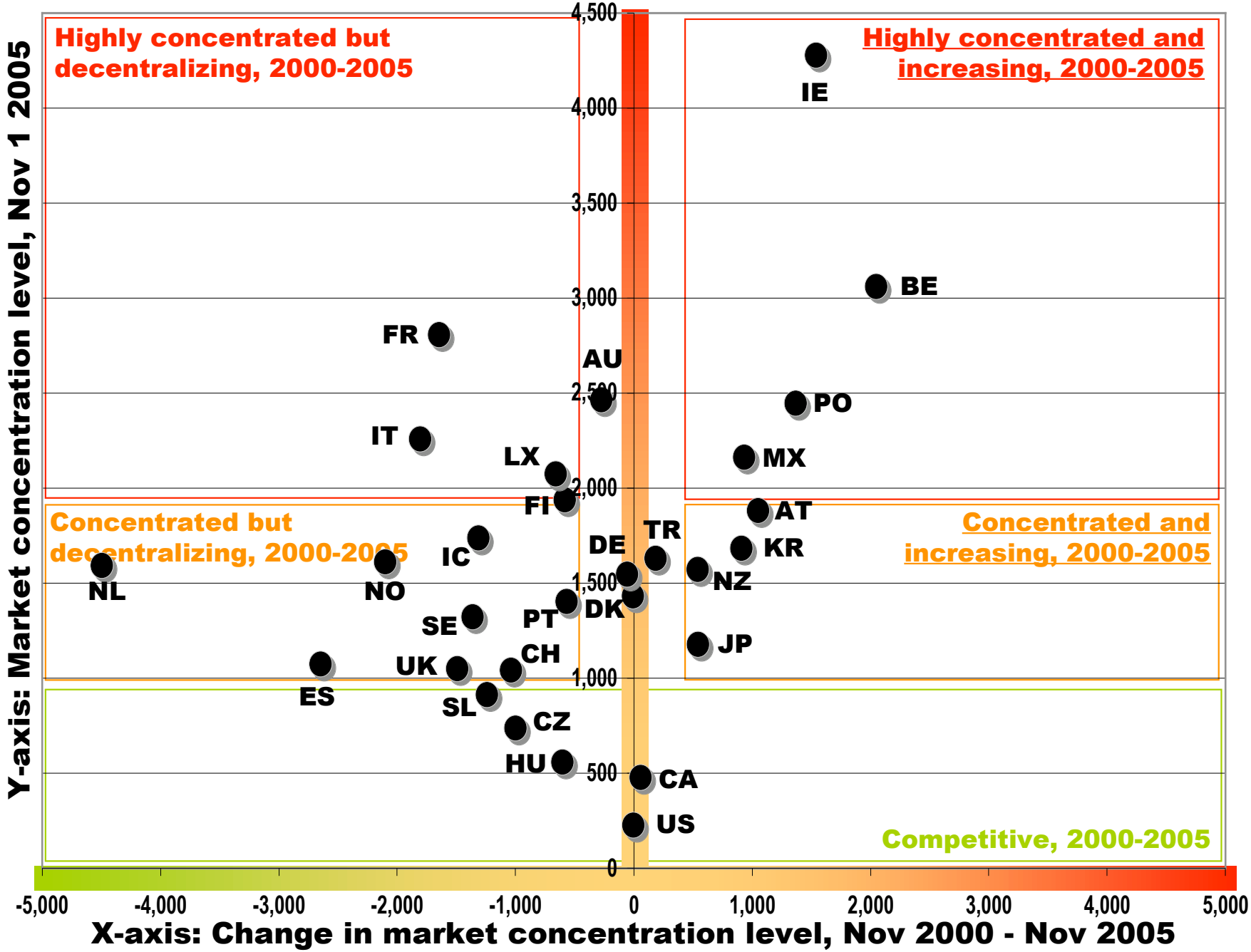
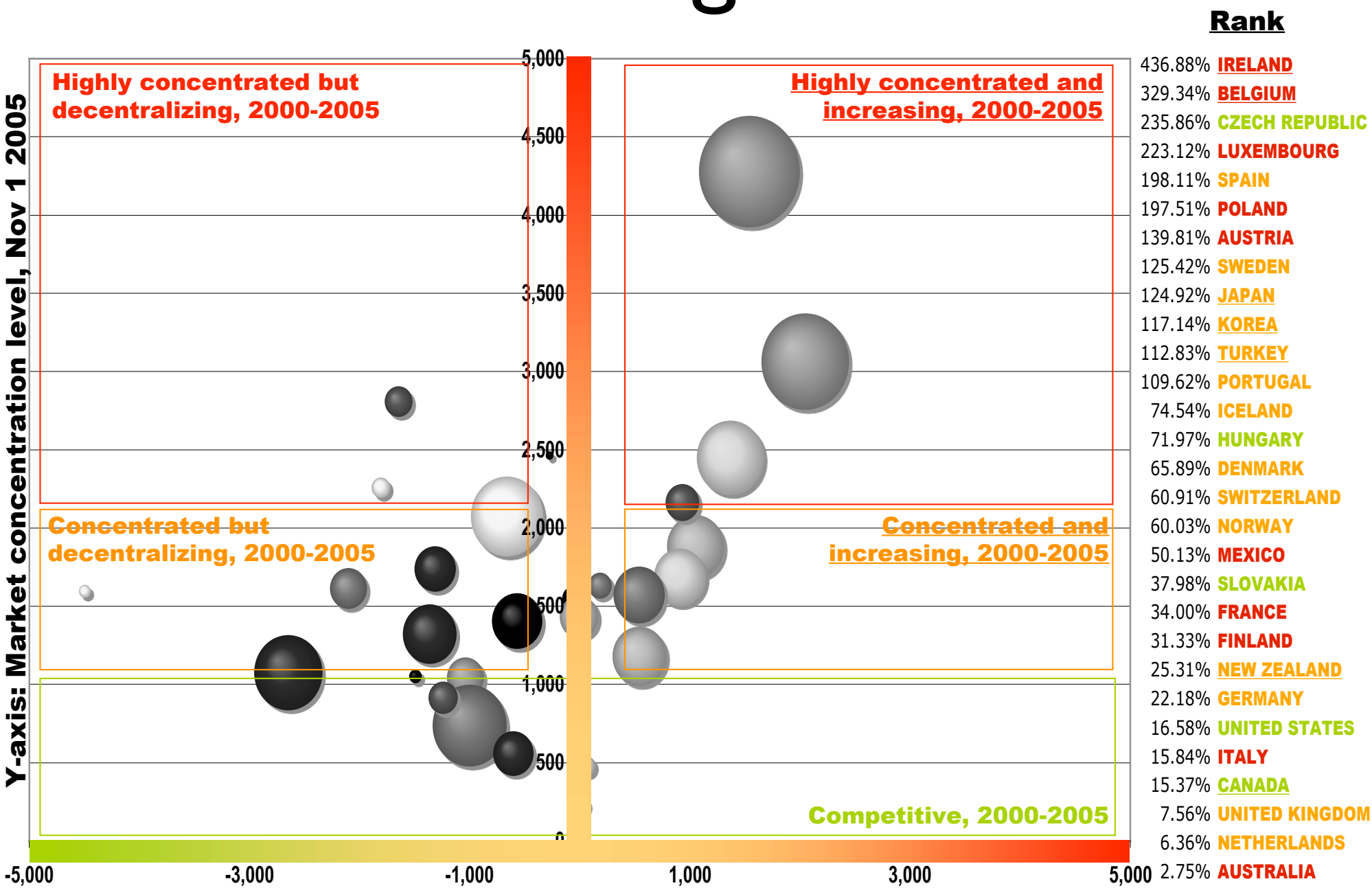
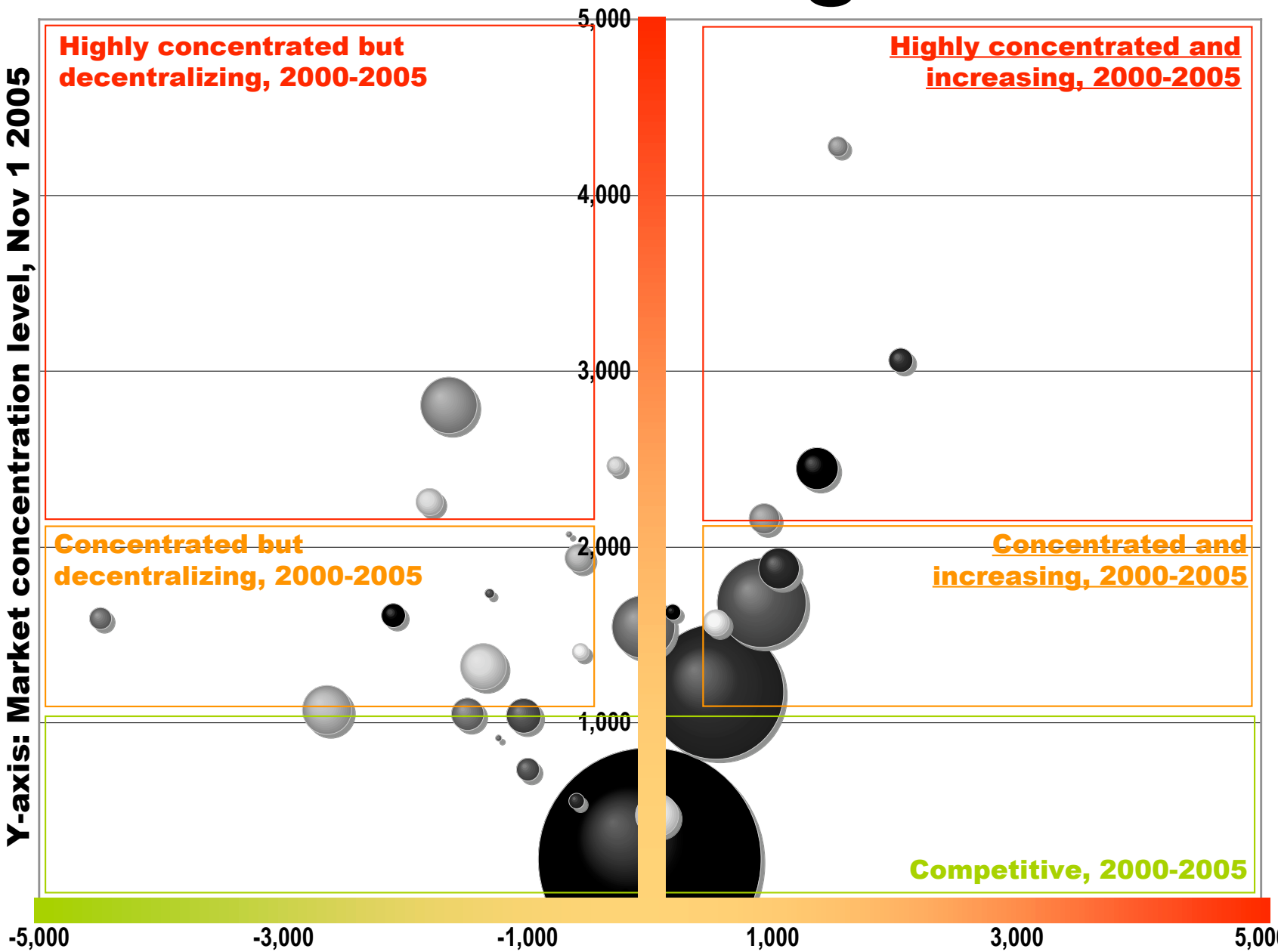


# relative growth




**X-axis: Change in market concentration level, Nov 2000 - Nov 2005**

# absolute growth




**Rank**

- UNITED STATES
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- FRANCE
- SPAIN
- SWEDEN
- CANADA
- POLAND
- AUSTRIA
- SWITZERLAND
- UNITED KINGDOM
- MEXICO
- FINLAND
- ITALY
- TURKEY
- NORWAY
- BELGIUM
- CZECH REPUBLIC
- NETHERLANDS
- IRELAND
- DENMARK
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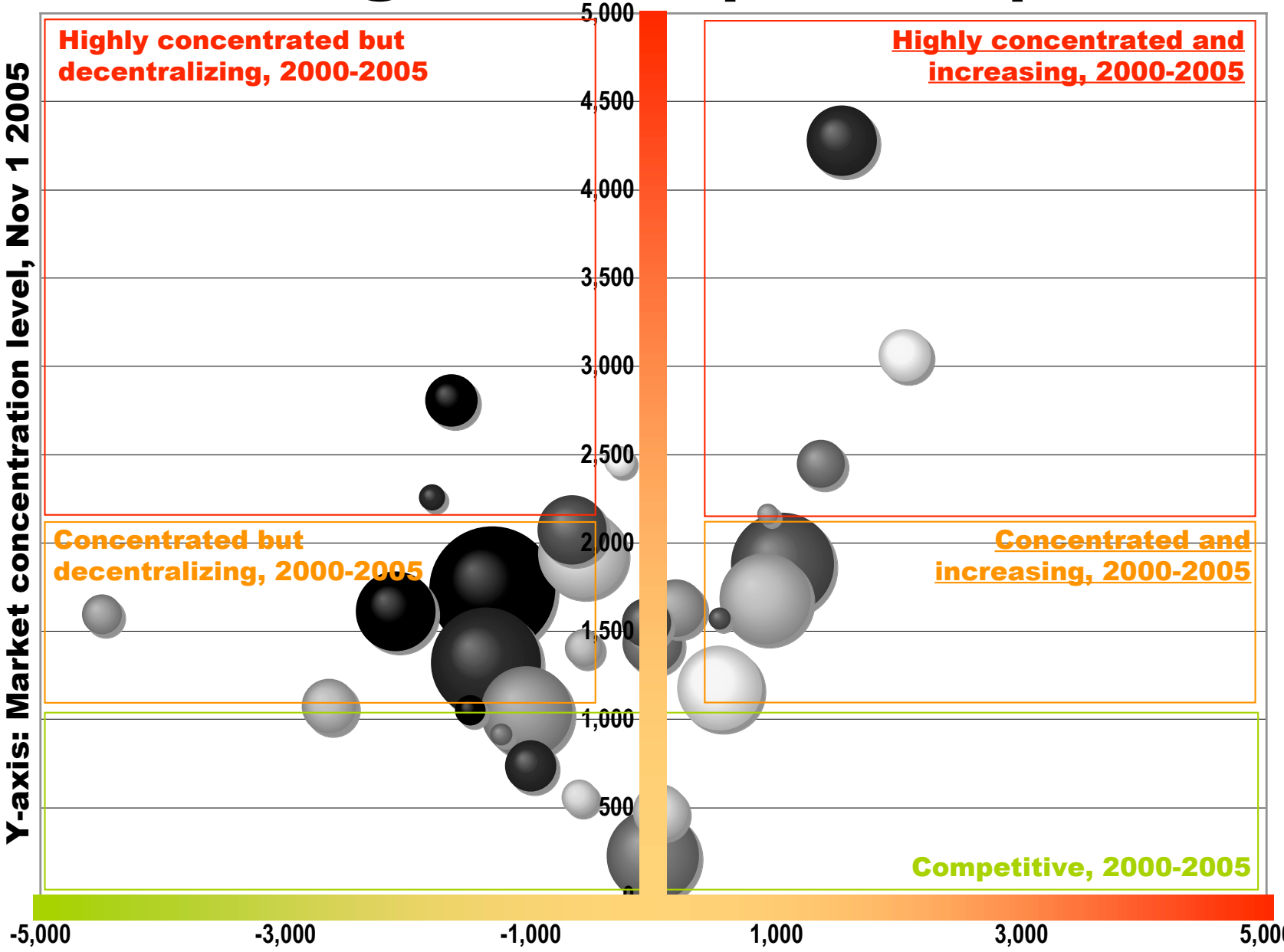
- PORTUGAL
- NEW ZEALAND
- HUNGARY
- ICELAND
- SLOVAKIA
- LUXEMBOURG

# growth per capita

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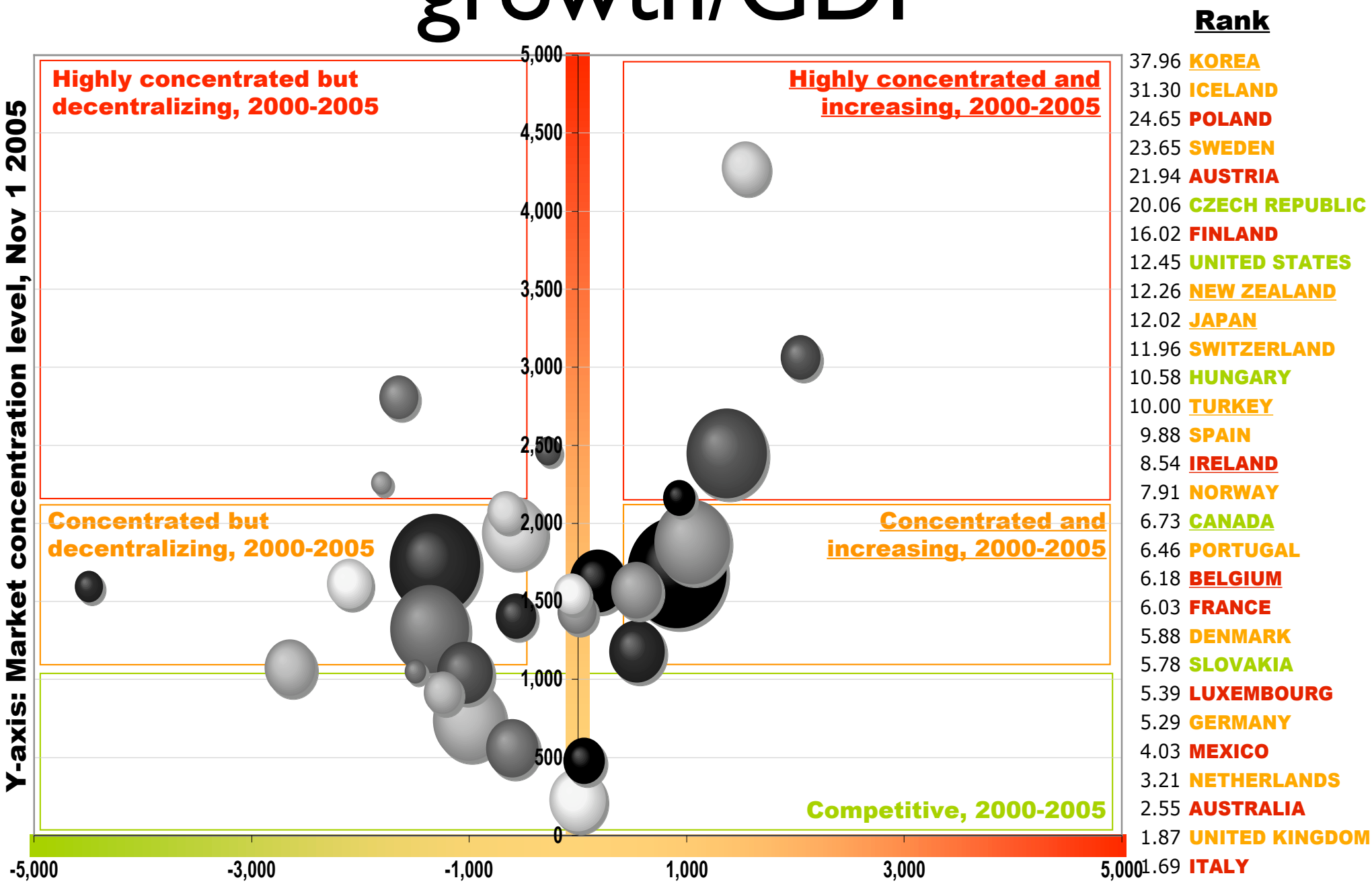
- MEXICO

# growth/GDP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24.65 POLAND
23.65 SWEDEN
21.94 AUSTRIA
20.06 CZECH REPUBLIC
16.02 FINLAND
12.45 UNITED STATES
12.26 NEW ZEALAND
12.02 JAPAN
11.96 SWITZERLAND
10.58 HUNGARY
10.00 TURKEY
9.88 SPAIN
8.54 IRELAND
7.91 NORWAY
6.73 CANADA
6.46 PORTUGAL
6.18 BELGIUM
6.03 FRANCE
5.88 DENMARK
5.78 SLOVAKIA
5.39 LUXEMBOURG
5.29 GERMANY
4.03 MEXICO
3.21 NETHERLANDS
2.55 AUSTRALIA
1.87 UNITED KINGDOM
1.69 ITALY
Highly concentrated but decentralizing, 2000-2005
Highly concentrated and increasing, 2000-2005
Concentrated but decentralizing, 2000-2005
Concentrated and increasing, 2000-2005
Competitive, 2000-2005
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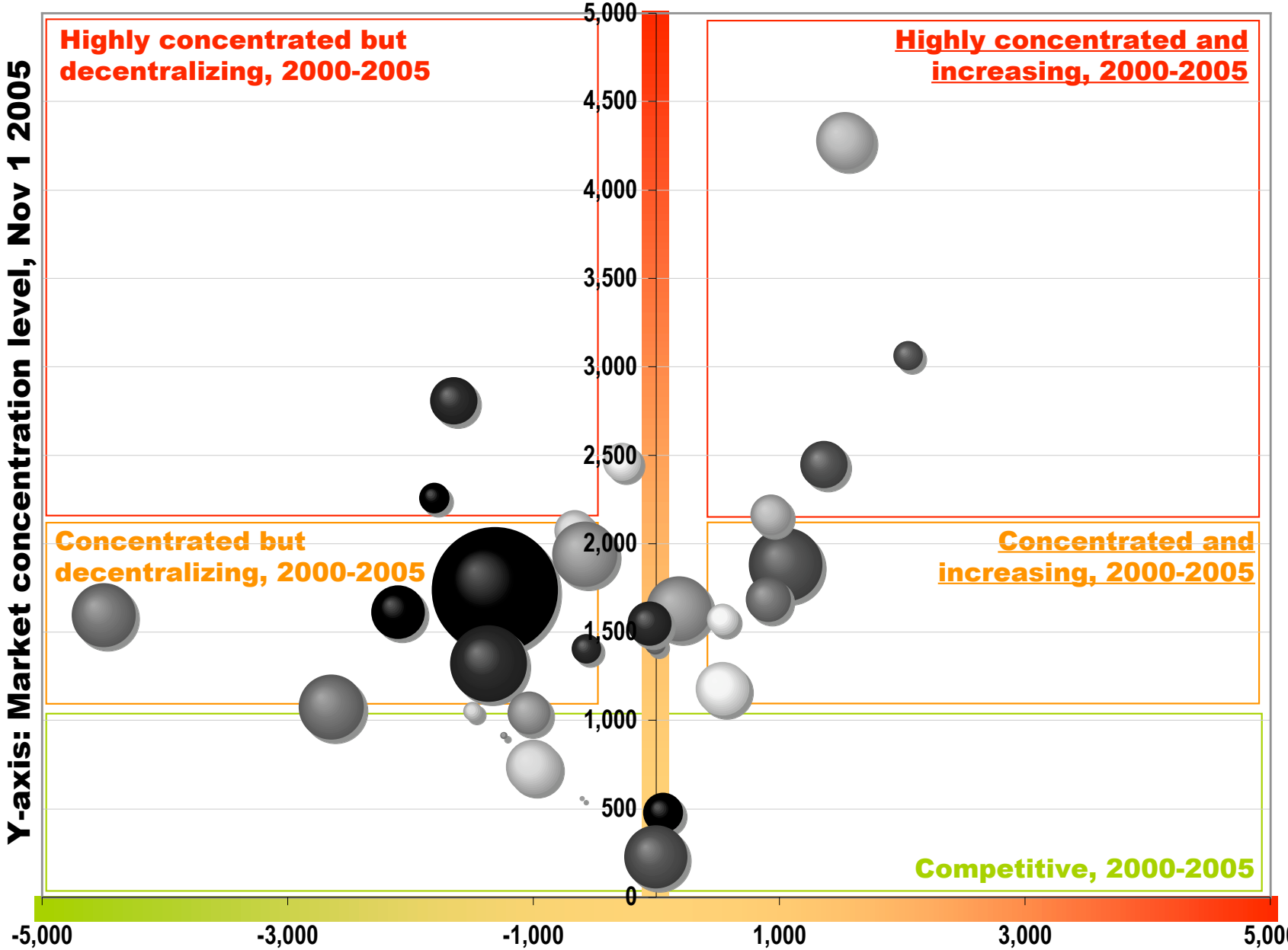
Y-axis: Market concentration level, Nov 1 2005
X-axis: Change in market concentration level, Nov 2000 - Nov 2005

# Layer 3 / Layer 1 Intensity change




Y-axis: Market concentration level, Nov 1 2005

1.21 ICELAND
0.45 SWEDEN
0.41 AUSTRIA
0.32 SPAIN
0.32 NEW ZEALAND
0.26 IRELAND
0.23 CZECH REPUBLIC
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0.22 NORWAY
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0.17 POLAND
0.16 KOREA
0.14 SWITZERLAND
0.13 MEXICO
0.13 LUXEMBOURG
0.08 TURKEY
0.07 ITALY
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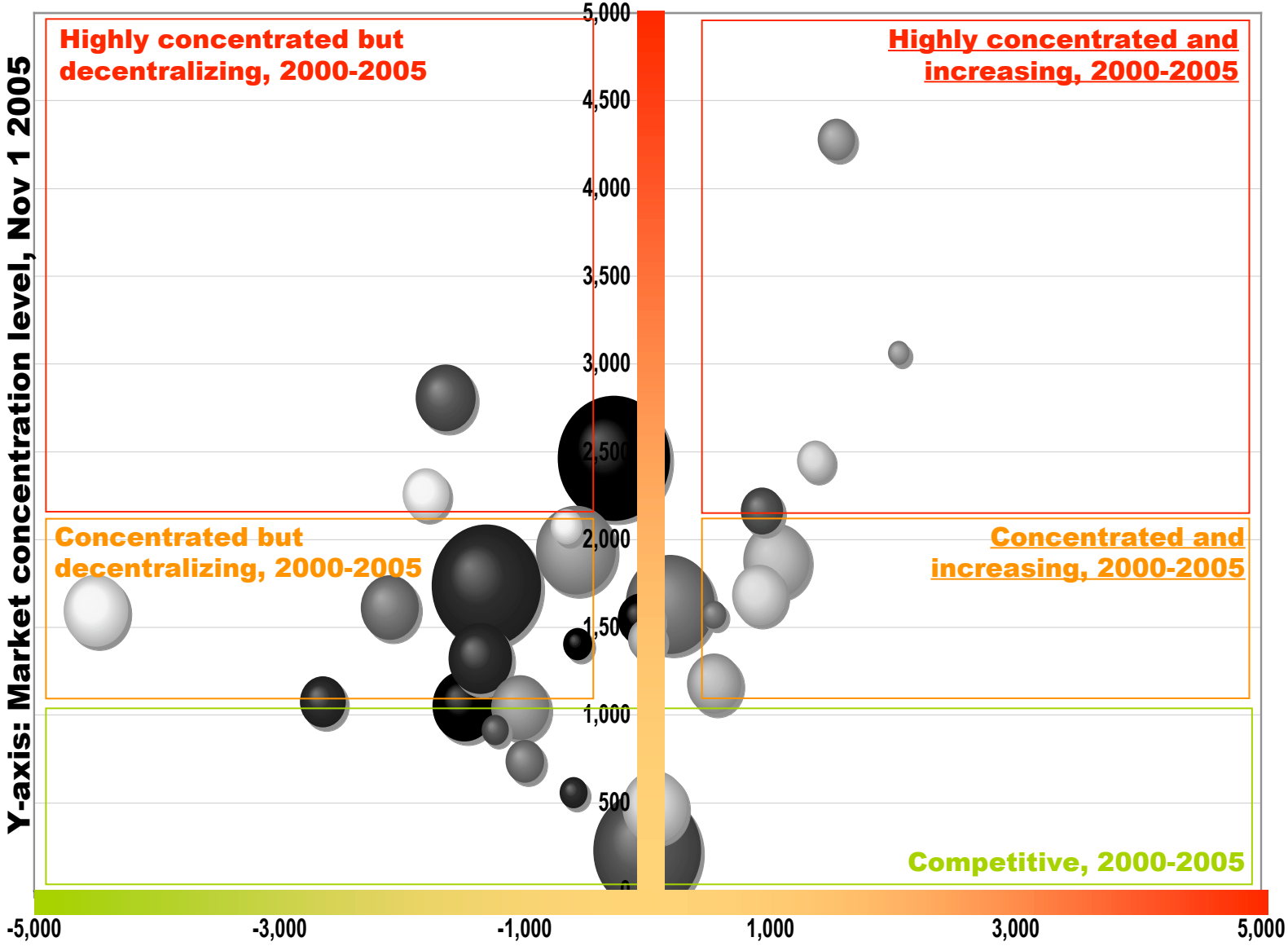
0.07 BELGIUM
0.04 DENMARK
0.00 SLOVAKIA
0.00 HUNGARY
-0.02 UNITED KINGDOM
-0.10 AUSTRALIA
-0.12 CANADA
-0.14 GERMANY
-0.29 UNITED STATES
-0.30 NETHERLANDS
-0.31 FINLAND

X-axis: Change in market concentration level, Nov 2000 - Nov 2005

# Layer 3 / Layer 1 Intensity




| Rank | |
|---|---|
| 3.04 | AUSTRALIA |
| 2.90 | ICELAND |
| 2.80 | UNITED STATES |
| 1.92 | NEW ZEALAND |
| 1.54 | FINLAND |
| 1.07 | AUSTRIA |
| 1.03 | CANADA |
| 1.01 | NETHERLANDS |
| 1.00 | UNITED KINGDOM |
| 0.98 | SWEDEN |
| 0.87 | FRANCE |
| 0.83 | NORWAY |
| 0.81 | SWITZERLAND |
| 0.72 | JAPAN |
| 0.71 | KOREA |
| 0.53 | ITALY |
| 0.52 | GERMANY |
| 0.50 | SPAIN |
| 0.44 | MEXICO |
| 0.36 | CZECH REPUBLIC |
| 0.35 | IRELAND |
| 0.34 | DENMARK |
| 0.33 | POLAND |
| 0.25 | LUXEMBOURG |
| 0.21 | PORTUGAL |
| 0.19 | HUNGARY |
| 0.18 | SLOVAKIA |
| 0.16 | TURKEY |
| 0.12 | BELGIUM |

**X-axis: Change in market concentration level, Nov 2000 - Nov 2005**

# preliminary observations

Average national Internet production growth between 2000-2005

Overall Internet production on 1 Nov 2005, plus growth since the launch of Southern Cross

Group share of overall OECD Internet production in 2000 and 2005

| | | | | | | |
|---|---|---|---|---|---|---|
| **Concentrated** | **79.34%** | **290,775,181** | **104,981,957** | **56.50%** | **16.93%** | **21.26%** |
| Concentrating | 118.29% | 128,342,830 | 70,580,382 | 122.19% | 5.26% | 9.38% |
| Diffusing | 80.32% | 98,330,863 | 22,143,547 | 29.06% | 6.94% | 7.19% |
| Stationary | 37.79% | 64,101,488 | 12,258,028 | 23.64% | 4.72% | 4.69% |

| | | | | | | |
|---|---|---|---|---|---|---|
| **Highly Concentrated** | **146.07%** | **121,313,020** | **28,181,331** | **30.26%** | **8.49%** | **8.87%** |
| Concentrating | 230.73% | 25,671,332 | 14,278,451 | 125.33% | 1.04% | 1.88% |
| Diffusing | 76.07% | 57,818,688 | 12,890,136 | 28.69% | 2.94% | 4.23% |
| Stationary | 2.75% | 37,823,000 | 1,012,744 | 2.75% | 3.35% | 2.77% |

- OECD's "highly concentrated" markets, though growing are either barely pacing, or in some cases shrinking relative to overall OECD Internet growth.

# preliminary observations

- Among the OECD's stable "competitive" national network economies* (HHI 1,000 or less), GDP and telecoms infrastructure tend to drive twice as much Internet production growth over time

*Includes US, CA, HU, & CZ

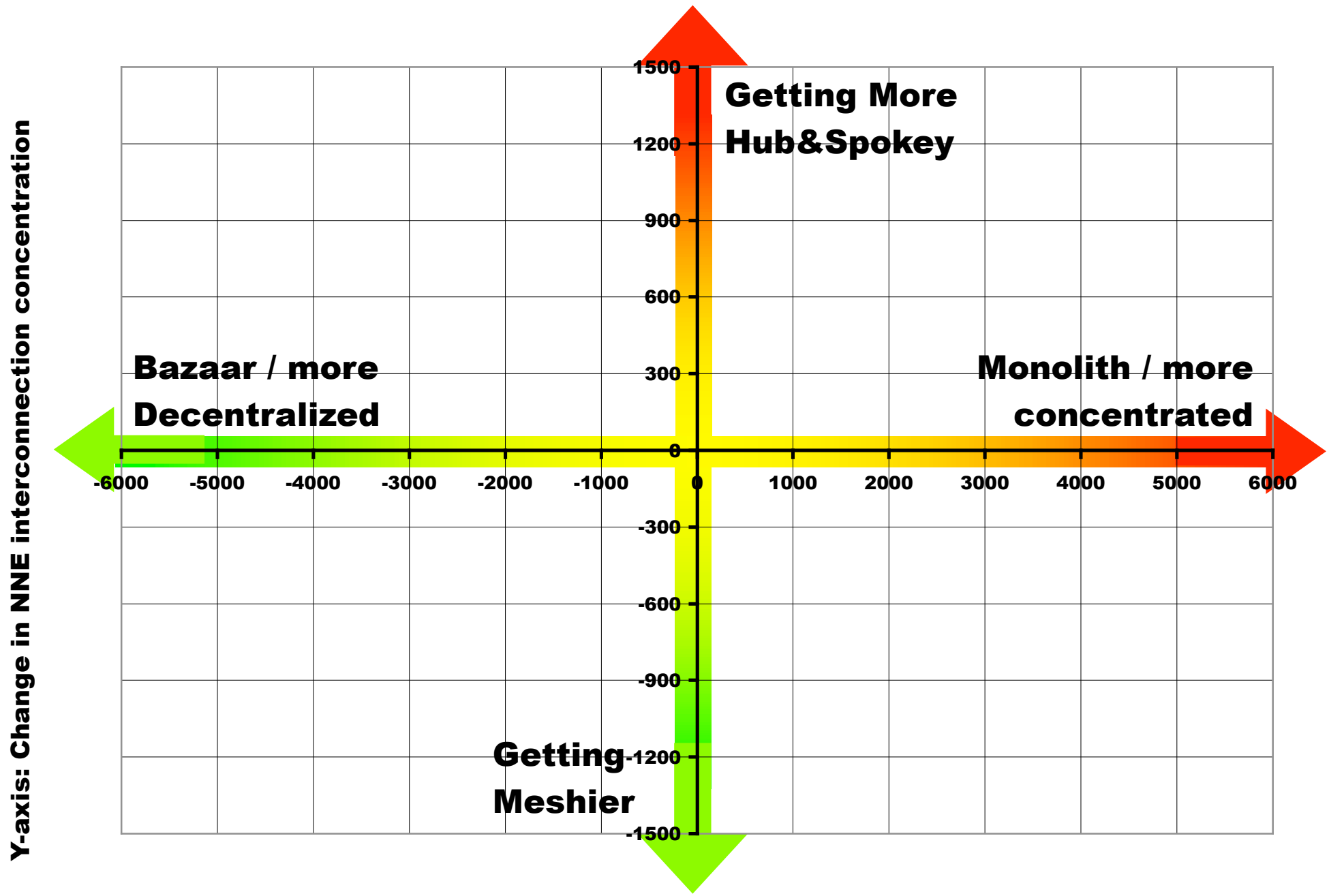
| | 2000-2005 Internet production growth relative to national GDP (2003) | 2000-2005 Internet production growth relative to national population (2003) | 2005 Internet production intensity relative to nat'l layer1, & change since 2000 | |
|---|---|---|---|---|
| **Competitive** | **0.17** | **11.12** | **0.91** | **-0.04** |
| Concentrating | *na* | *na* | *na* | *na* |
| Diffusing | 0.08 | 12.14 | 0.24 | -0.14 |
| Stationary | 0.30 | 9.59 | 1.91 | 0.12 |
| **Concentrated** | **0.28** | **12.83** | **0.90** | **0.20** |
| Concentrating | 0.28 | 19.99 | 0.53 | 0.15 |
| Diffusing | 0.32 | 12.03 | 1.03 | 0.26 |
| Stationary | 0.16 | 7.81 | 0.93 | 0.07 |
| **Highly Concentrated** | **0.20** | **9.70** | **0.85** | **0.10** |
| Concentrating | 0.22 | 13.07 | 0.46 | 0.21 |
| Diffusing | 0.21 | 7.28 | 0.80 | 0.02 |
| Stationary | 0.05 | 2.55 | 3.04 | -0.10 |

*Really need Bayesian analysis to evaluate results (coming soon)*

# methodology 1.1:
## production + interconnection

- HHI for internet production as before
- Interconnection as second dimension == sum of [AS degree (adjacencies) minus one] for ASNs with country code of ASN(s) allocation
- Subtracting one degree per AS to eliminate measurement error caused by singlehomers -- which currently constitute 15-60% of **every** NNE
- Market share == ratio of individual:total AS adjacencies grouped by country code of ASN(s) allocation
- National HHI == sum of squared (ASN adjacency shares) grouped by country code of ASN(s) allocation
- Adjacencies (AS degrees) generated with straightenRV

# Framework


Getting More
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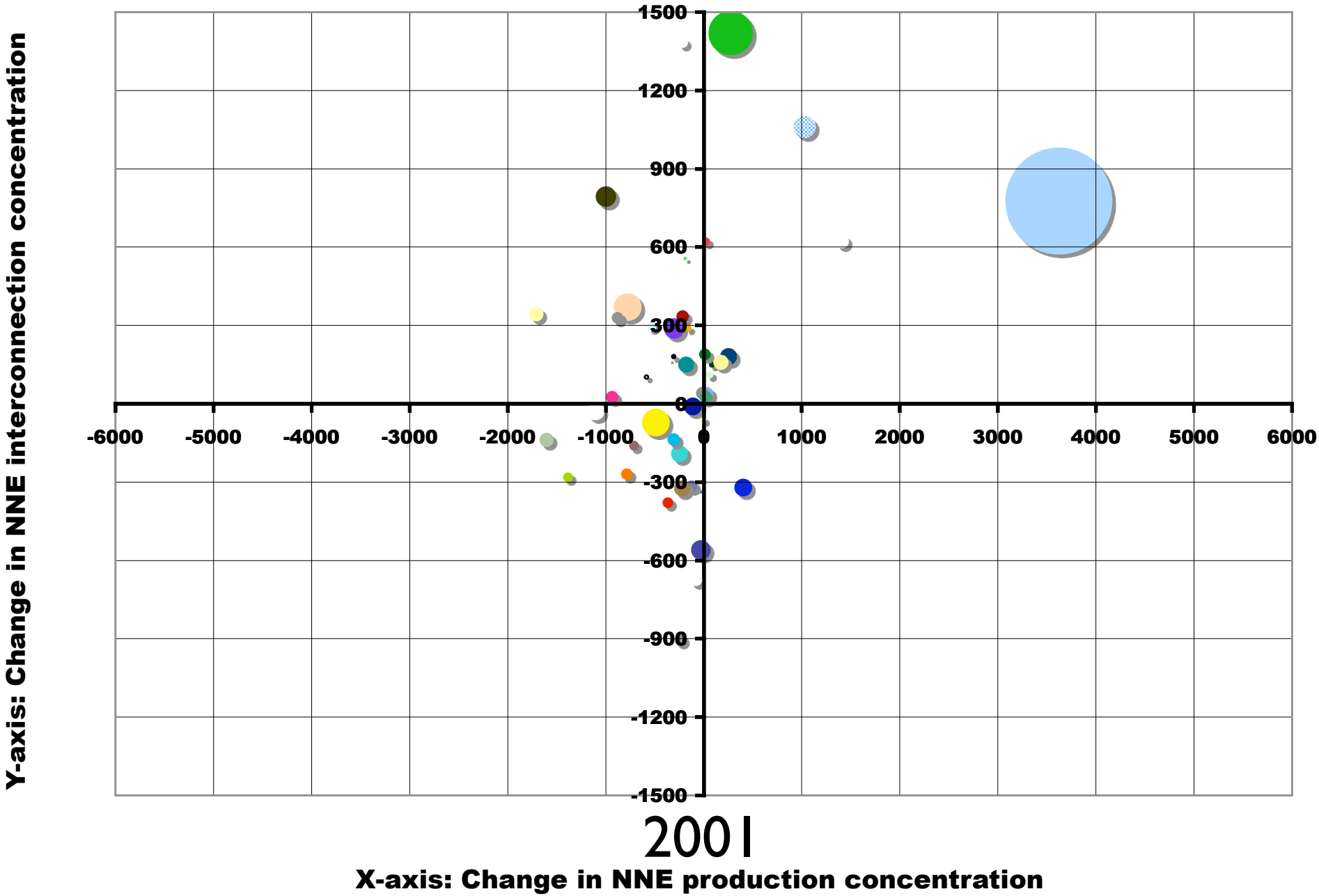
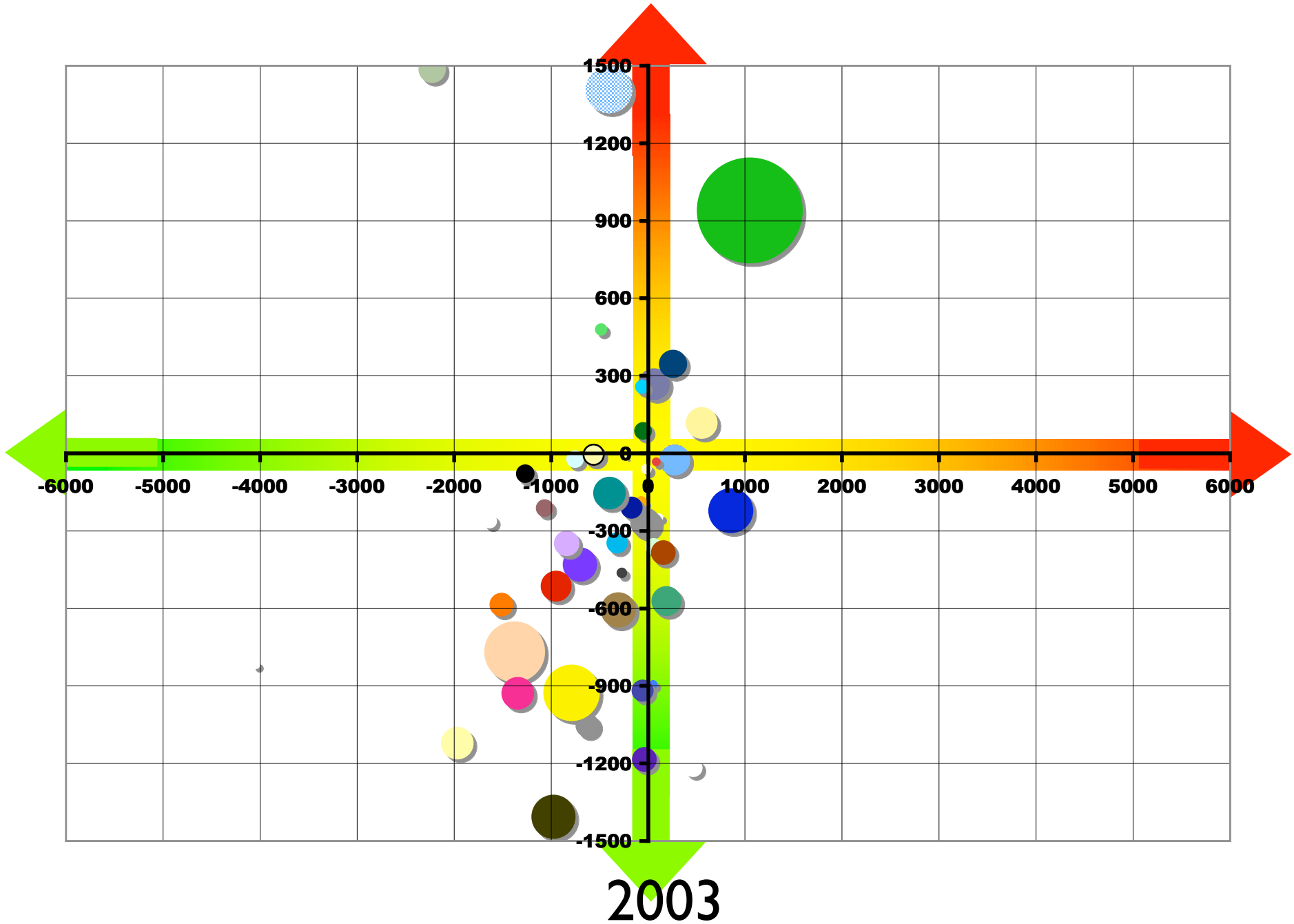
Y-axis: Change in NNE interconnection concentration
X-axis: Change in NNE production concentration

# relative growth

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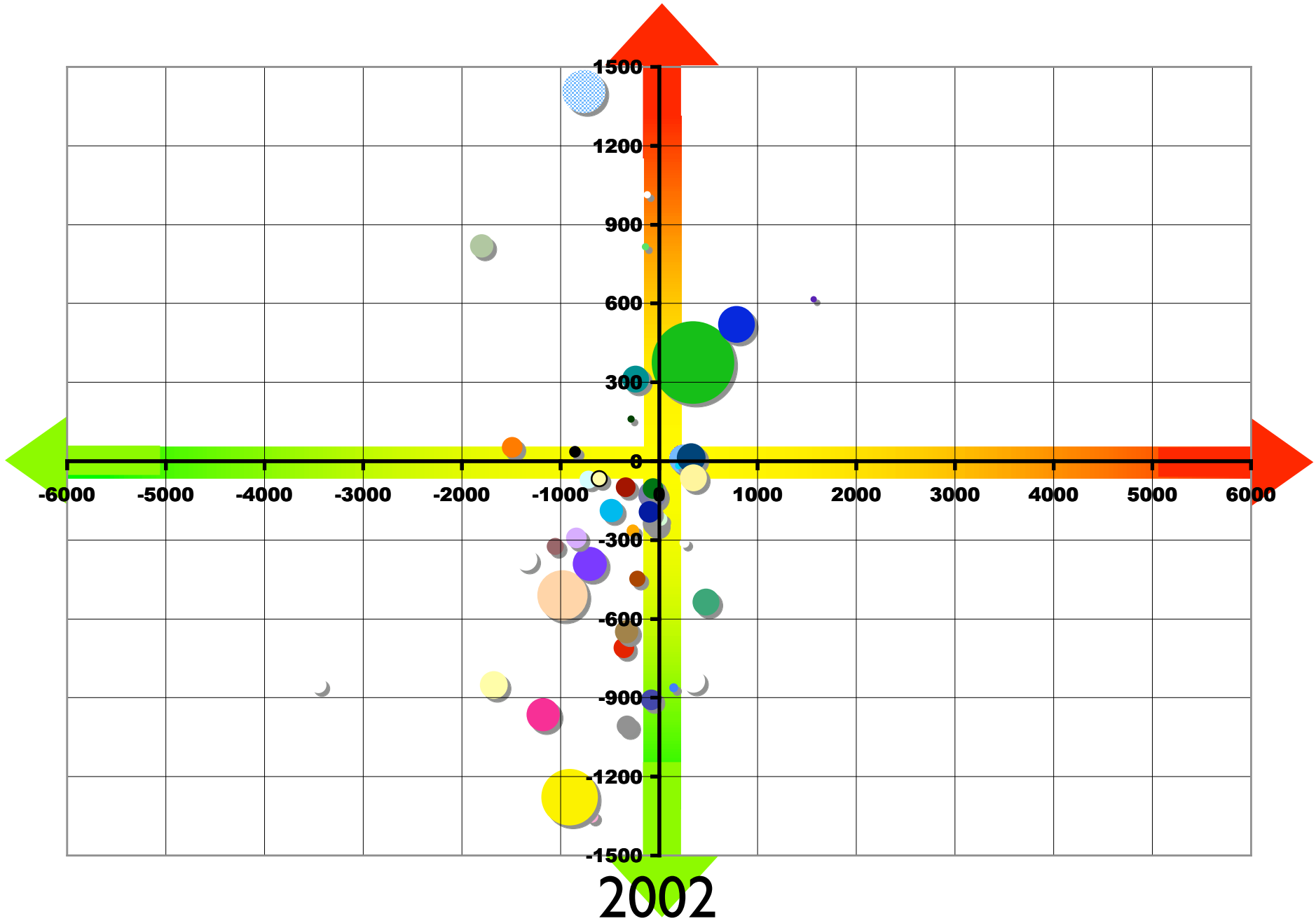
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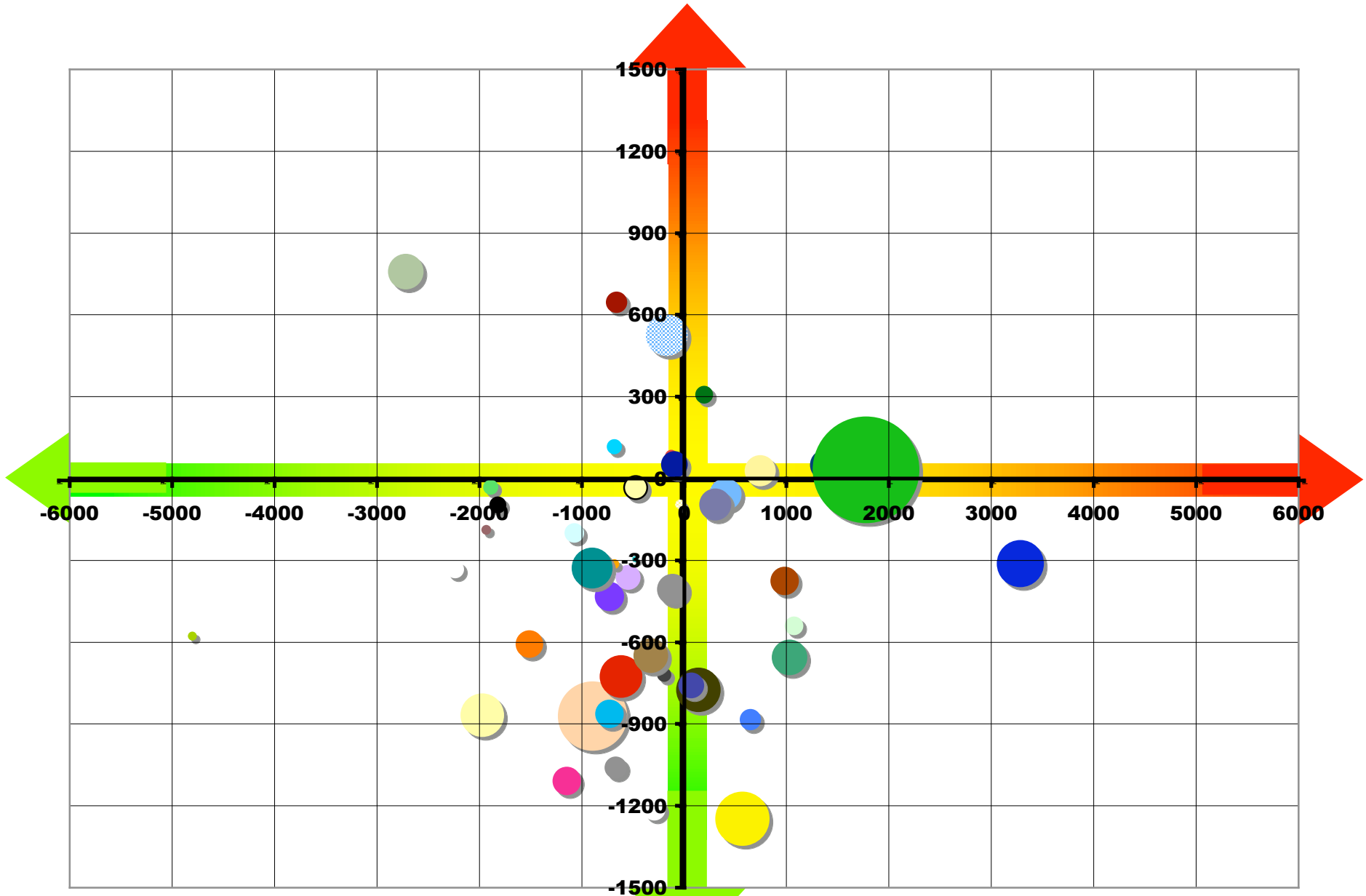
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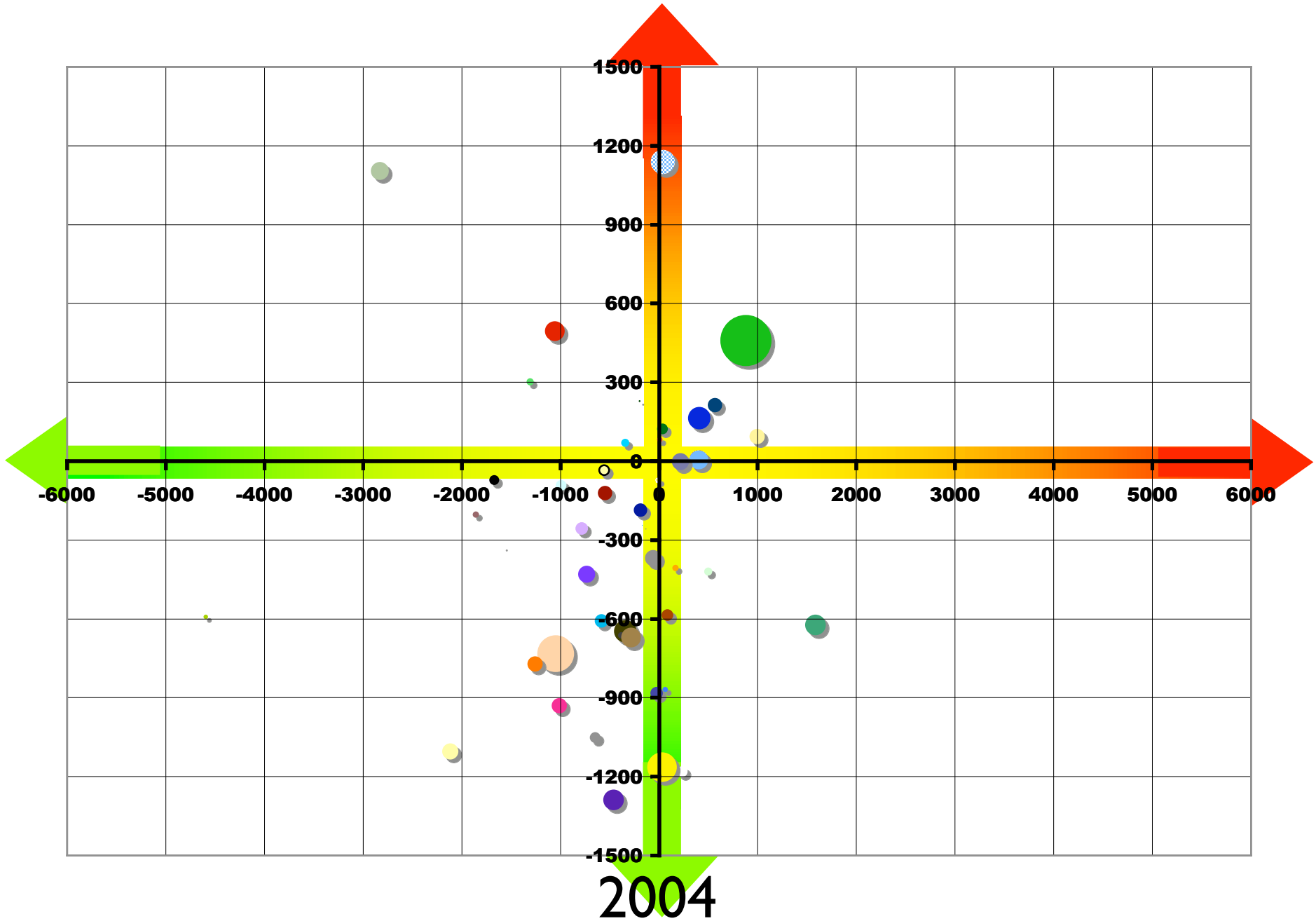
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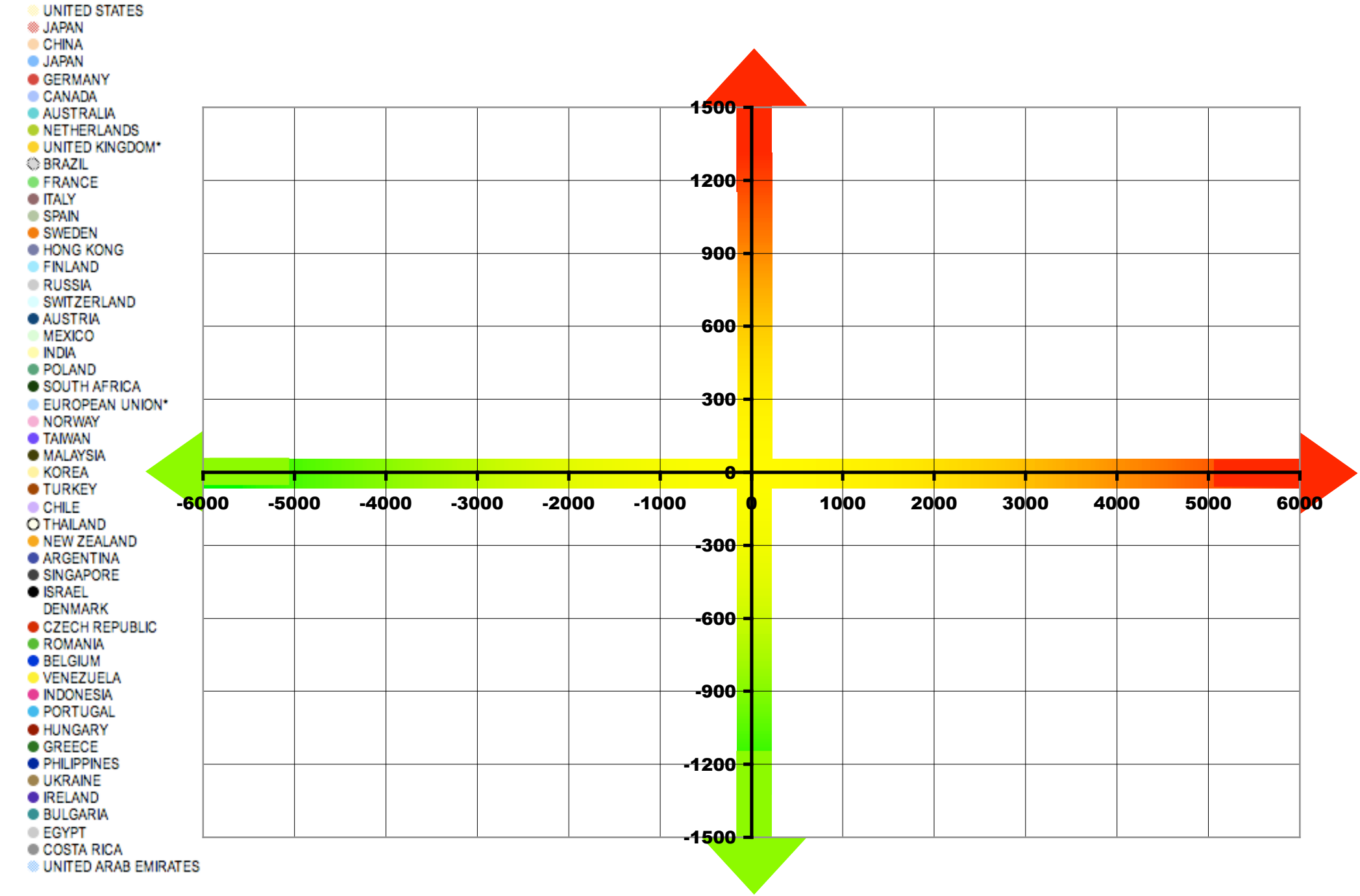
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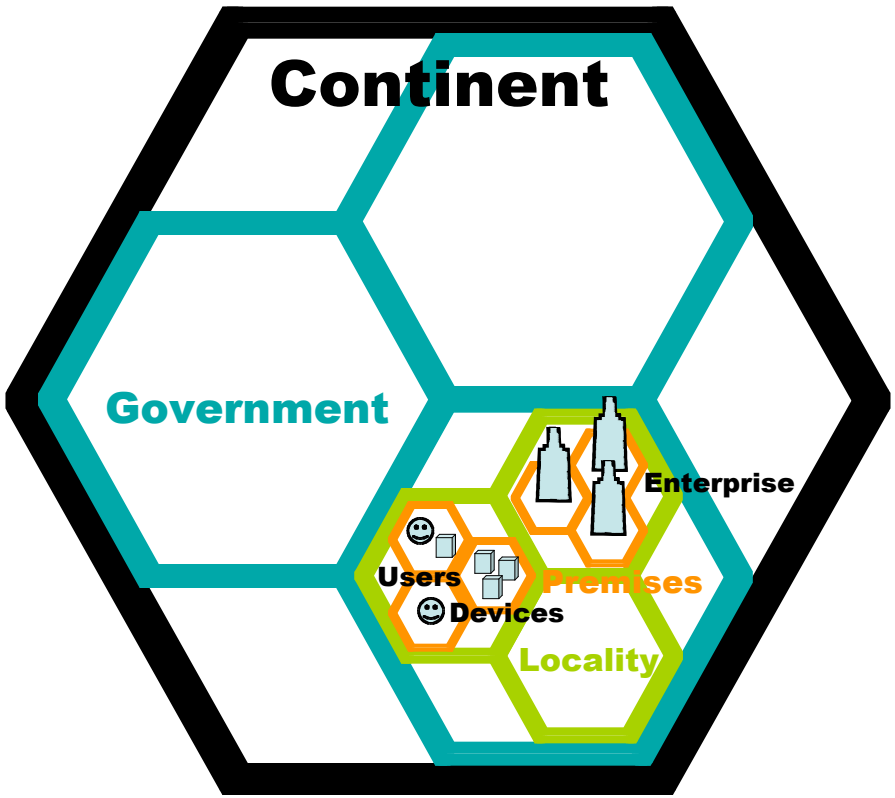
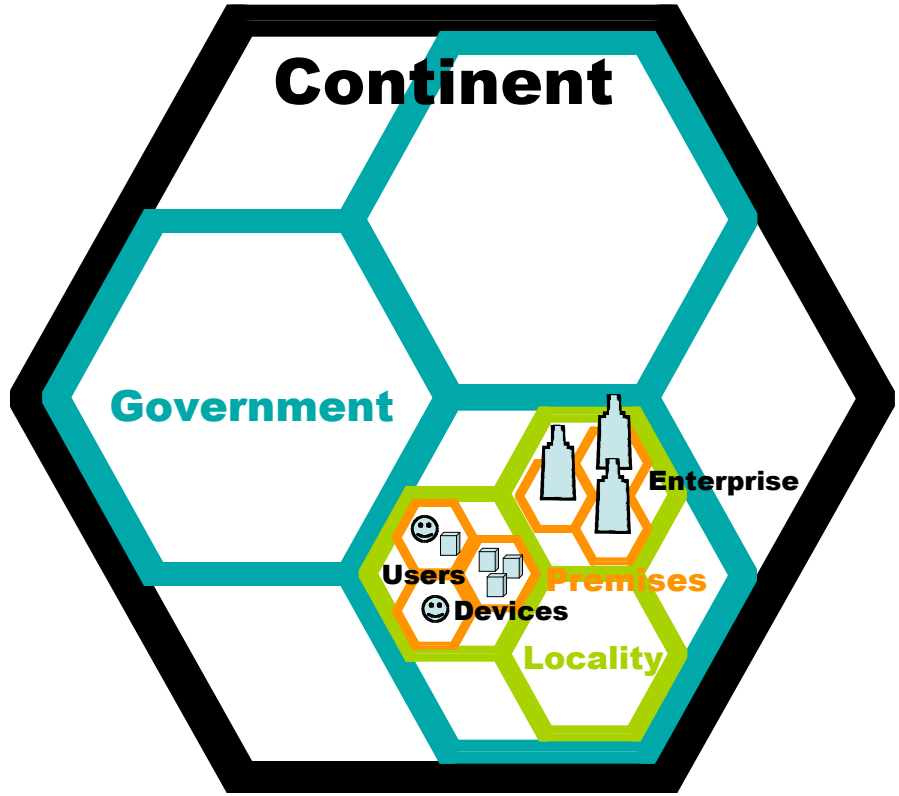
# future work (next week)

- International adjacencies as third dimension
- Identify multi-AS ARDs and recalculate market shares
- Examine NNE market structure as consequence of other factors:
  - Fully loaded local cost (availability, regulatory treatment, price) of gross infrastructure inputs, esp. access segments and international segments
  - Fractal treatment of "locality"...

# future work

Measuring local effects of variable treatment of intervening critical inputs




intercontinental
international
enterprise-enterprise
enterprise-residential
residential-residential

治大『网路』若烹小鮮

# toward an empirical network macro-economics..?

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