# Inquiry into the Nature & Causes of the Wealth of Networks

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**28 March 2006**

# research program

- Define Internet public interests
- Identify empirical data resources to illuminate whether/how those interests are being realized
- Compare direct and normalized measurements, over time and across different network economies, to identify "main case" patterns and outliers -- both overachievers and underachievers
- Empirically evaluate different explanations for those variations
- Assess utility of this methodology, identify possible misuses, and suggest steps to reduce the risk of strategic abuse in the future

# Defining the Wealth of Networks

# what is the Internet good for?

- **General purpose technology**
- Individual and social empowerment
- Economic development / productivity
- Open-ended innovation

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**Users**

**Usage**

**Uses**

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**Internet resources**

# what is the Internet good for?

- **Users**: Internet access methods, "eyeballs"; as more people enjoy one, and then multiple alternative, ever-improving means to interact with the Internet, the universe of Internet resources grows
- **Uses**: online applications, content and services of all kinds; as the variety of content, services, and content providers increases, so too does the universe of Internet resources
- **Usage**: qualitative / scaling factor relevant to both users and uses; as per-user time online and popularity of individual content sources increases, the Internet resource pool also grows accordingly
- Each new addition represents a direct or indirect growth accelerant for all of the others

# how does the Internet deliver?

Uses-Usage

Users-Usage

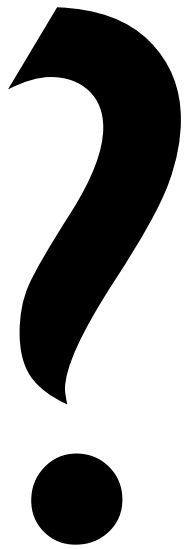
Uses-Usage

Users-Usage

Users-Usage

Users-Usage

Uses-Usage



Users-Usage

Users-Usage

Uses-Usage

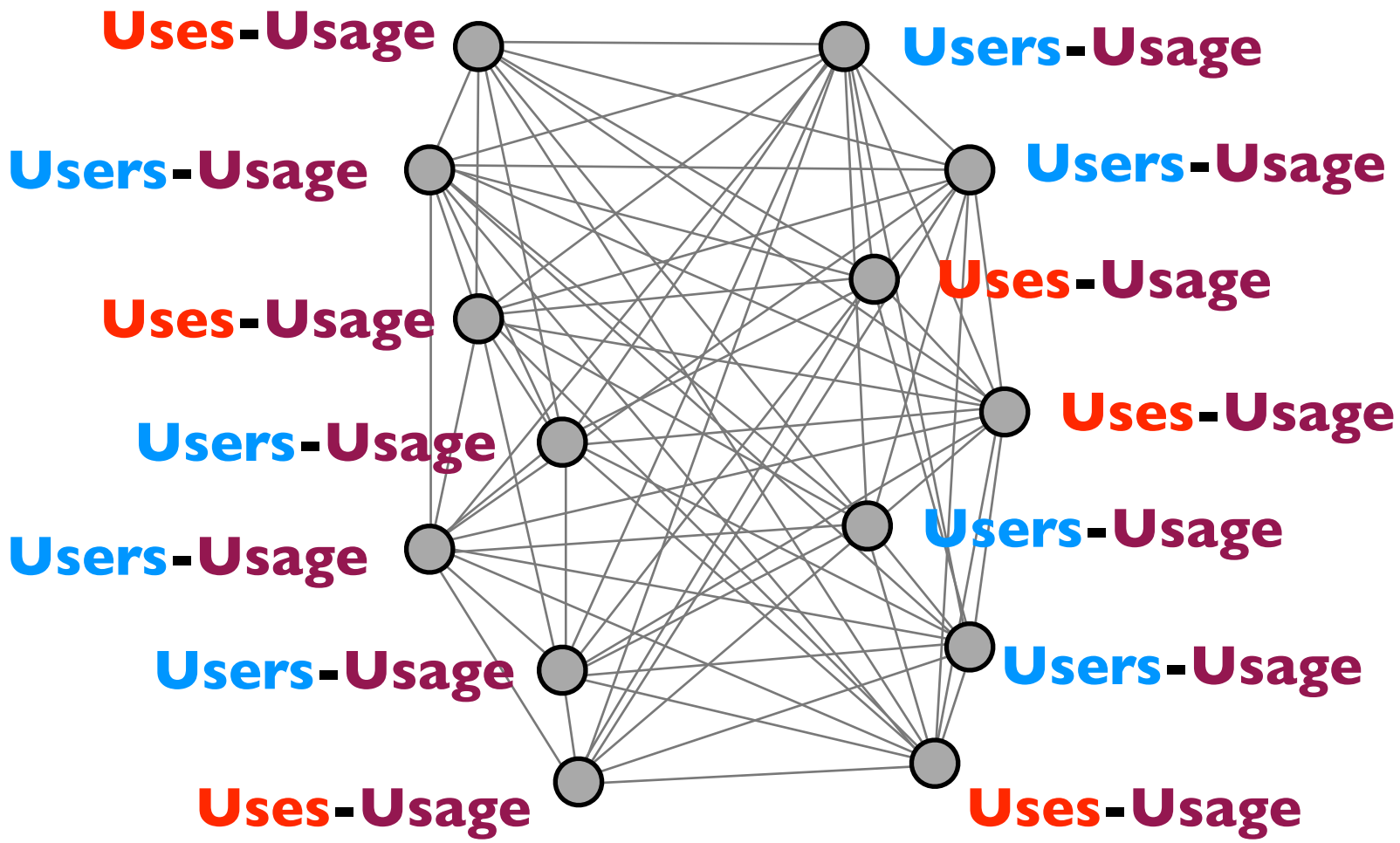
Uses-Usage

Users-Usage

Users-Usage

Uses-Usage

# how does the Internet deliver?



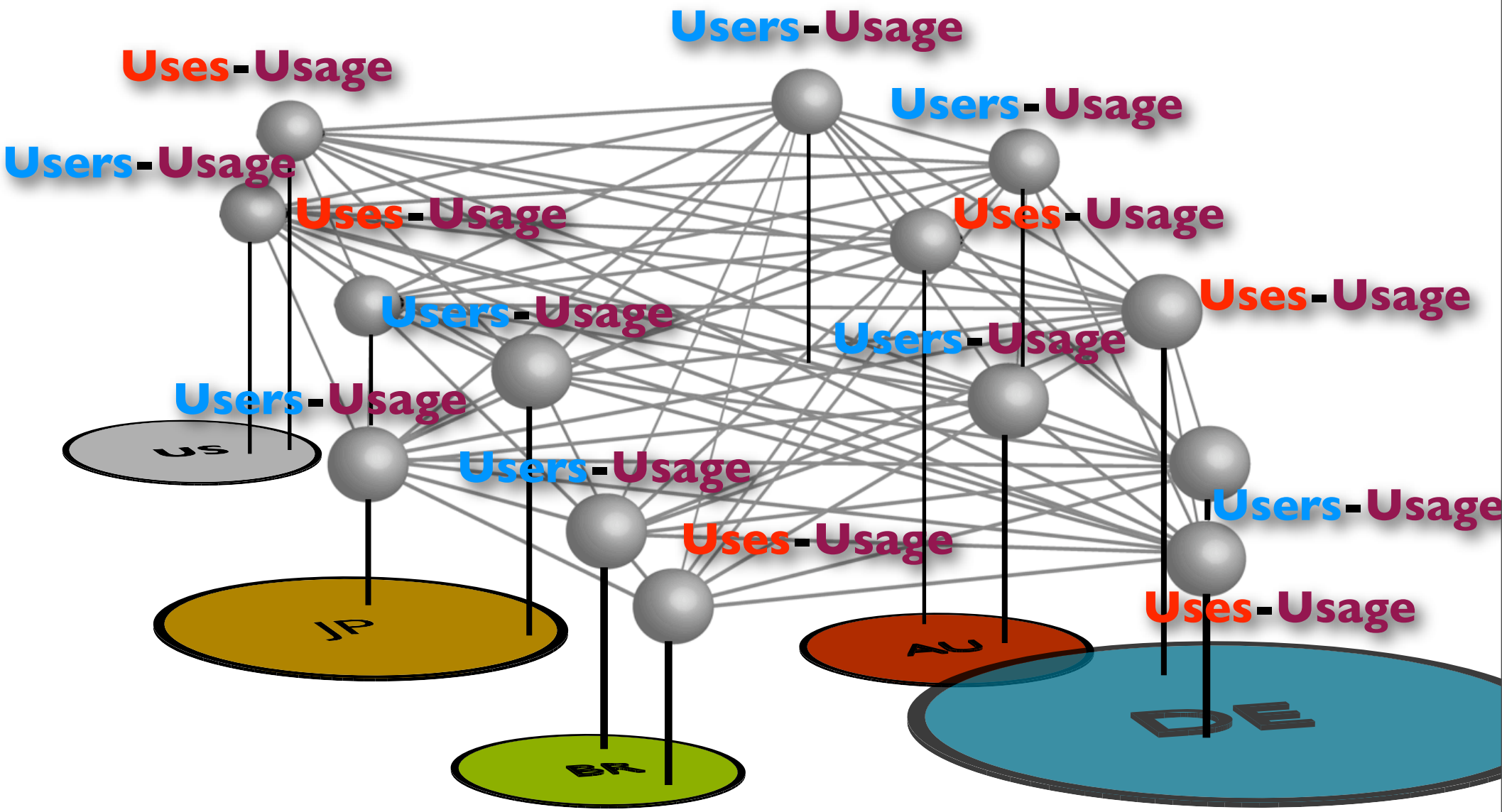

e2e: the end-to-end design principle

# e2e: end-to-end systems design

- "System elements should be located as close as possible to functions/processes that require them."
- Originally conceived as vertical **cost/complexity reducing** strategy (Saltzer, Reed, Clark)
- Later reinterpreted as a horizontal **innovation/ flexibility enhancing** principle, e.g., "Stupid Network" (Isenberg)
- Alternately envisioned as a functional mechanism for individual interaction, creativity, **empowerment** (Levin, Cohen, Corwin, Pollack, Wulf)
- Finally, imported into national policy arguments as a vehicle for social and economic **development** (WSIS)

# Measuring the Wealth of Networks

# IP addresses as identifier *and* locator




Each is uniquely associated with a service provider, each of which is uniquely associated with a *country of administration**

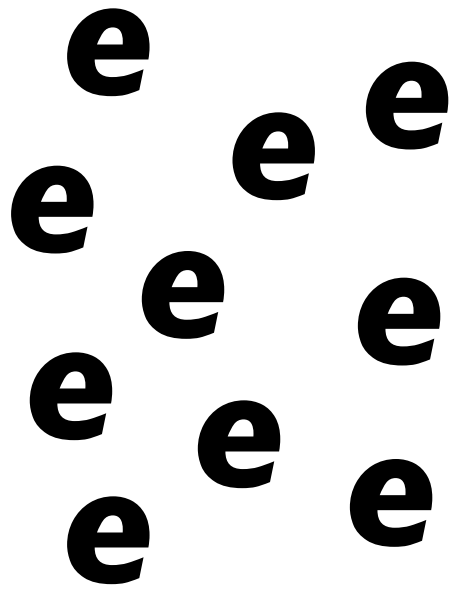
# IP addresses as measurable indicators of *promises fulfilled*

- For close to a decade, all IP addresses have started as administrative assets under the trusteeship of Regional Internet Registries (RIRs)
- RIRs operate under mandate to distribute IP addresses only to institutions that make a credible promise to deliver new Internet users, usage, or uses, in quantities no greater than that required to support the promised additional Internet resources
- RIRs withhold subsequent IP address allocations unless/until the institution has *verifiably* delivered on its original promise
- Empirical analysis suggests that 75% of

# the Internet routing table: an institutionalist interpretation

+

+



**users.....usage..... uses**

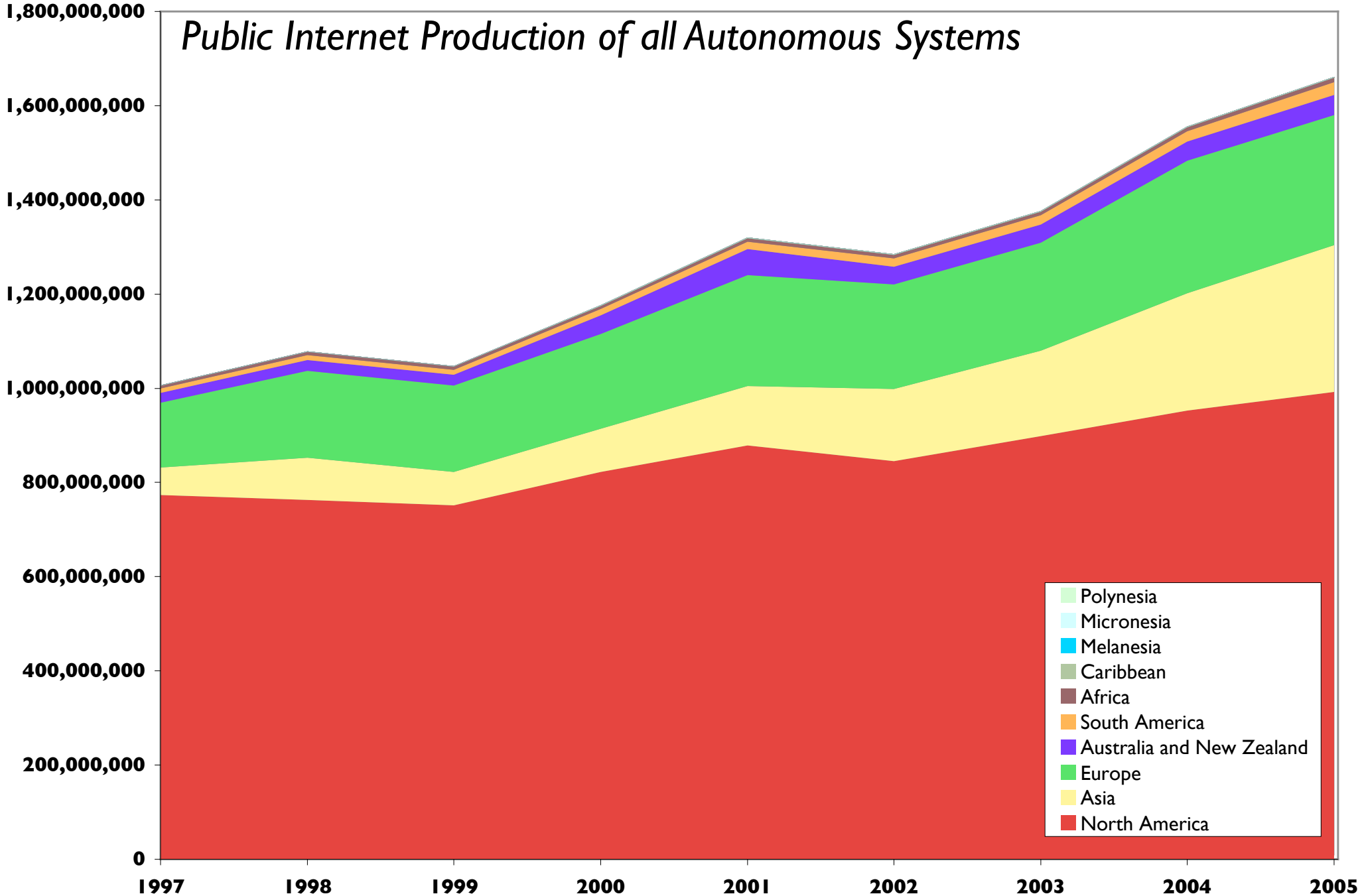
**scaling factors**
**historical factors**
**temporal factors**

= IP addresses injected into the routing table by individual networks... aka "***Internet production***"

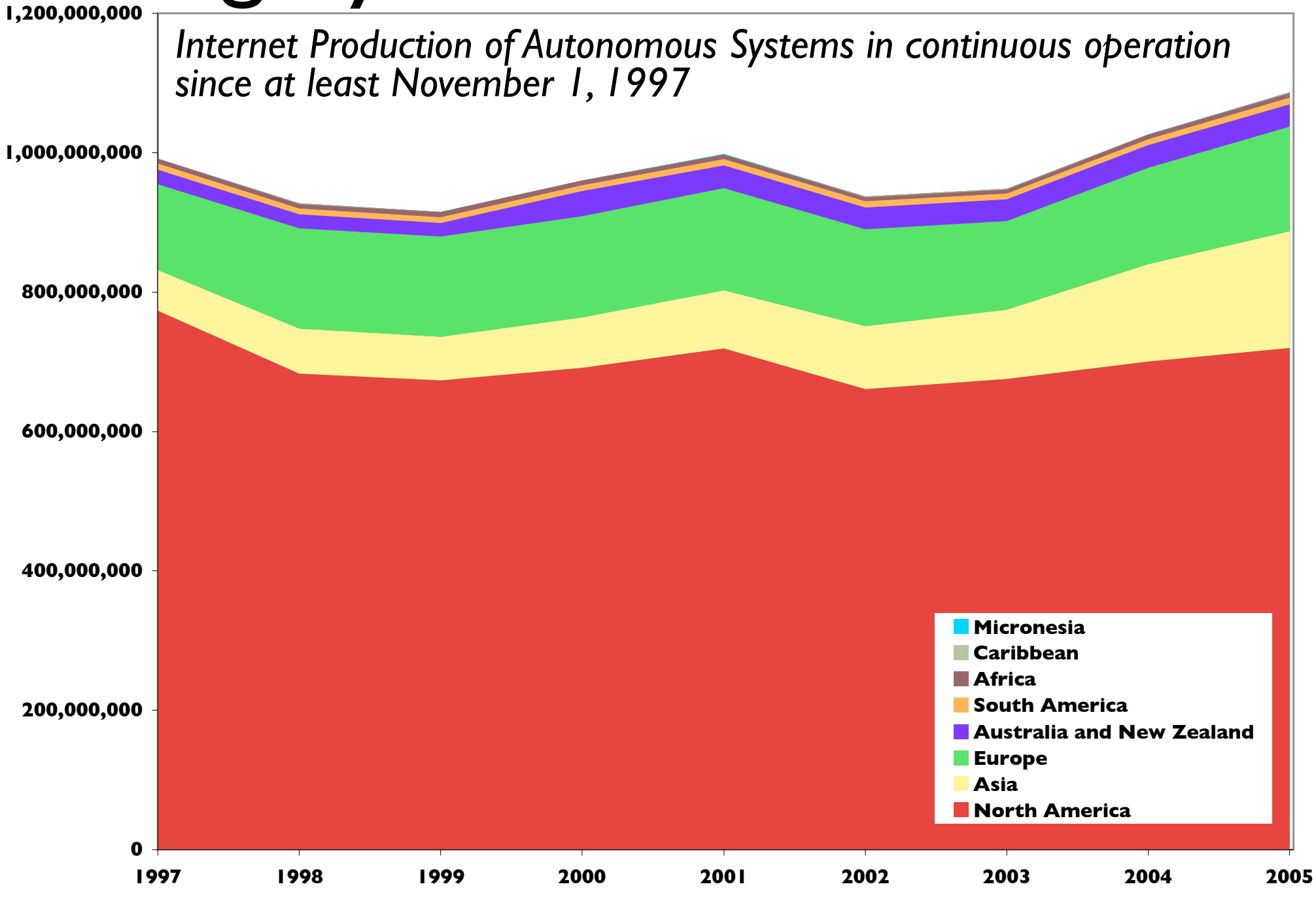
# WoN core metric

- **Internet production, Internet resources** == summed unique public routed IP addresses
- **Unique**: each IP address is counted once, at the point where it is *originated* to the Internet*
- **Public**: countable public IP addresses are understood to represent the *peak simultaneous internetworking* needs of a much large number of uncountable *private* Internet resources -- and to completely miss some purely private networking activities
- **Routed**: each IP address that appears in the *routing table* is indicative of a commitment of economic, technical, and human resources to the fulfillment of a promise to deliver new Internet users, usage, uses

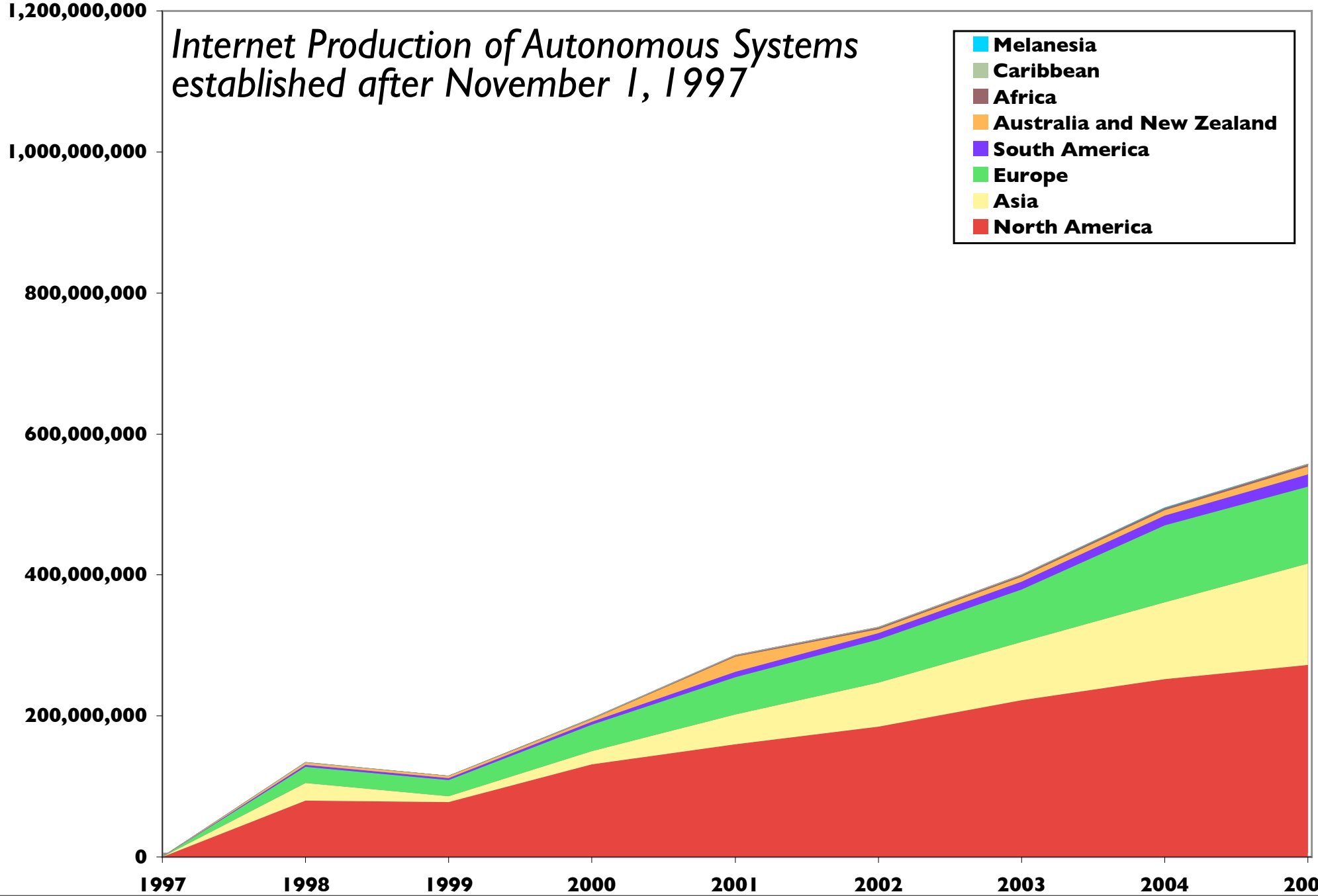
# Total Internet Production



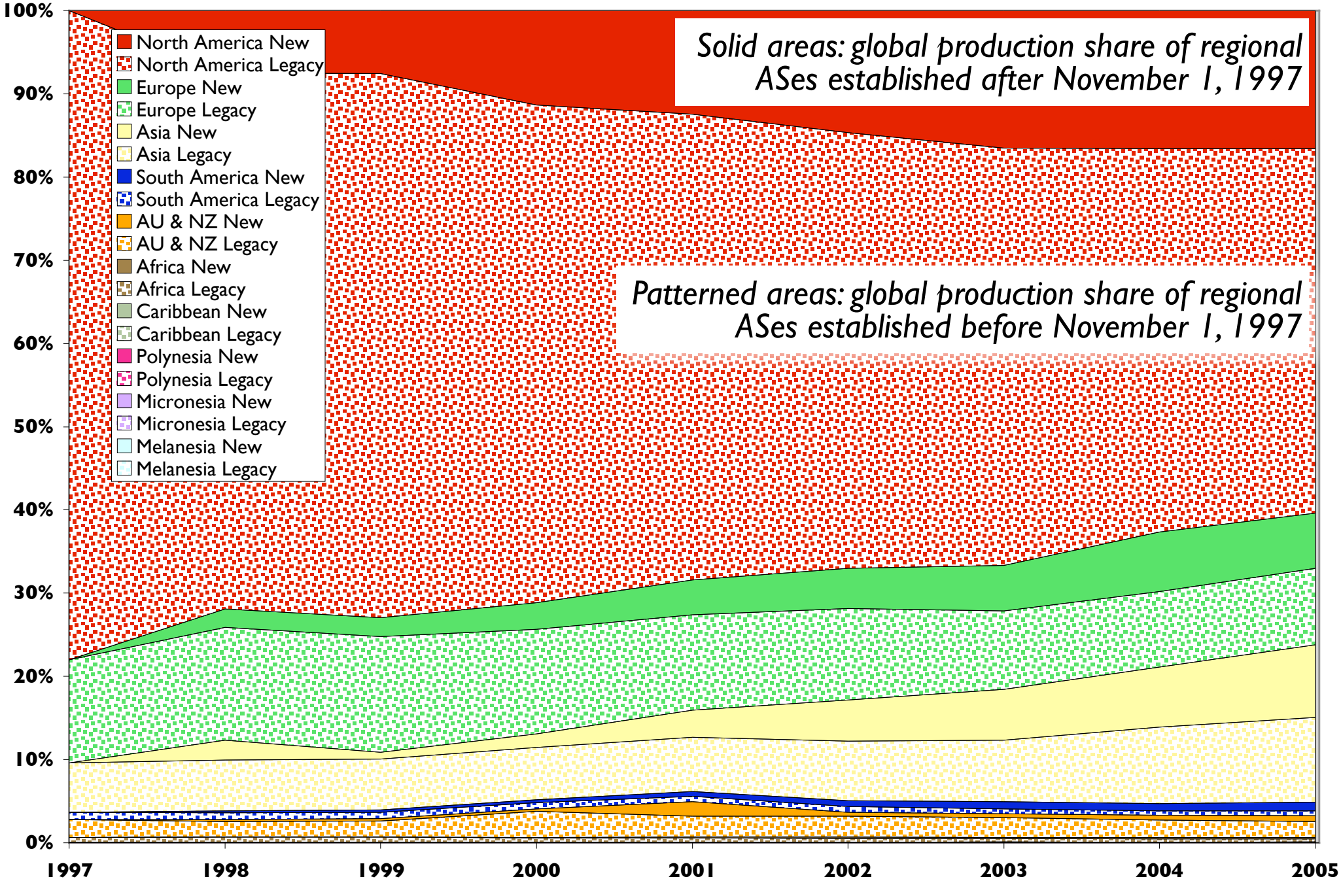
# "Legacy" Internet Production



# "New Network" Production



# Global Internet Production, Shares



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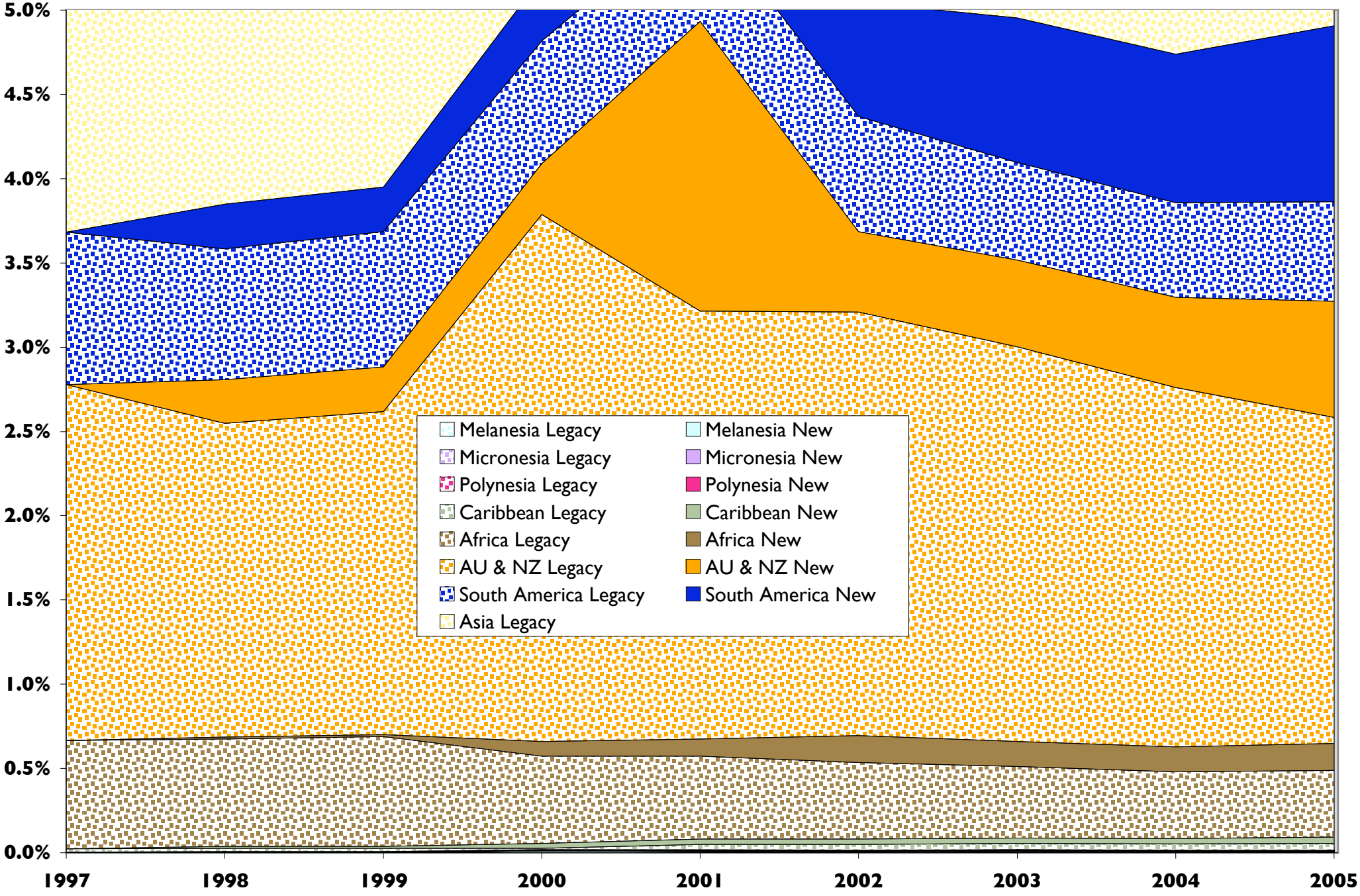

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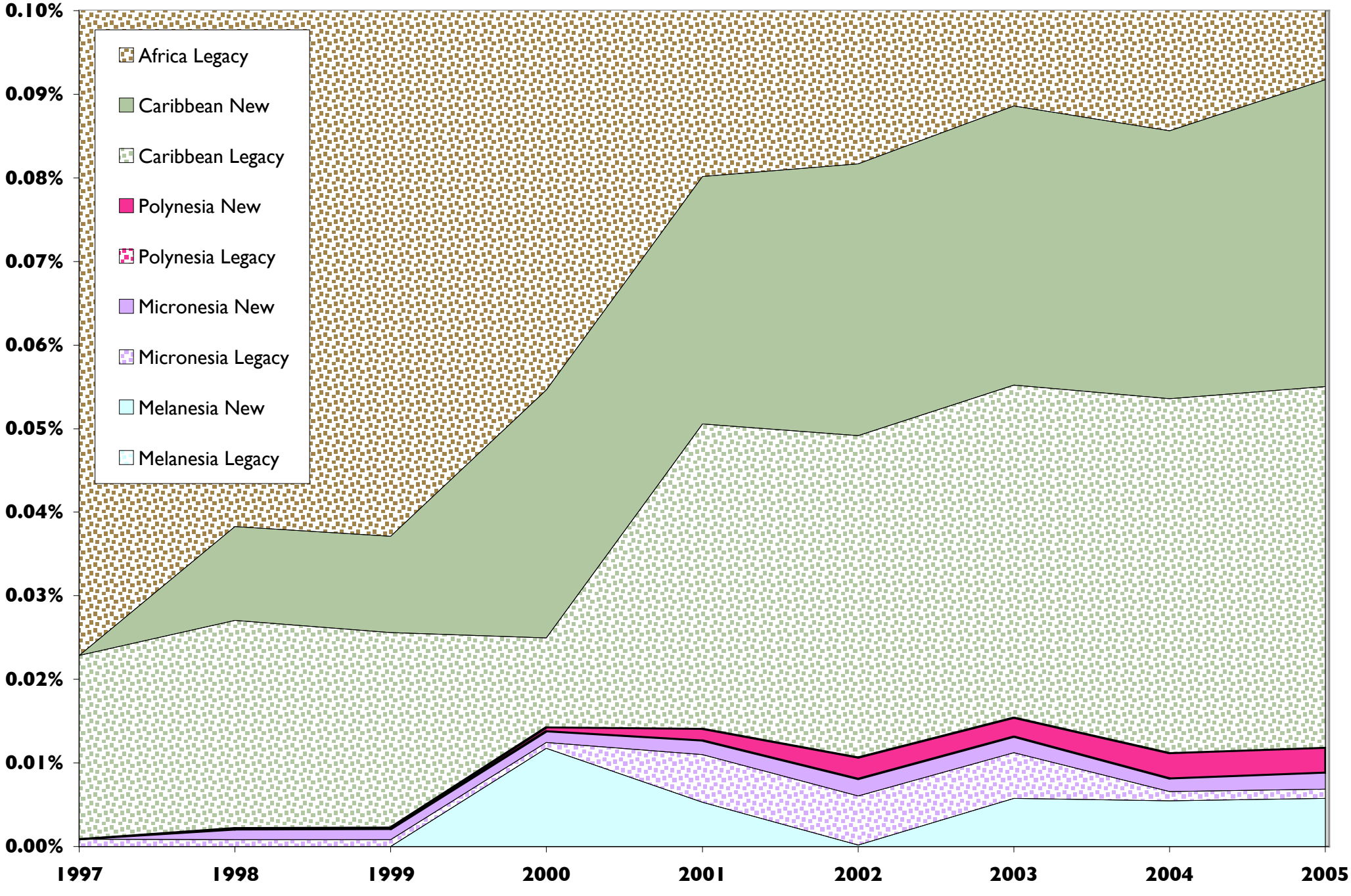
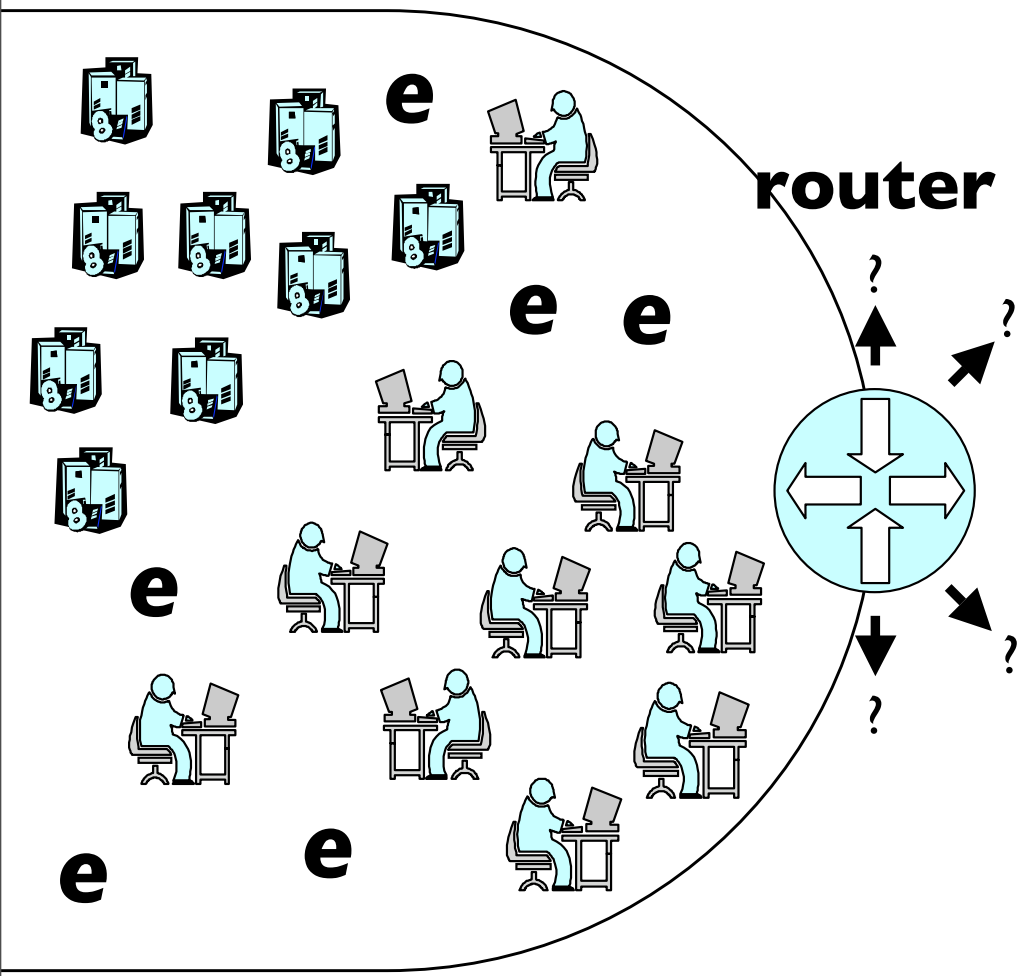


# where to count Internet resources ?



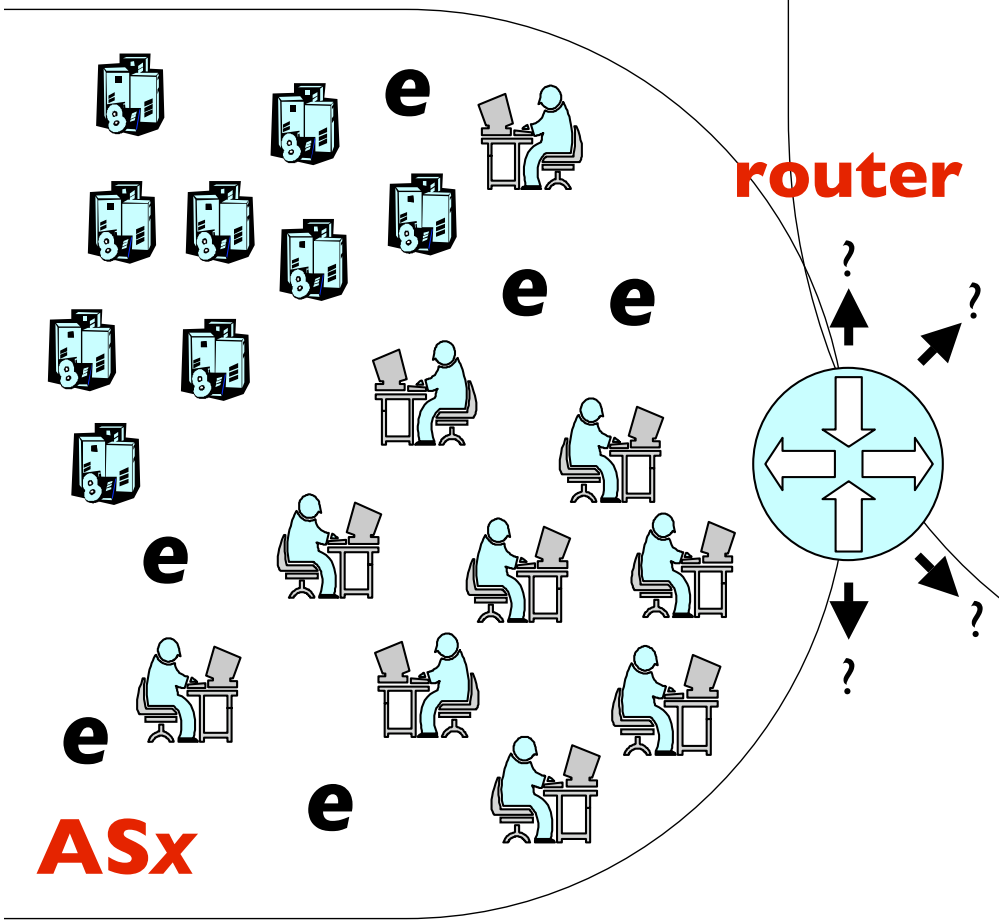

Autonomous System*

each router connected to the Internet maintains a local view of paths leading to every Internet resource

each of those views may vary substantially in almost every possible way -- except one:

**all will share a common view of the domain* of origination for each Internet resource**

# what are Autonomous Systems (ASes)?




hardware, software, and network elements integrated into a unique logical grouping controlled by a specific administrative authority

logically distinct even when physically overlapping; spatial intersection does not guarantee logical interconnection

**sovereign entities of the Internet's logical layer**

**Autonomous System**
**with the unique number *x***

# WoN measurement device

- **Autonomous Systems (ASes)**: sovereign administrative units of the Internet's logical layer
- ASes represent the point of intersection (*origination*) between new users, usage, uses and the Internet, and the locus of accounting for Internet production
- Within an AS, connection terms and traffic flows are designed and dictated by the network operator
- Between ASes, interconnection and traffic flows are subject to bargaining, negotiation, and in

# ASes and network economics

- Costs of running an Autonomous System scale with price of wholesale telecom inputs, which are strongly influenced by competition and regulation
- While scale of operation remains modest, network services are outsourced, and online service provision/growth differentially benefits the encompassing "upstream" AS
- Once service provision requirements reach a level that compares favorably with outsourcing costs, a new AS is born...

# ASes and network economics

- **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 ASes "work" and survive or even grow; others stagnate, disappear, or are assimilated into other ASes. 300 +/- new ASes appear every month, while 100 +/- disappear, (mostly) forever (Uijterwaal, Wilhelm)
- Familiar-looking industrial patterns

# ASes and network economics

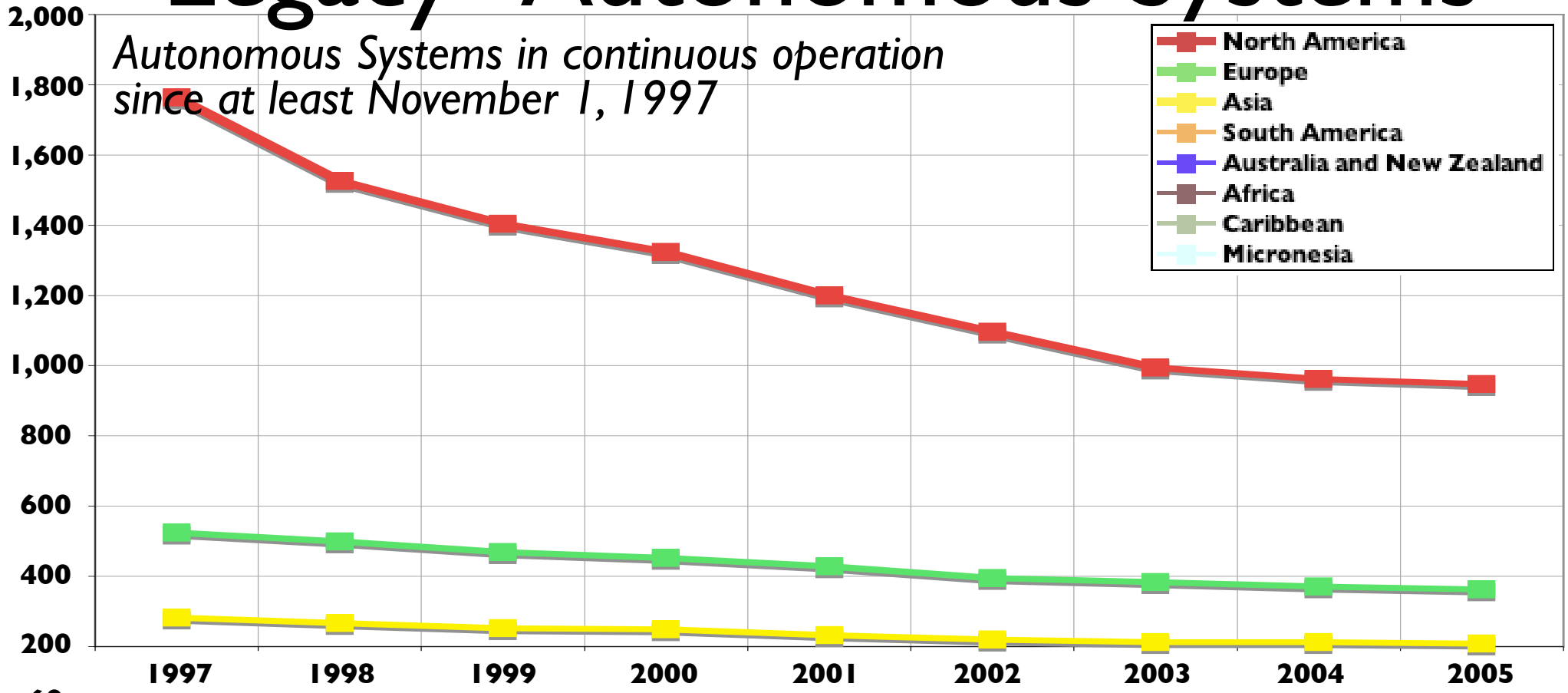
- **Macro-dynamics**: AS break-even point varies relative to cost of critical inputs for running an AS -- infrastructure, interconnection etc. -- many of which are determined at national level.

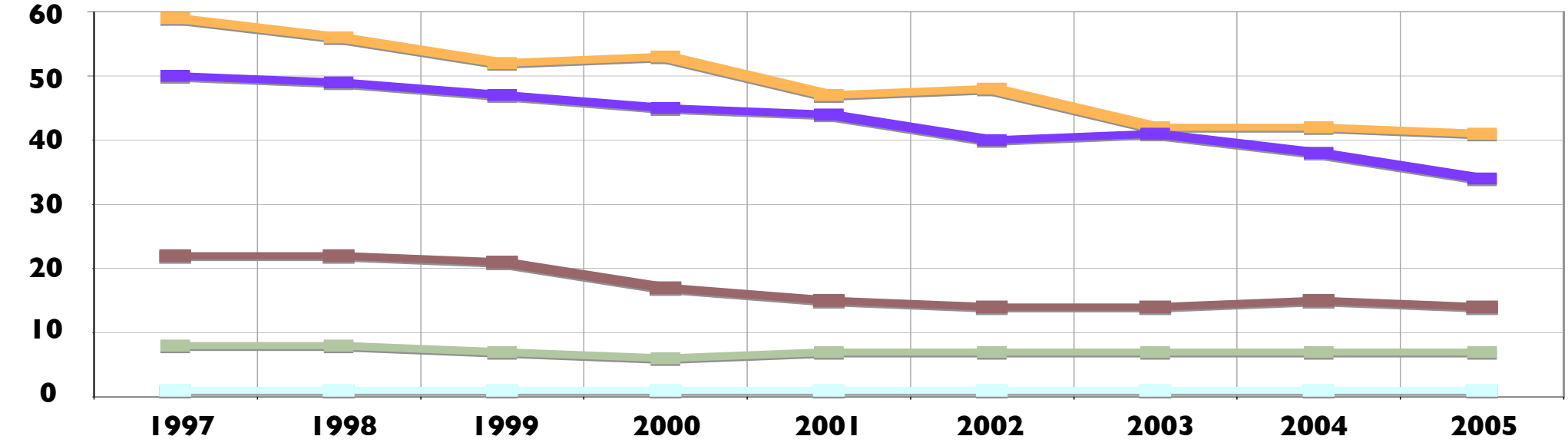
- Some environments may be attractive for Internet production, but inhospitable to new independent network creation, resulting in few, large ASes -- should Internet stakeholders care?

- In some cases, better networking terms may be available elsewhere, leading to "tromboning", offshoring and/or wholesale cross-border outsourcing, allof which further exacerbate divergent growth rates... again, should this matter to anyone?

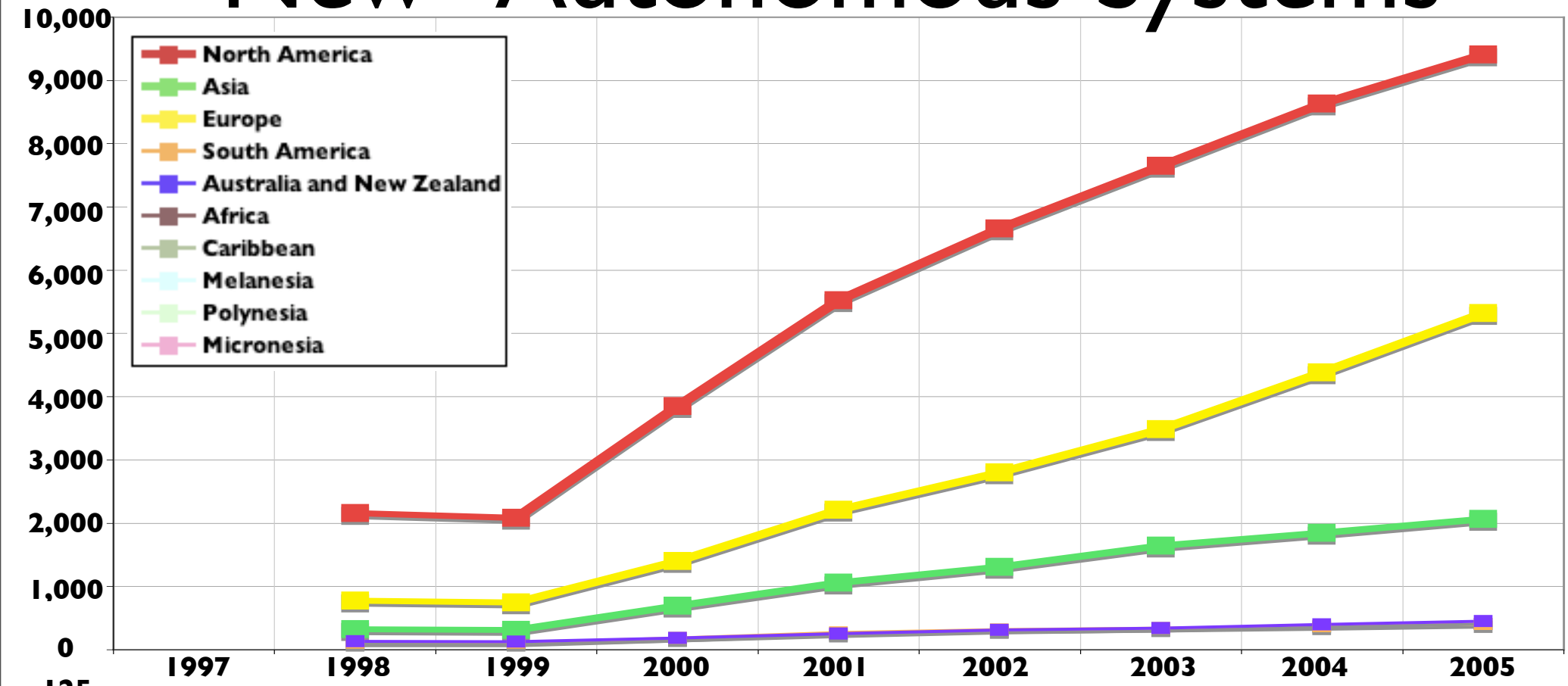
# “Legacy” Autonomous Systems

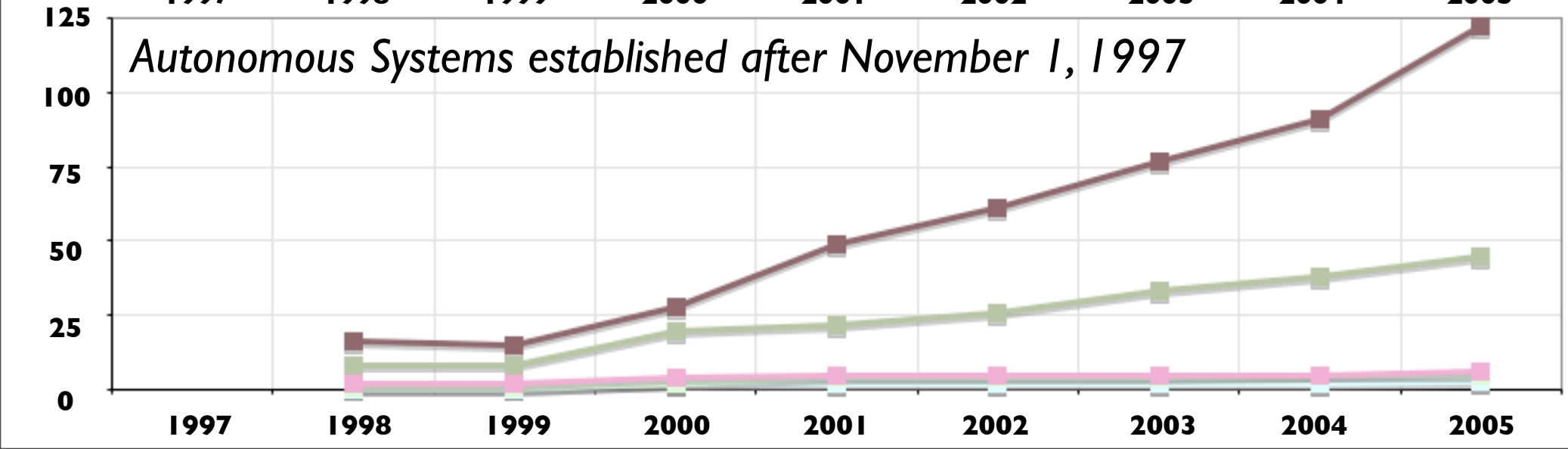
*Autonomous Systems in continuous operation since at least November 1, 1997*



# "New" Autonomous Systems



# WoN summary measures

- **National network economies (NNEs)**
- National markets, facilities owners, and regulatory power create vertical silos that influence or directly determine many factors relevant to Internet service provision
- Defined as the sum of Internet resources originated by ASes with a common country code, regardless of the geographic location of the corresponding users, usage, uses
- Equivalent to consolidated national reporting for ISPs and enterprise networks regardless of (domestic, multinational) scope of operations

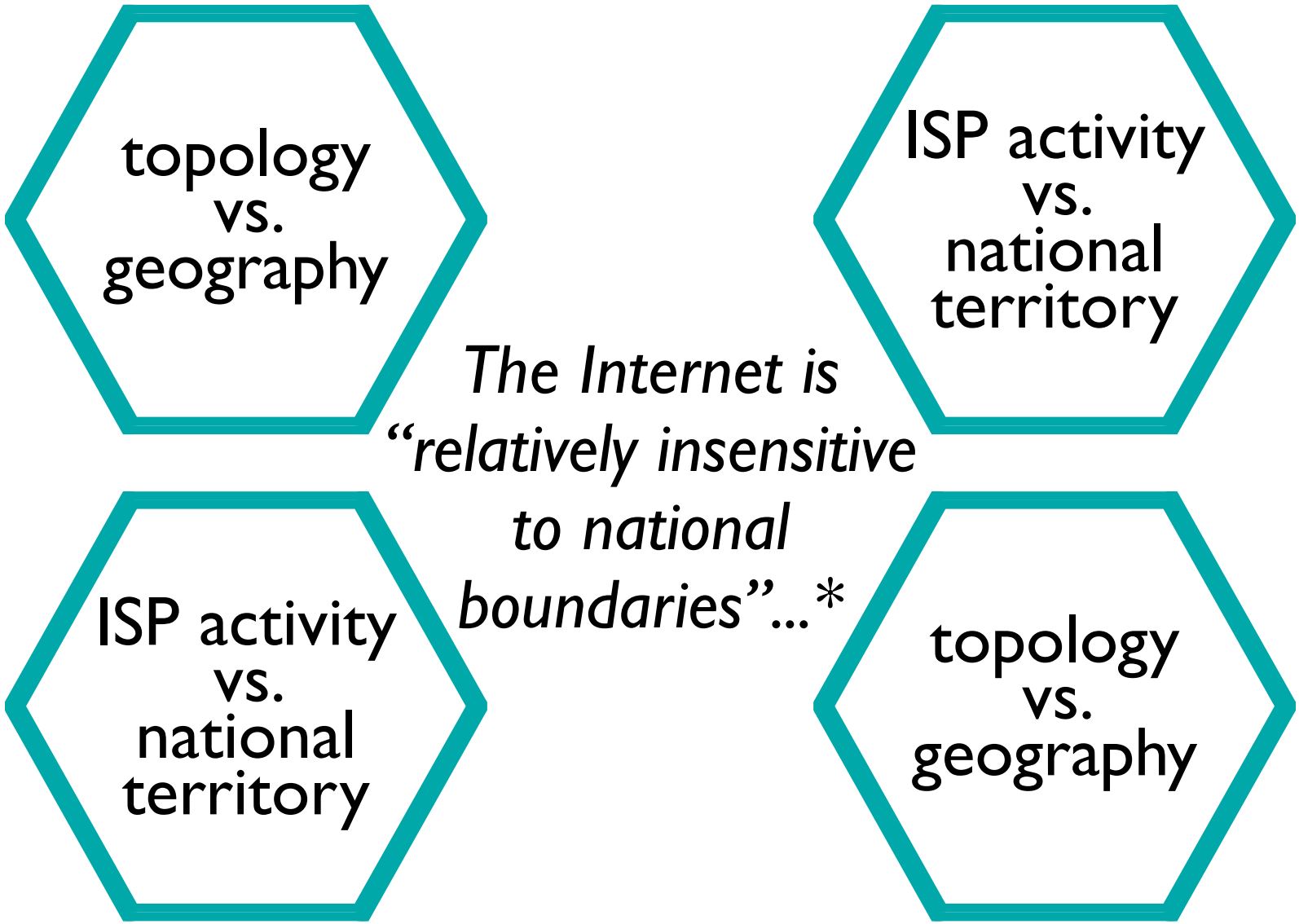
# WoN analytical framework

National Network Economies (NNEs)


"last mile"
international
infrastructure,
connectivity

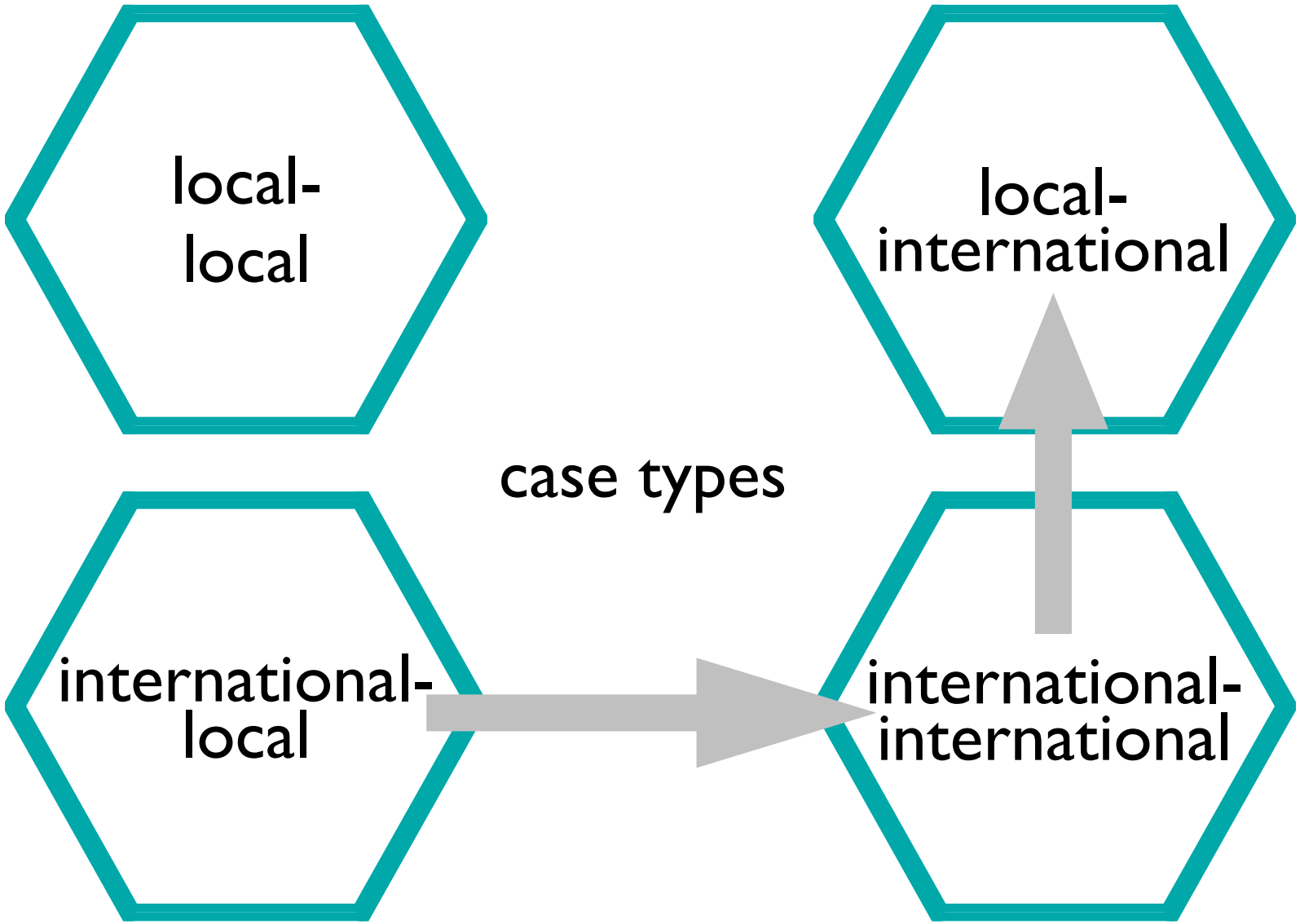
"first mile"
domestic access
infrastructure,
connectivity

# WoN analytical framework




*Vint Cerf, foreword to *Internet Governance: A Primer*

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



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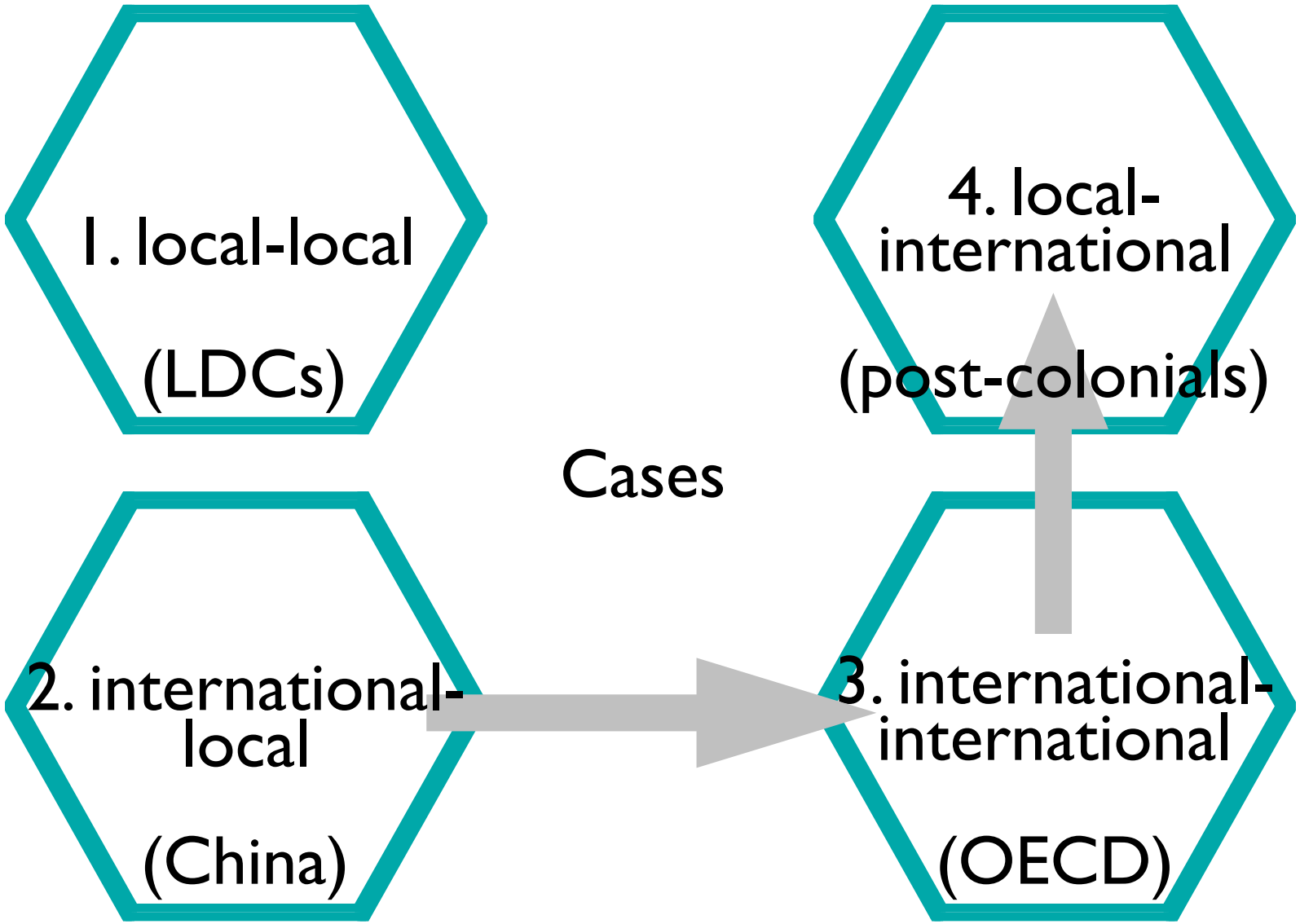


# supplementary WoN metrics

- **Adjacencies**: unique AS-to-AS relationships, representing established commercial relationships for fee-based or settlement-free traffic exchange
- **Domestic adjacencies**: relationship linking two ASes with the same country code, regardless of actual location(s) of traffic exchange; visibility may decay with distance from point of observation
- **International adjacencies**: relationship linking two ASes with different country codes; visibility likely to remain high despite distance from point of observation

# WoN benchmarks

- **Telecommunications facilities measures**: main lines (telephone subscribers), cable television subscribers
- **Economic measures**: GDP, per-capita GDP
- **Demographic measures**: population, population density
- **Geographic measures**: continent, direct access to terrestrial/submarine optical capacity
- **Temporal / historical measures**: number of years online

# Summary: core WoN metric features

- **Summarizes many dimensions of the Internet's importance that are not well represented in current measurements:**
  - **Users/consumers *and* enterprises/institutions**

    Individual education/empowerment and enhanced economic productivity are among the core public interests captured by Internet production accounting
  - **Internet access/eyeballs *and* content/services**

    A healthy regional network economy will encompass both users and content, but earlier measurement approaches (and the policies that they have spawned) often emphasized one of these sectors at the expense of the other
  - **Quantitative *and* qualitative dimensions**

    Internet production accounting captures major qualitative differences across "users" and "content" (e.g., low utilization metered dial-up vs. unmetered, always-on broadband, etc.)

# Summary: core WoN metric features

- Public accessibility
- Multiple, independent, continuous time series archives
- Consistent global scope view (origination)
- AS unit of measurement provides conceptual linkage between physical and logical network phenomena, issues, policies
- AS unit of measurement provides conceptual linkage between micro- and macro-level economic phenomena
- Most transparent, complete, accurate identifying records among all current Internet identifiers
- Now used by OECD for policy analysis

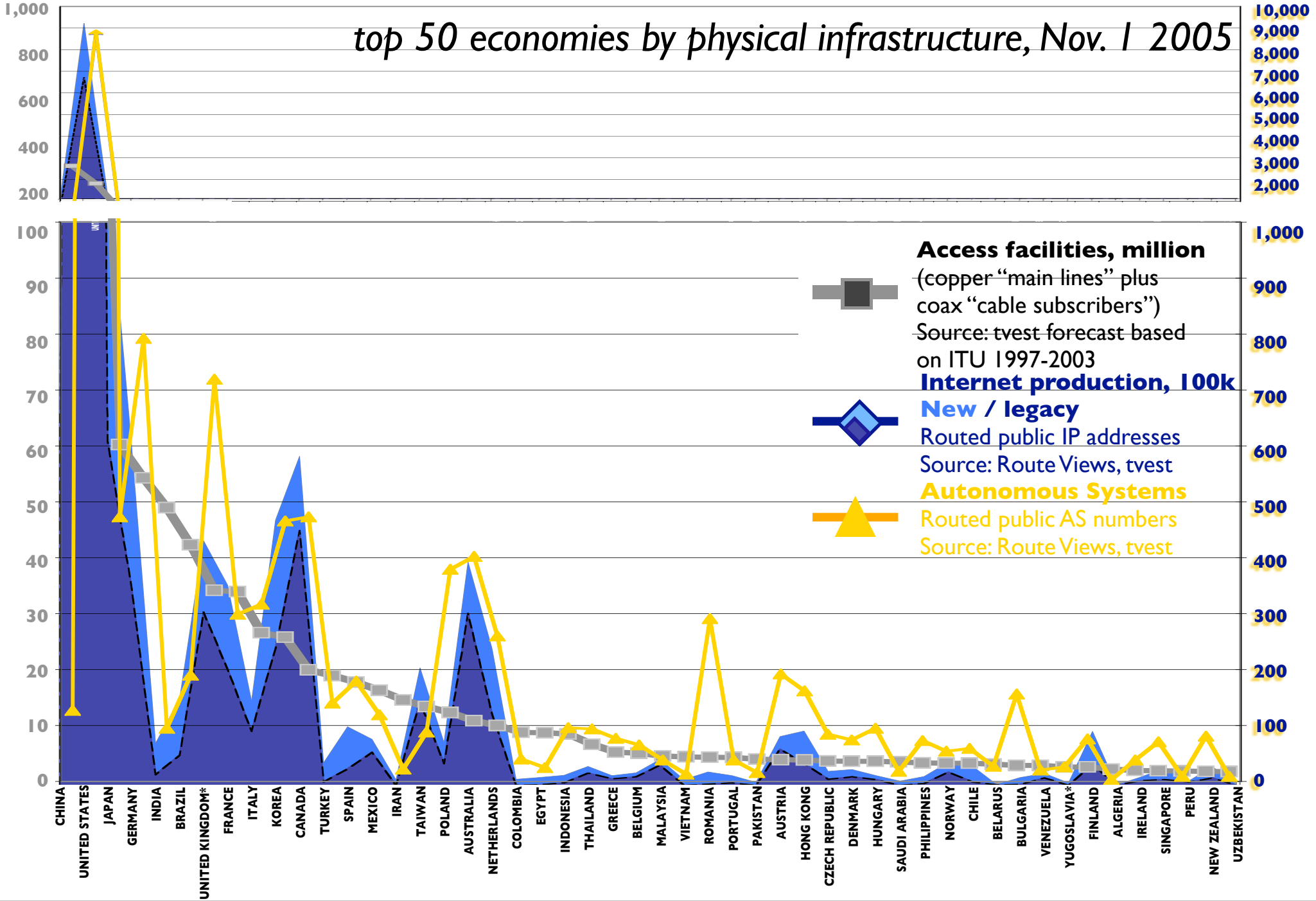
*Internet Traffic Exchange: Market developments and Measurement of Growth* (2006)

# Summary: core WoN metric caveats

- Historical variations in IP address allocation, efficiency
- Scale-related variations IP address assignment, efficiency
- Historical change (growth) in measurement apparatus
- Ambiguous semantics of identifying records
- Methodological bias in favor of diversity
- Methodological bias in favor of public interoperability
- Challenges of identifying multi-AS Autonomous Routing Domains (ARDs)
- Validity of supplemental metrics beyond IP origination (e.g., interconnection accounting) may be limited by point-of-measurement bias

# Evaluating the Wealth of Networks

# how much Internet production?



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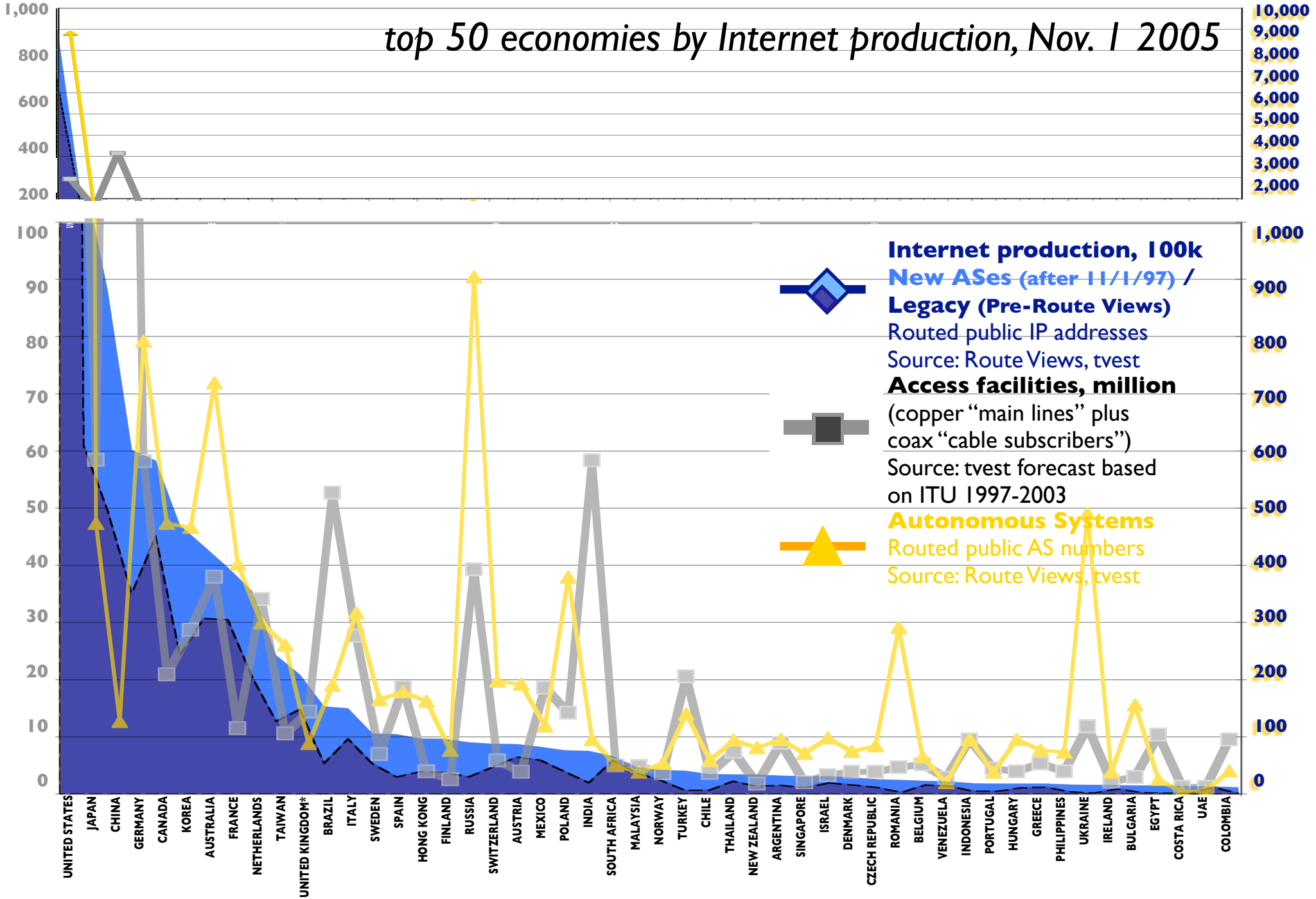

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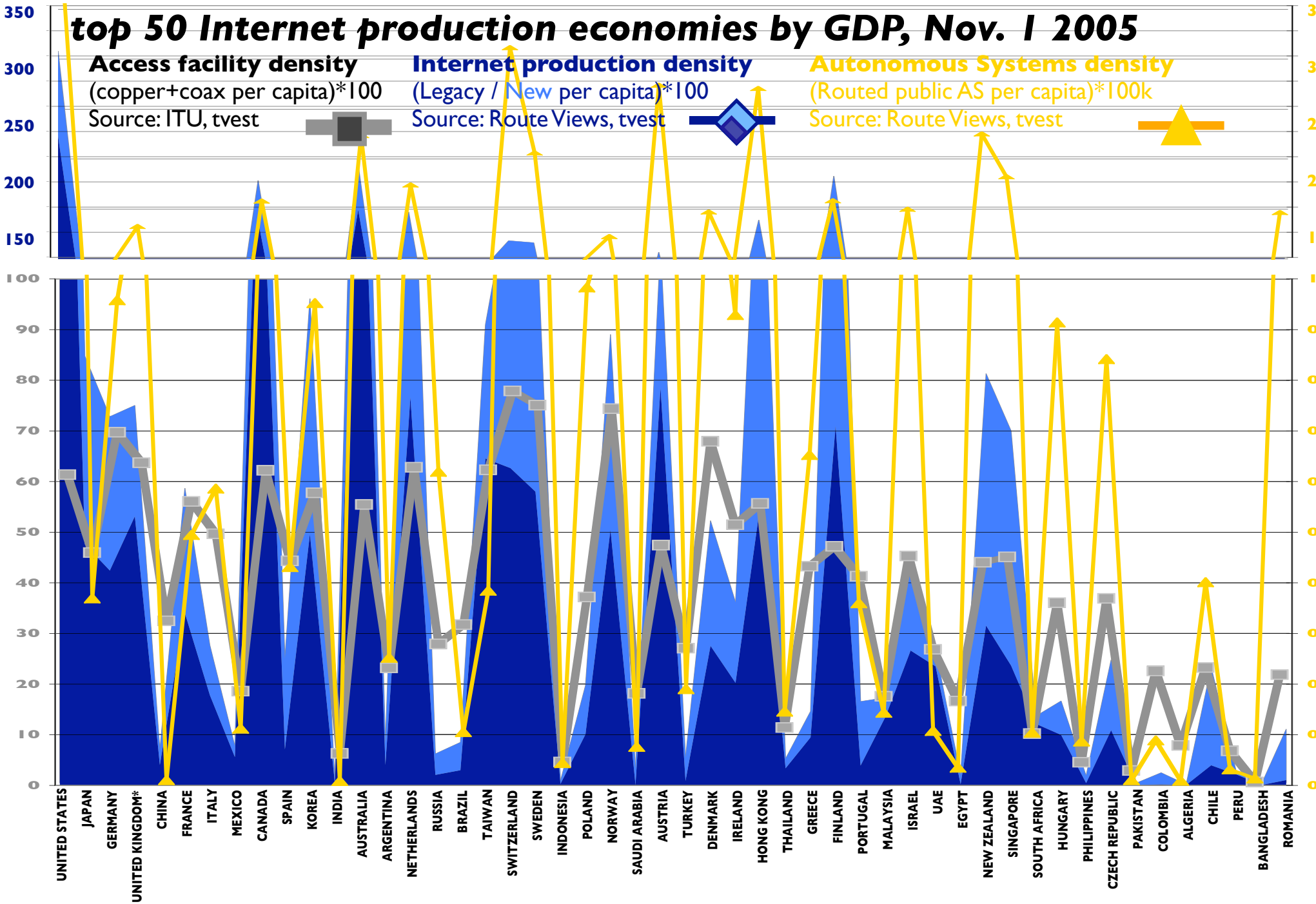

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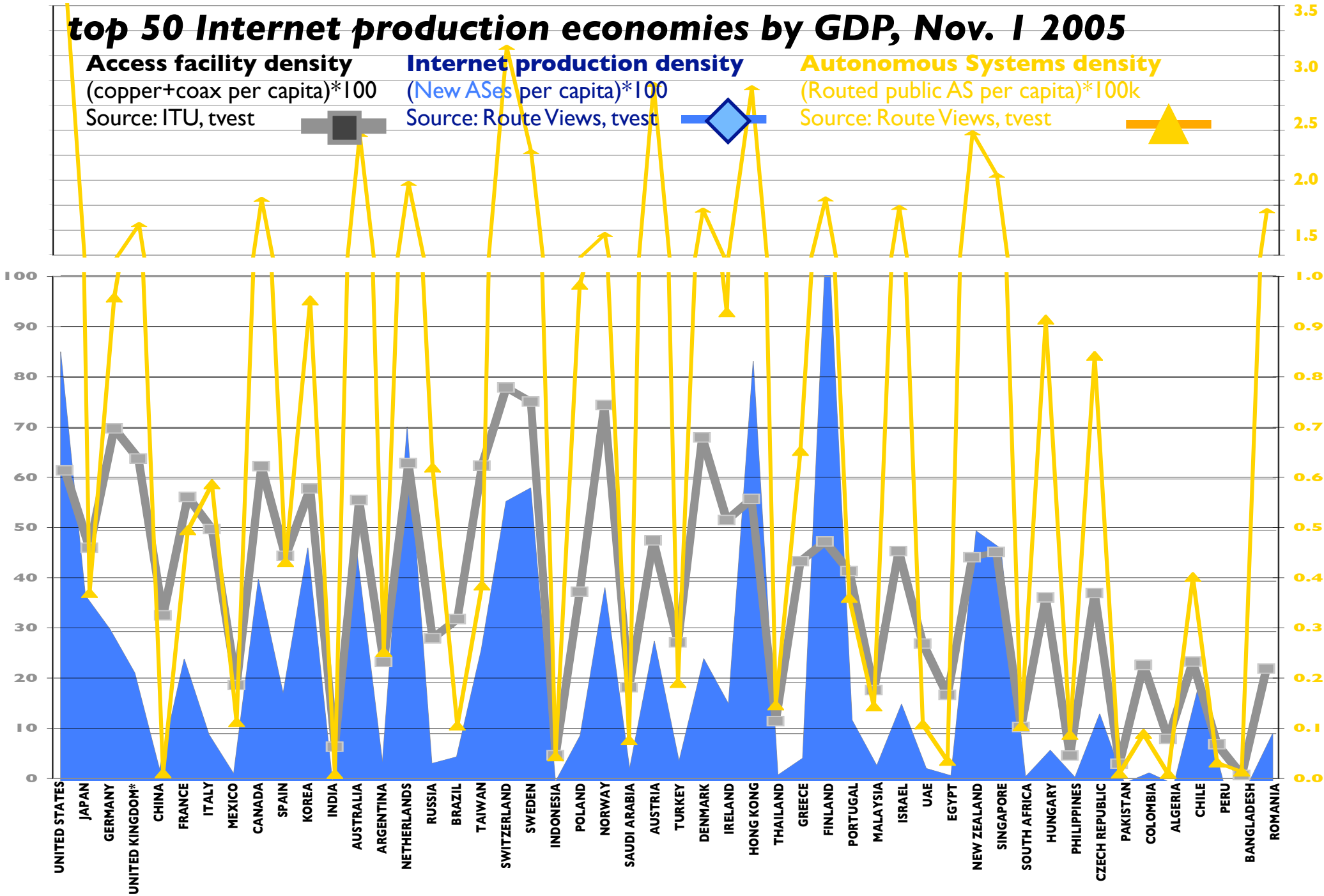


# Test (x): market structure & Internet development, OECD economies

# measuring market structure

## 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

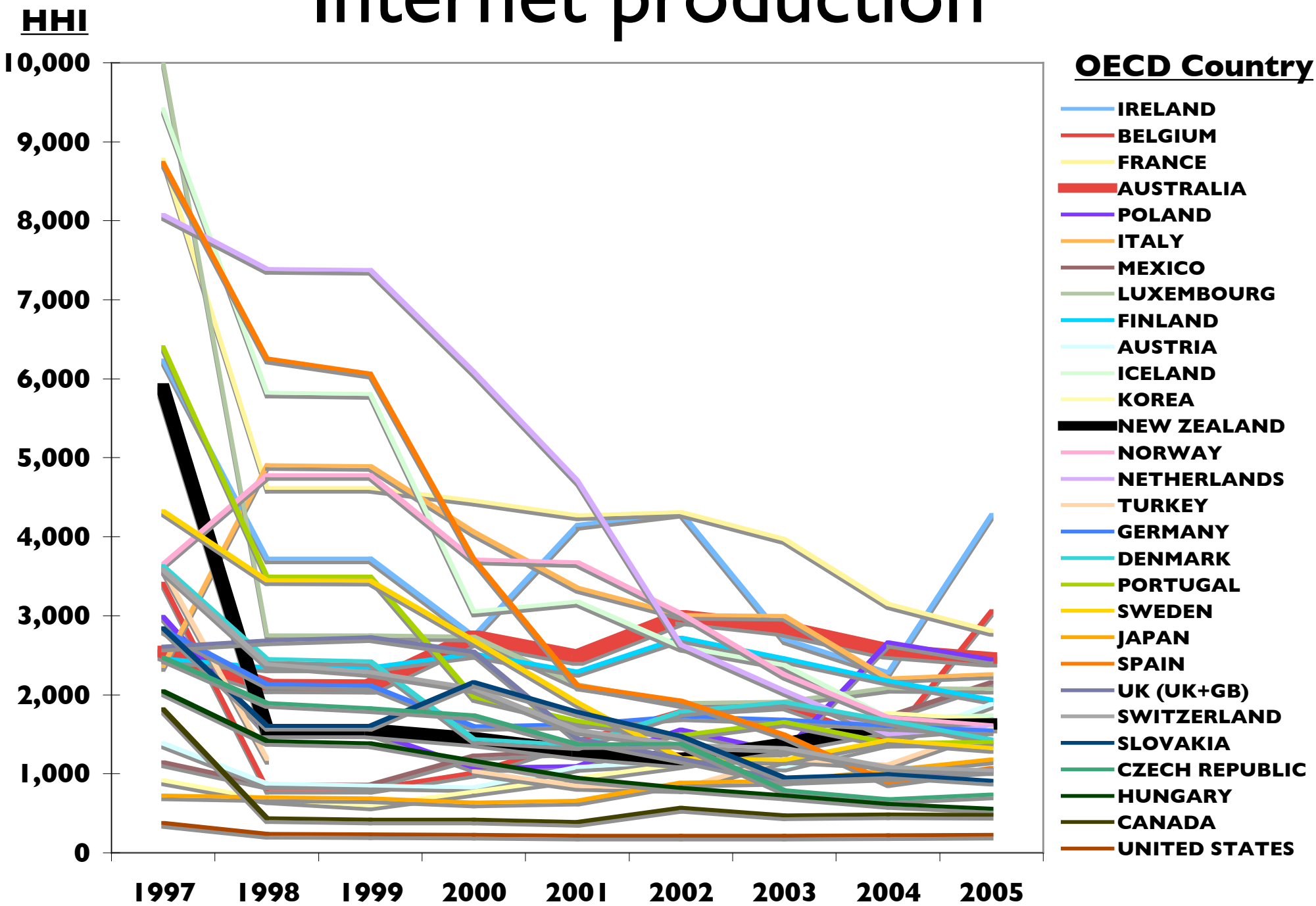
| Market Structure & Interpretation | Current HHI | Dynamic Change |
|---|---|---|
| Conditions/environments that are less likely to have anti-competitive effects. | <1000<br>1000-1800<br>>1800 | Any<br><100<br><50 |
| Conditions that "may raise significant competitive concerns." | 1000-1800<br>>1800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

# measuring market structure

## The Herfindahl-Hirschman Index (HHI)

- Firms == routed Autonomous Systems (ASes) grouped by whois country code of AS Number(s) allocation
- Industry == "national Internet production" == sum of unique public IP addresses originated by ASes with country code of AS Number(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

# changing market structures: Internet production



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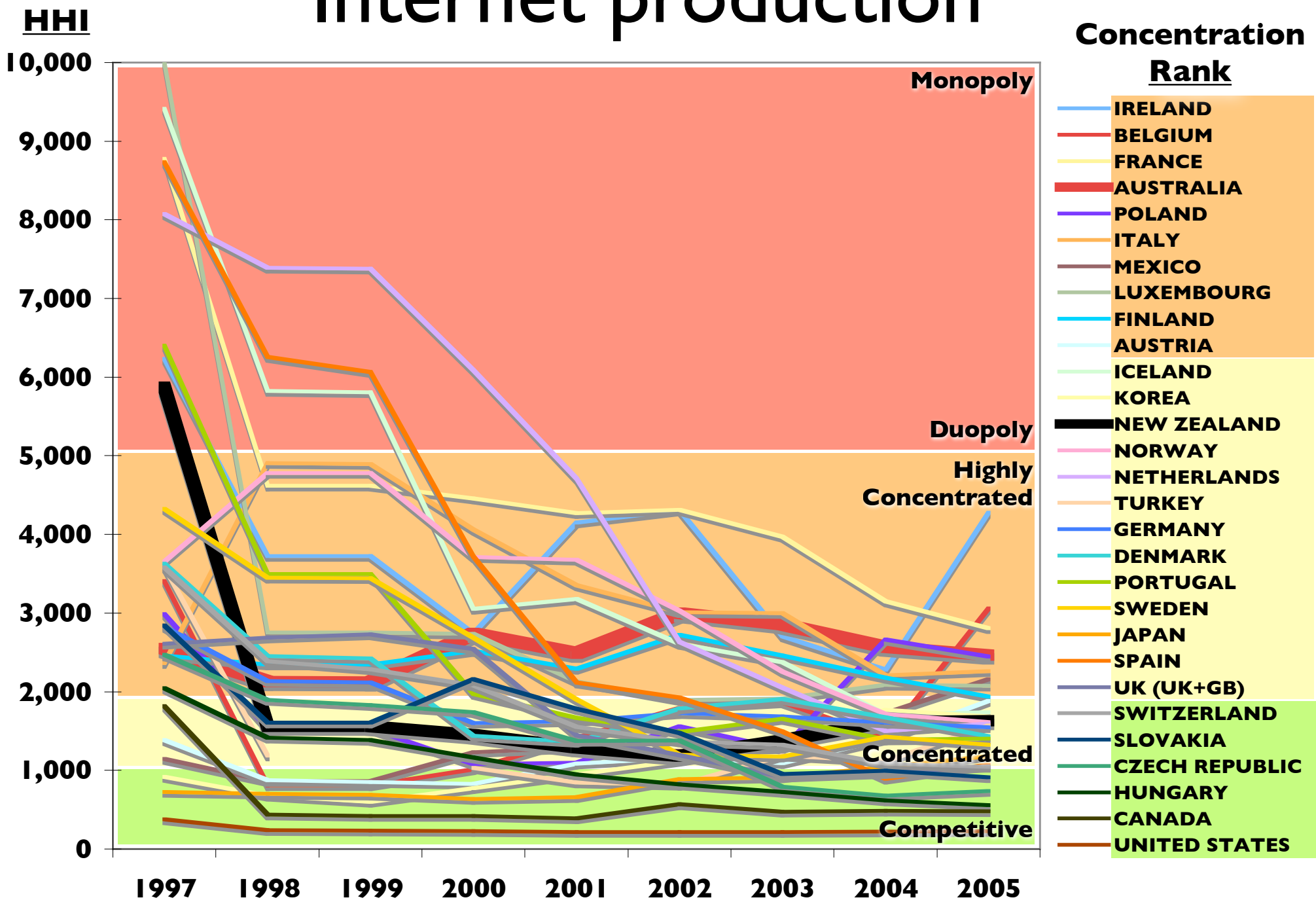
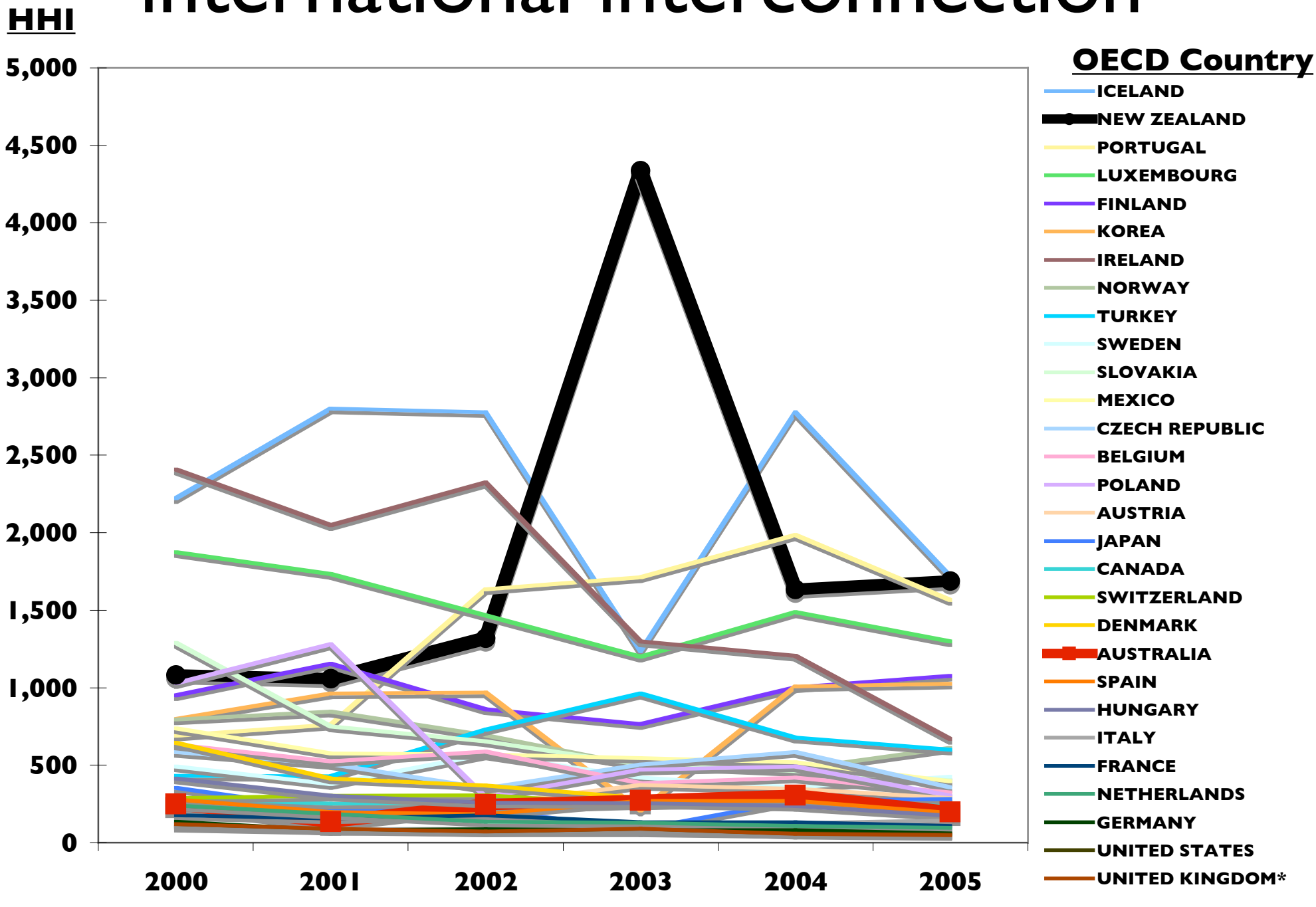


# changing market structures: international interconnection



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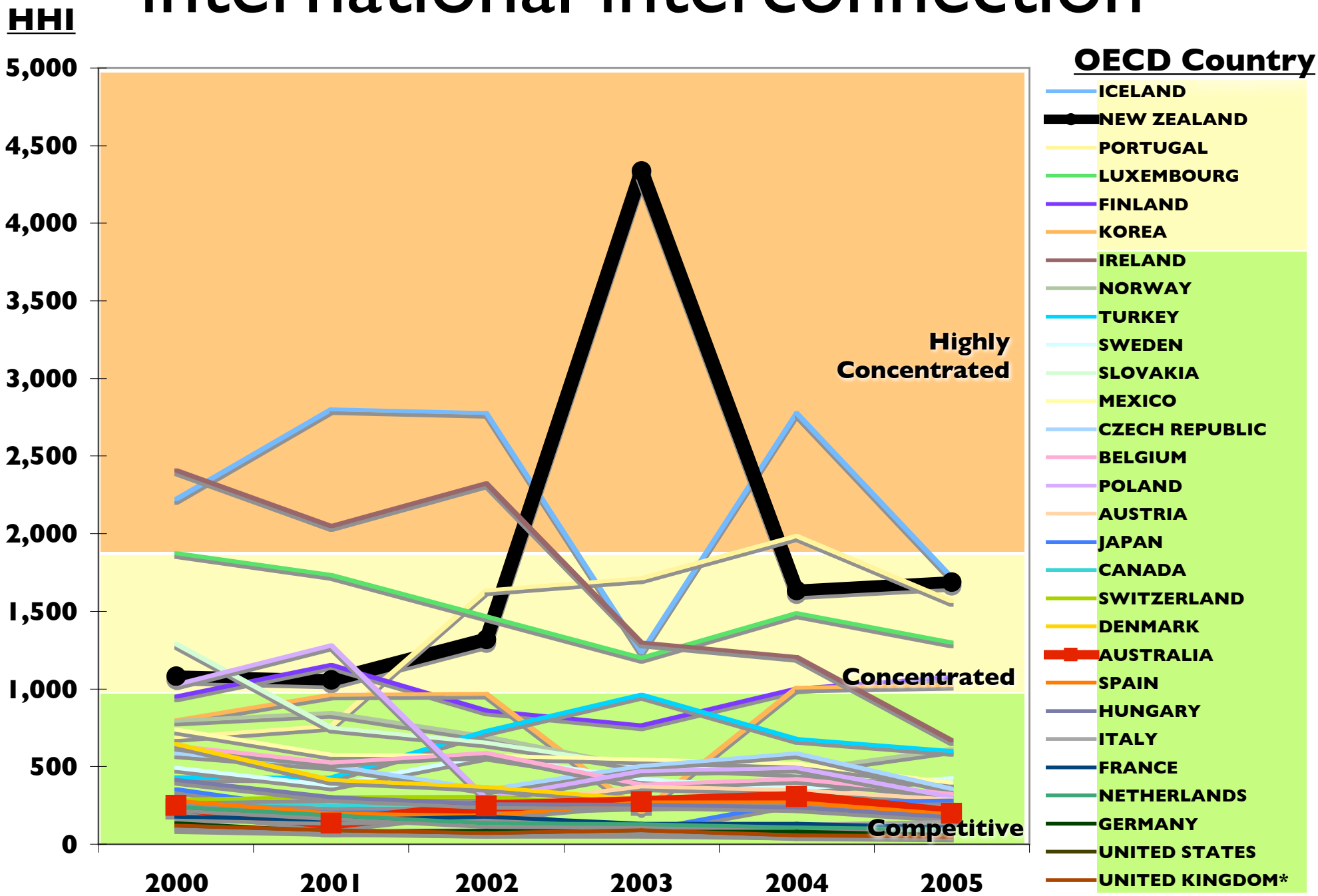

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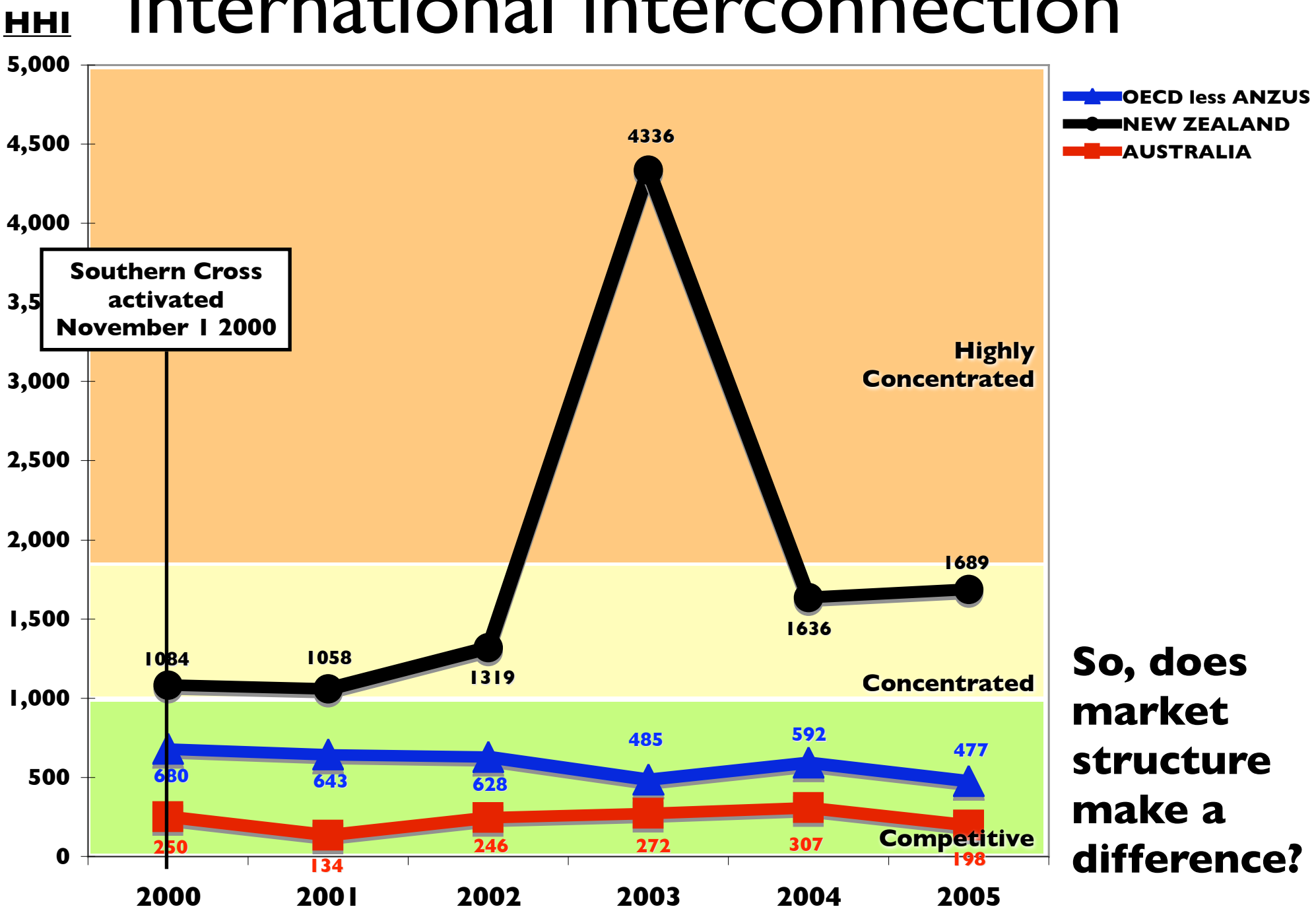
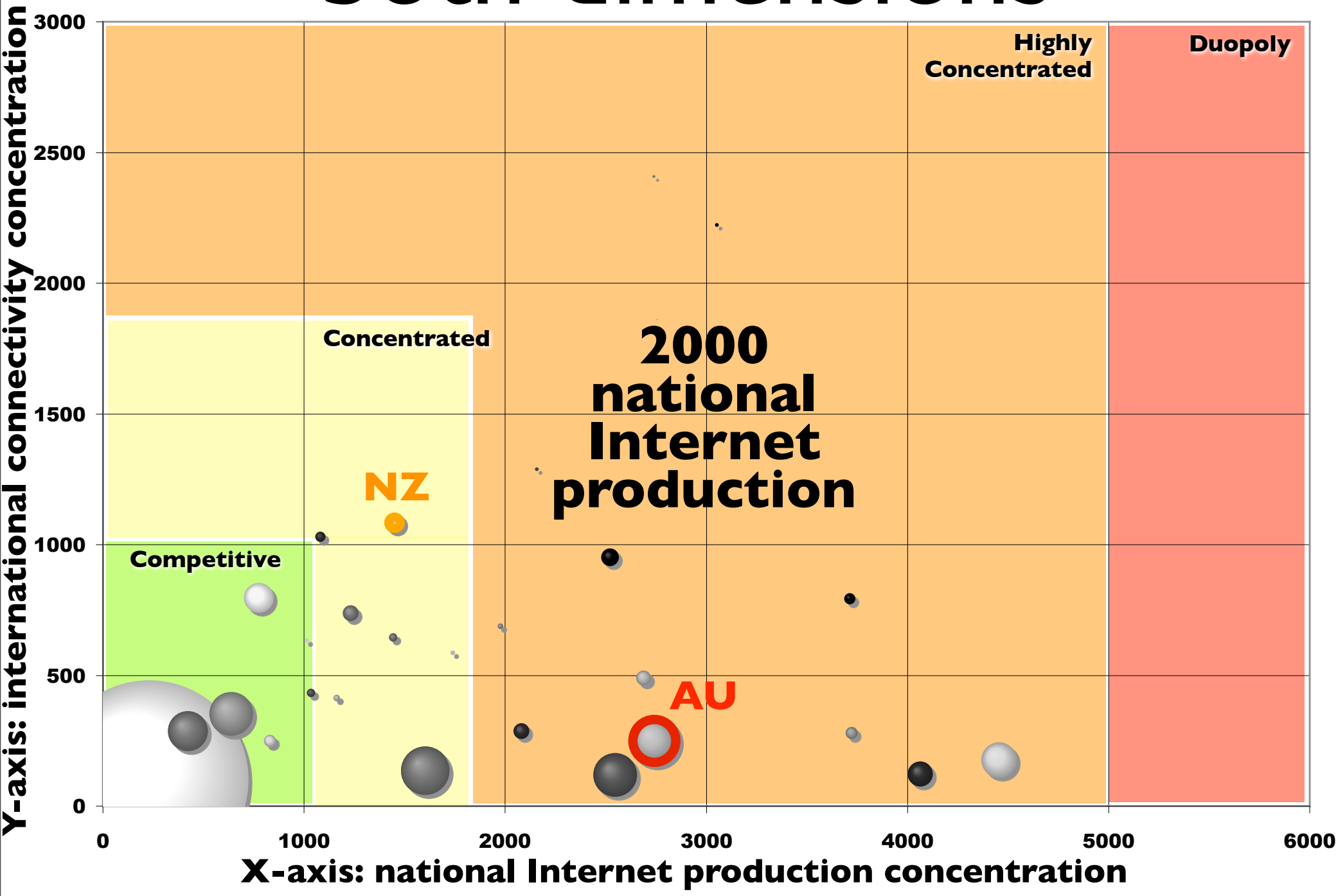



**So, does market structure make a difference?**

# both dimensions



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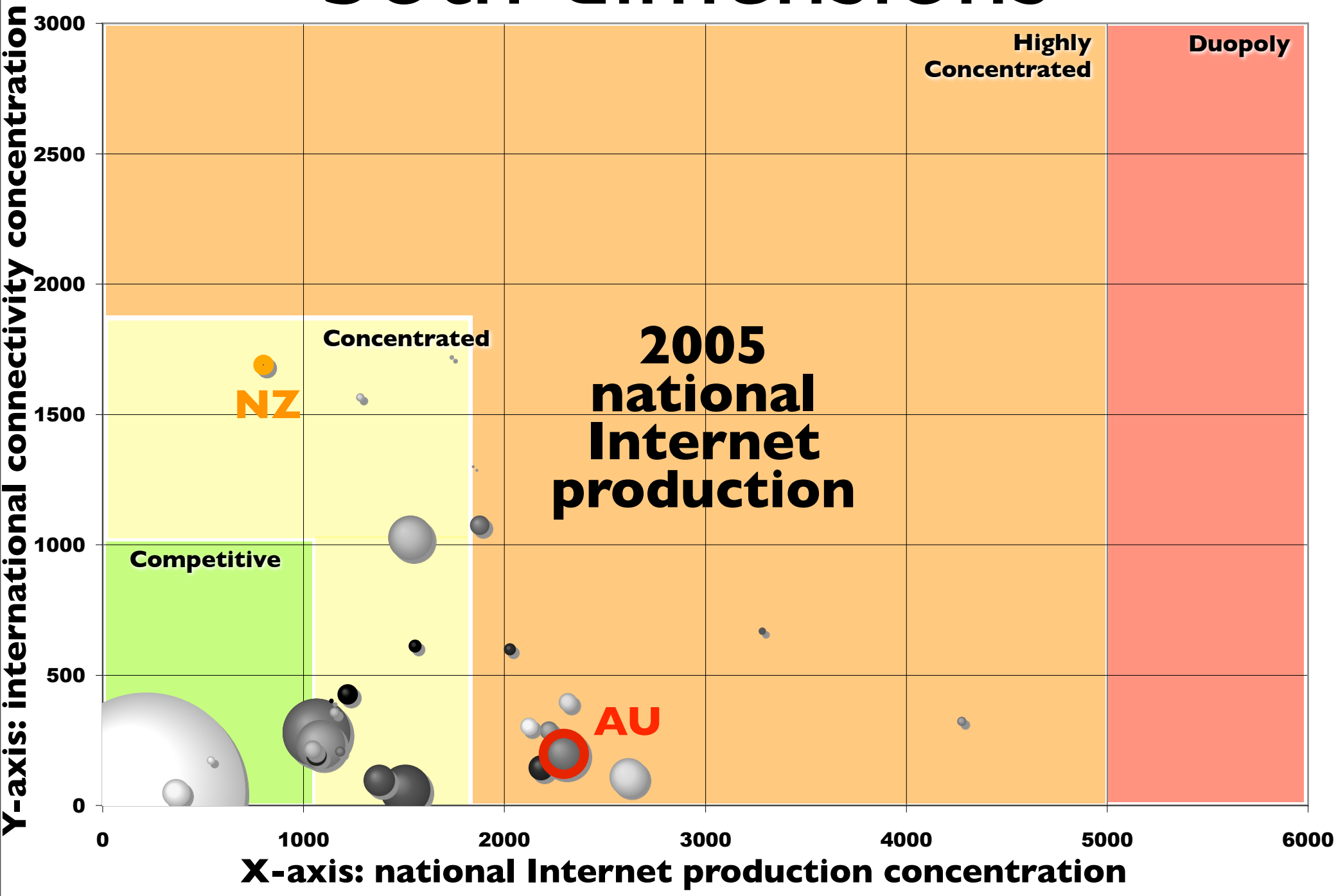
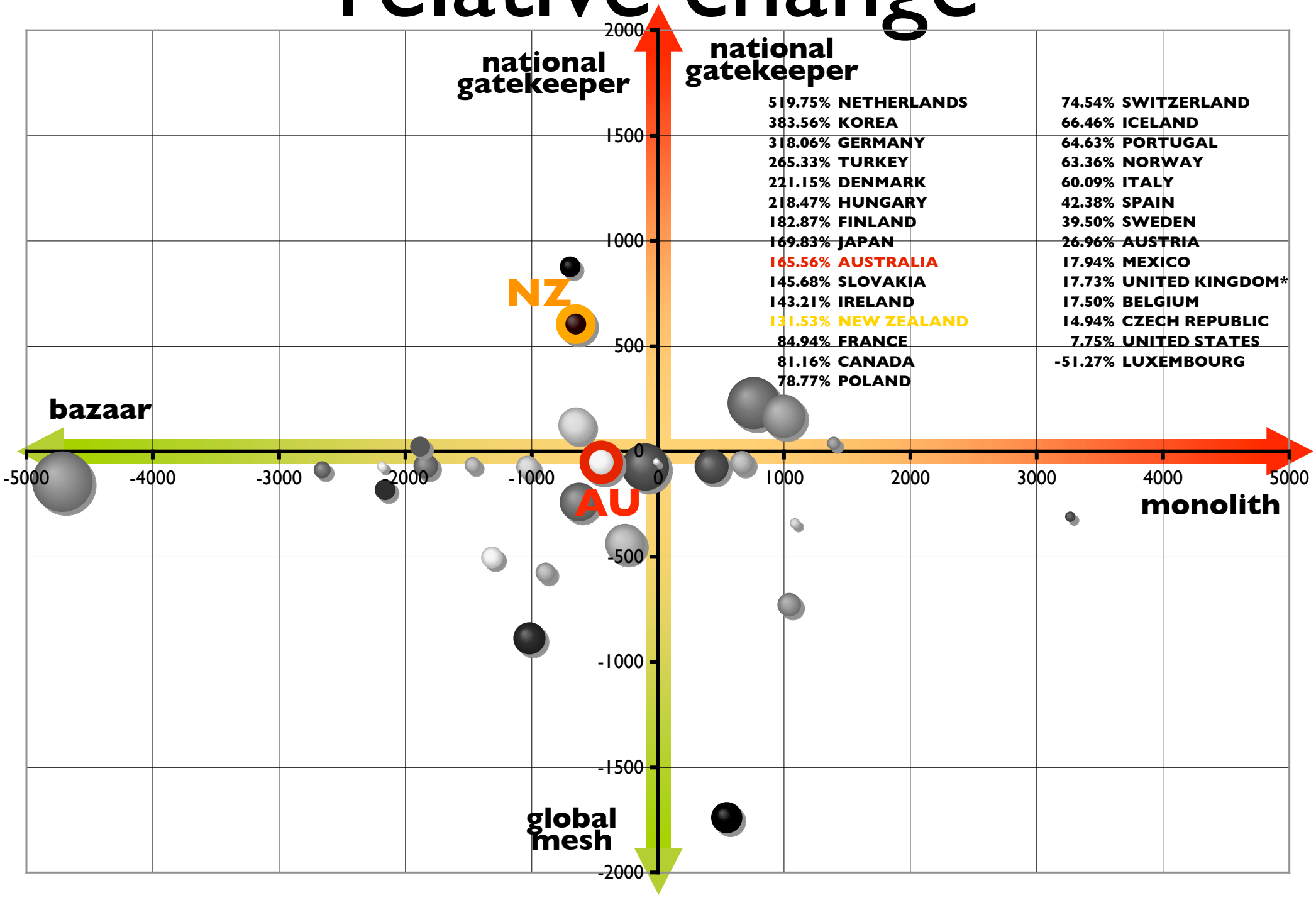
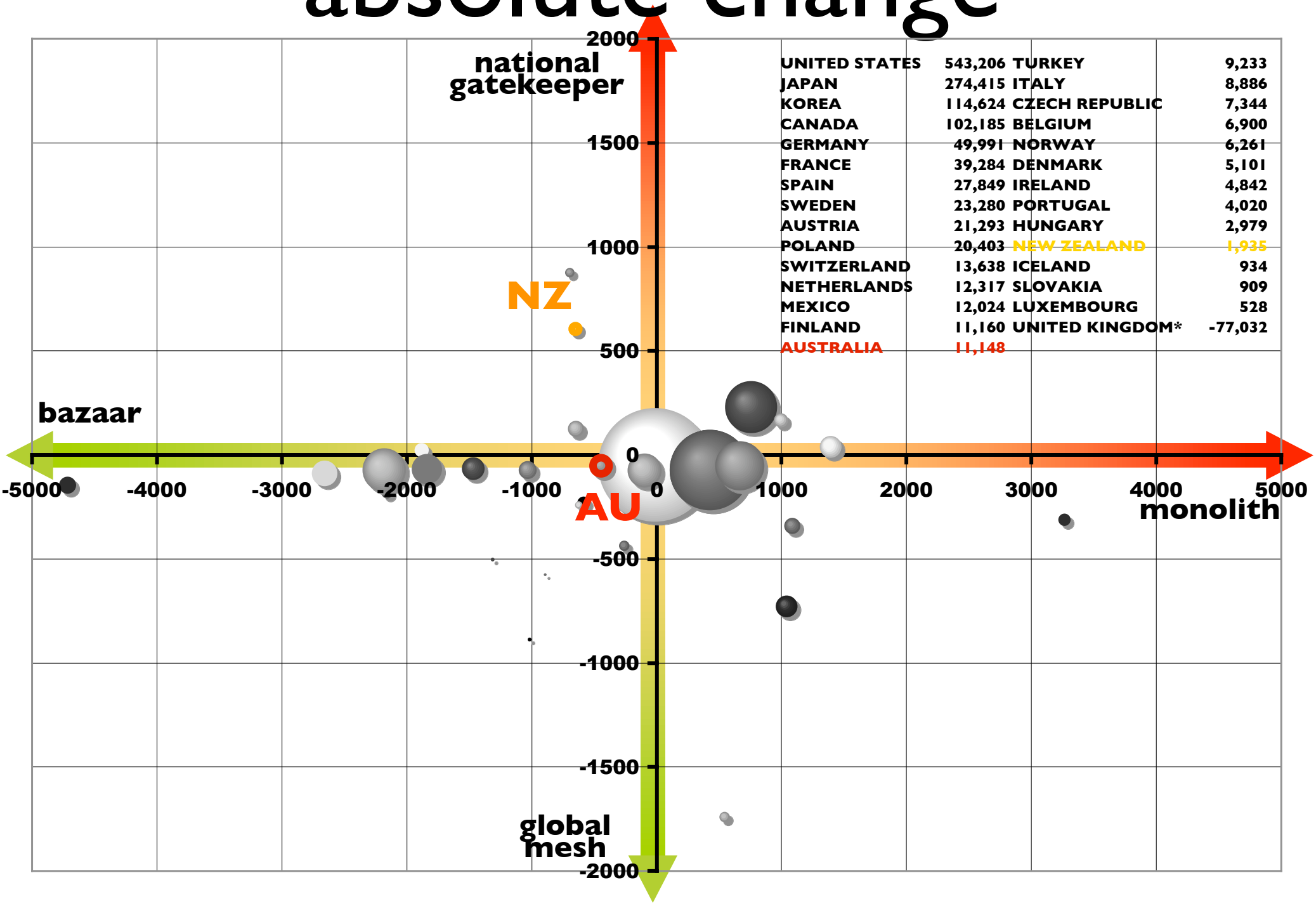


# relative change

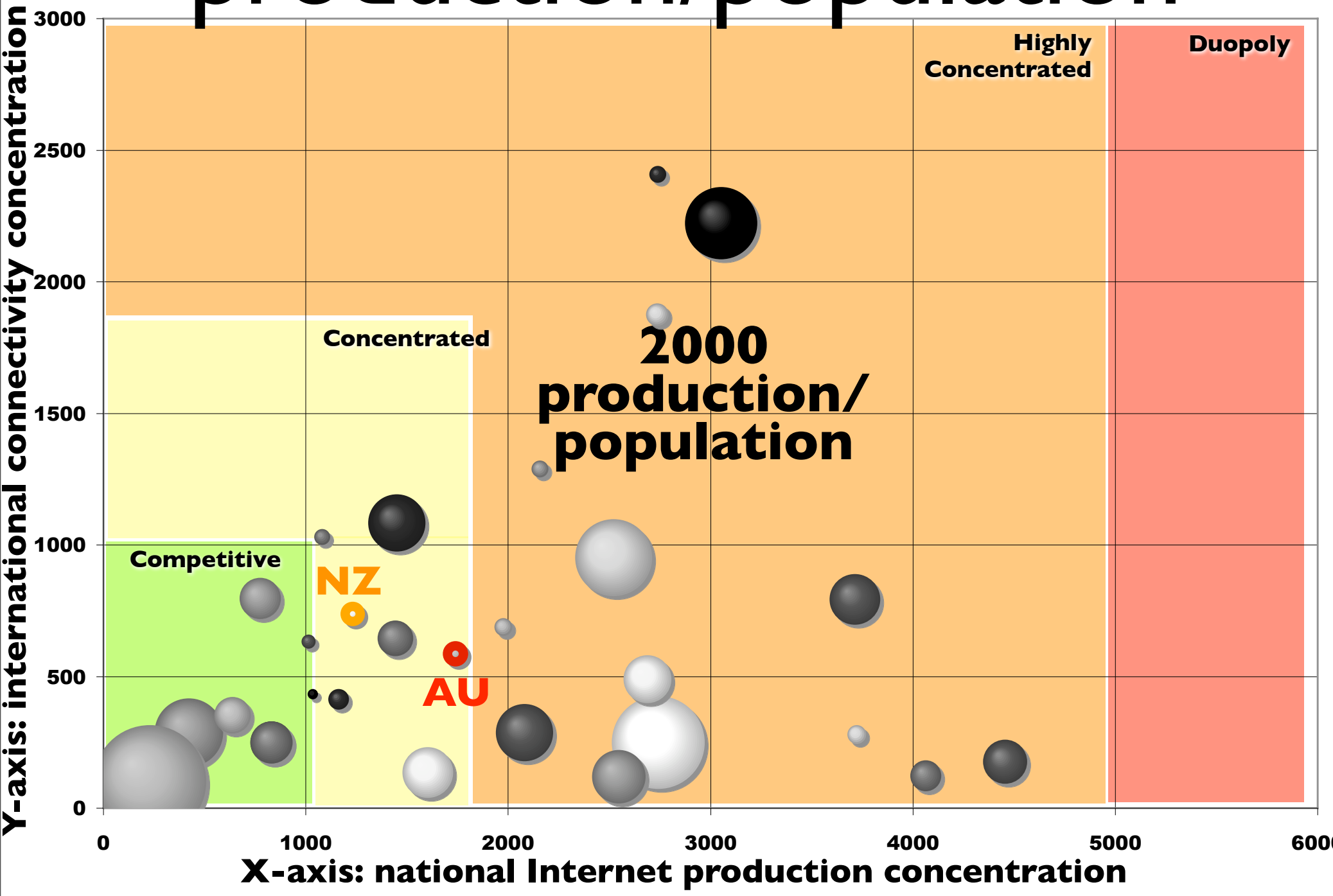


# absolute change




| | | | |
|---|---|---|---|
| UNITED STATES | 543,206 | TURKEY | 9,233 |
| JAPAN | 274,415 | ITALY | 8,886 |
| KOREA | 114,624 | CZECH REPUBLIC | 7,344 |
| CANADA | 102,185 | BELGIUM | 6,900 |
| GERMANY | 49,991 | NORWAY | 6,261 |
| FRANCE | 39,284 | DENMARK | 5,101 |
| SPAIN | 27,849 | IRELAND | 4,842 |
| SWEDEN | 23,280 | PORTUGAL | 4,020 |
| AUSTRIA | 21,293 | HUNGARY | 2,979 |
| POLAND | 20,403 | NEW ZEALAND | 1,935 |
| SWITZERLAND | 13,638 | ICELAND | 934 |
| NETHERLANDS | 12,317 | SLOVAKIA | 909 |
| MEXICO | 12,024 | LUXEMBOURG | 528 |
| FINLAND | 11,160 | UNITED KINGDOM* | -77,032 |
| AUSTRALIA | 11,148 | | |

# production/population



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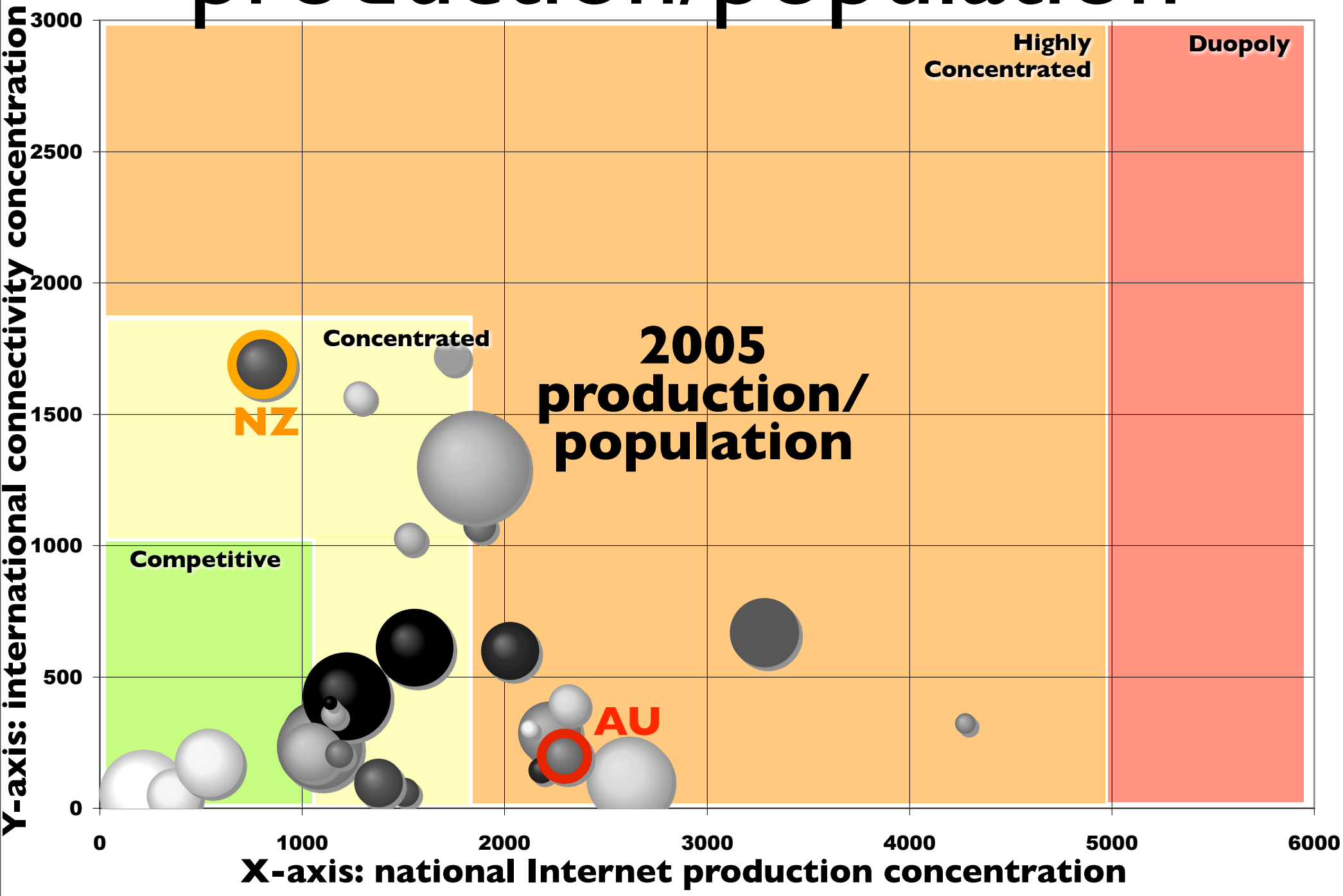
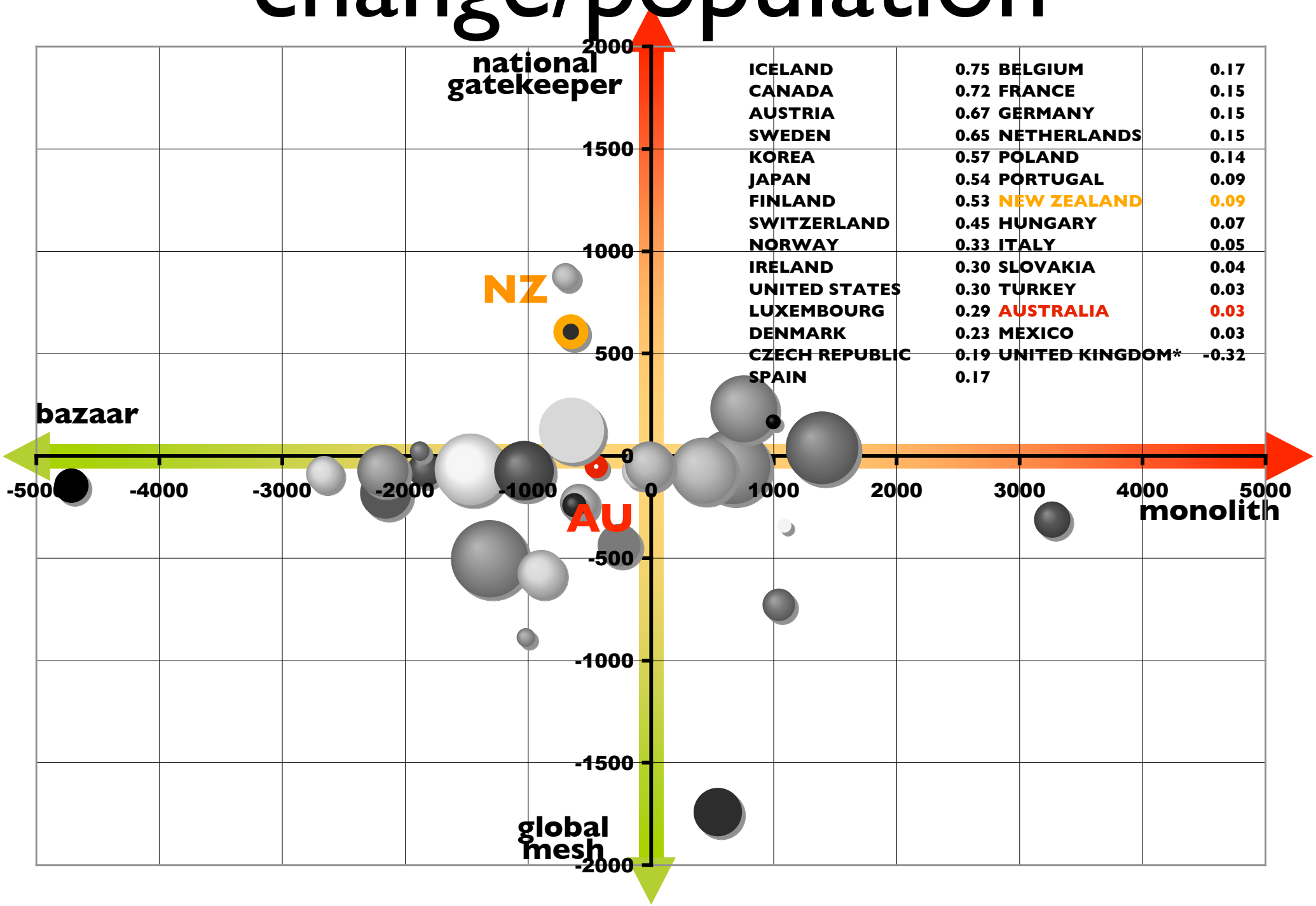
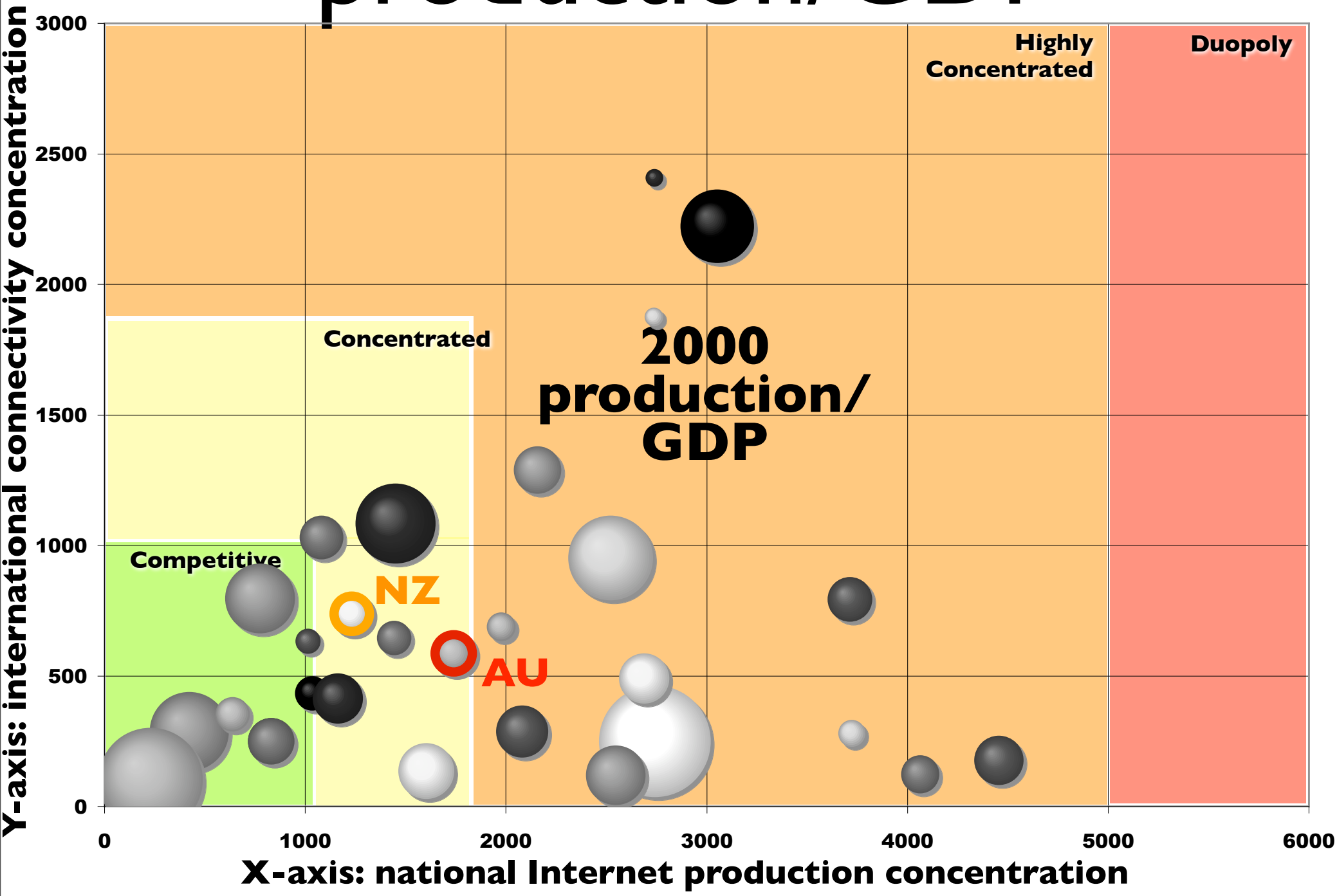


# change/population

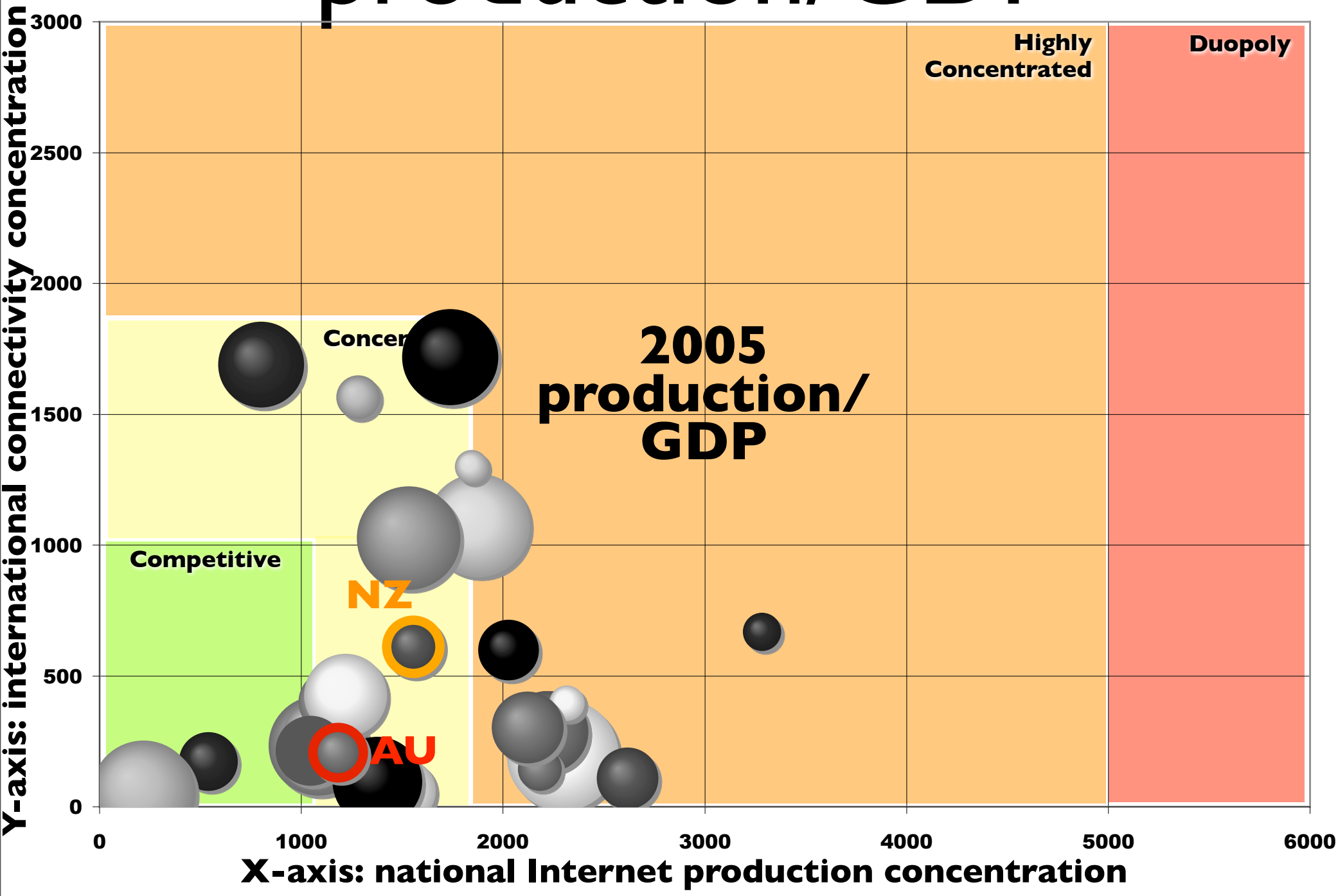



| | | | |
|---|---|---|---|
| ICELAND | 0.75 | BELGIUM | 0.17 |
| CANADA | 0.72 | FRANCE | 0.15 |
| AUSTRIA | 0.67 | GERMANY | 0.15 |
| SWEDEN | 0.65 | NETHERLANDS | 0.15 |
| KOREA | 0.57 | POLAND | 0.14 |
| JAPAN | 0.54 | PORTUGAL | 0.09 |
| FINLAND | 0.53 | NEW ZEALAND | 0.09 |
| SWITZERLAND | 0.45 | HUNGARY | 0.07 |
| NORWAY | 0.33 | ITALY | 0.05 |
| IRELAND | 0.30 | SLOVAKIA | 0.04 |
| UNITED STATES | 0.30 | TURKEY | 0.03 |
| LUXEMBOURG | 0.29 | AUSTRALIA | 0.03 |
| DENMARK | 0.23 | MEXICO | 0.03 |
| CZECH REPUBLIC | 0.19 | UNITED KINGDOM* | -0.32 |
| SPAIN | 0.17 | | |

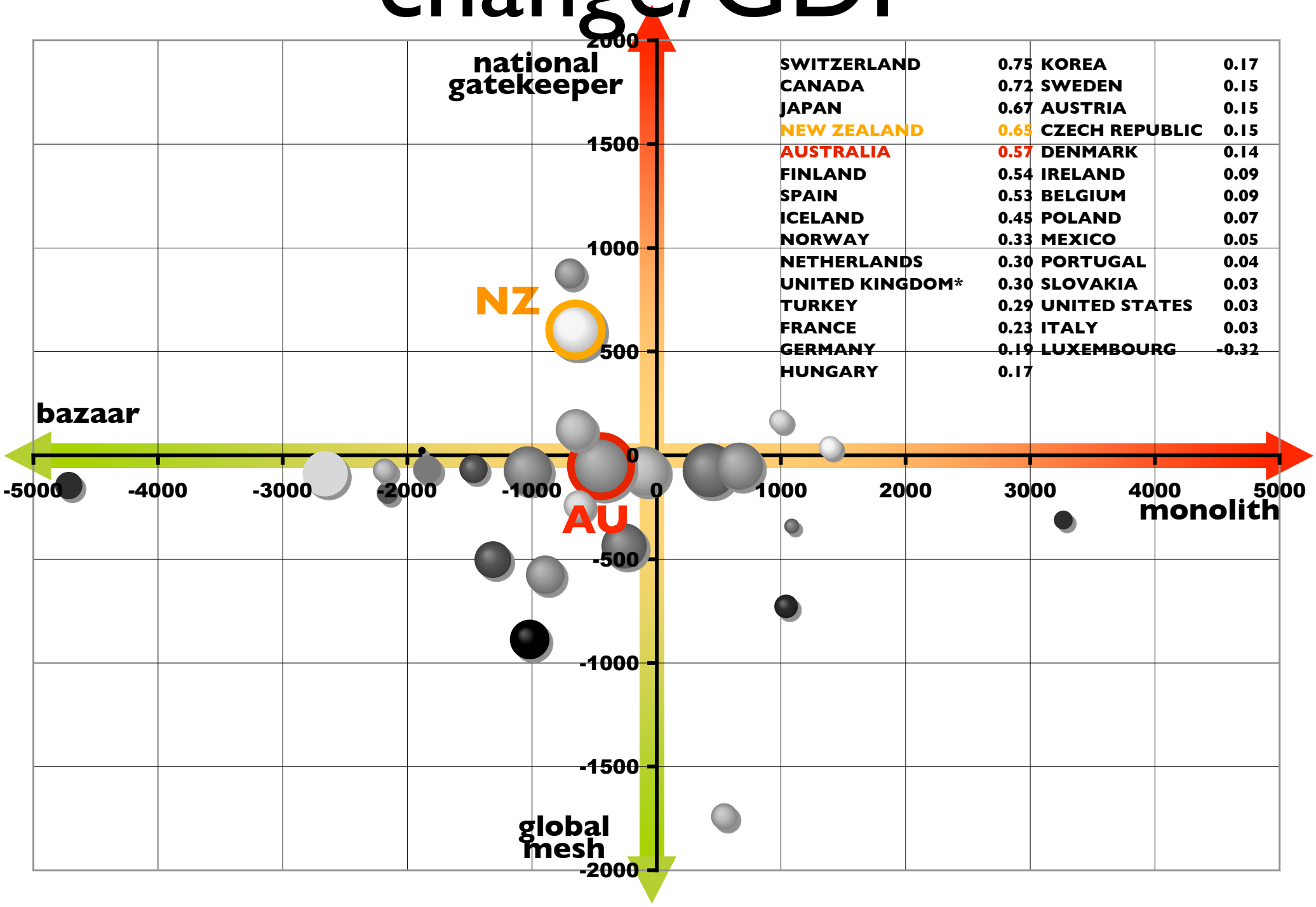
# production/GDP



# production/GDP

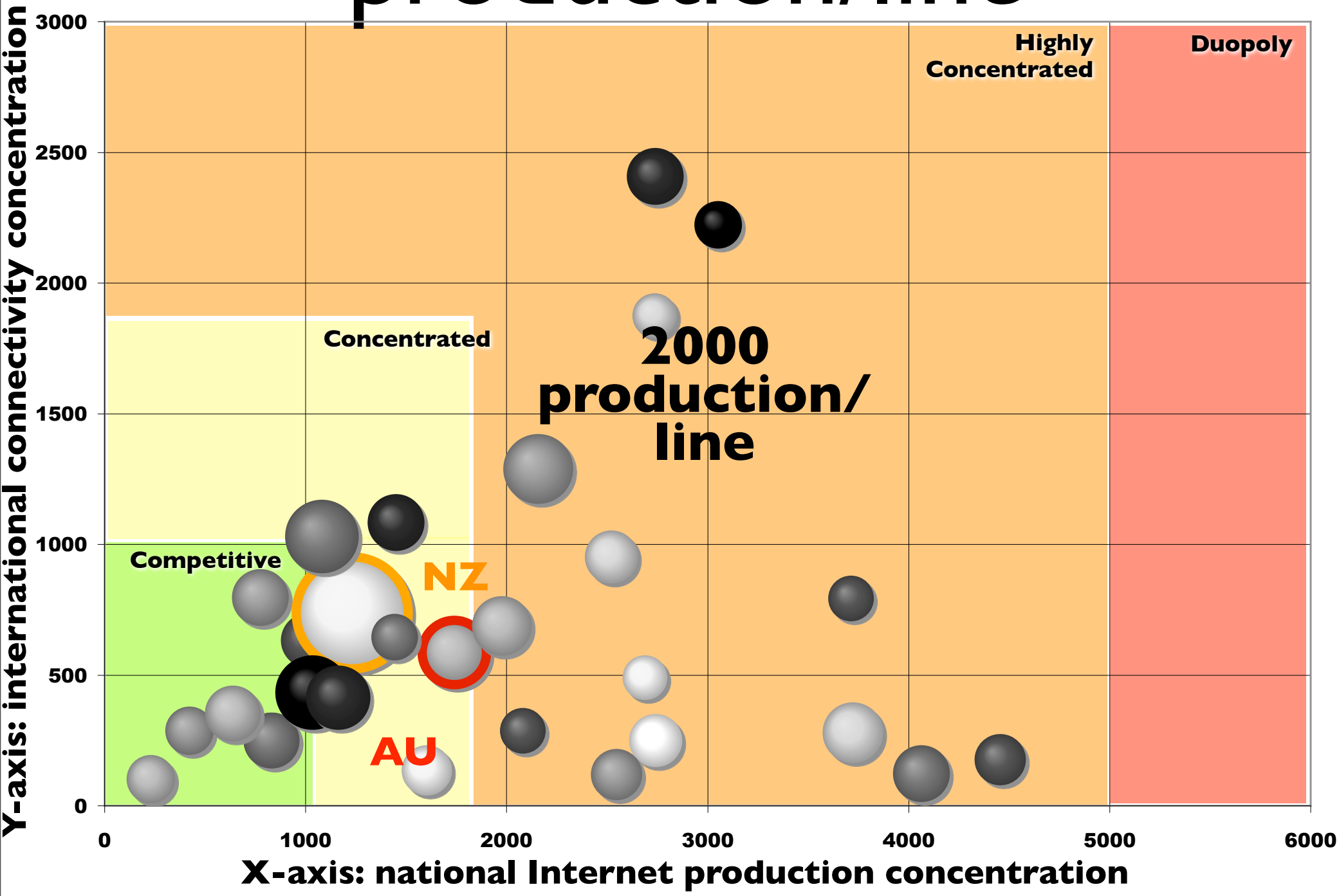


# change/GDP

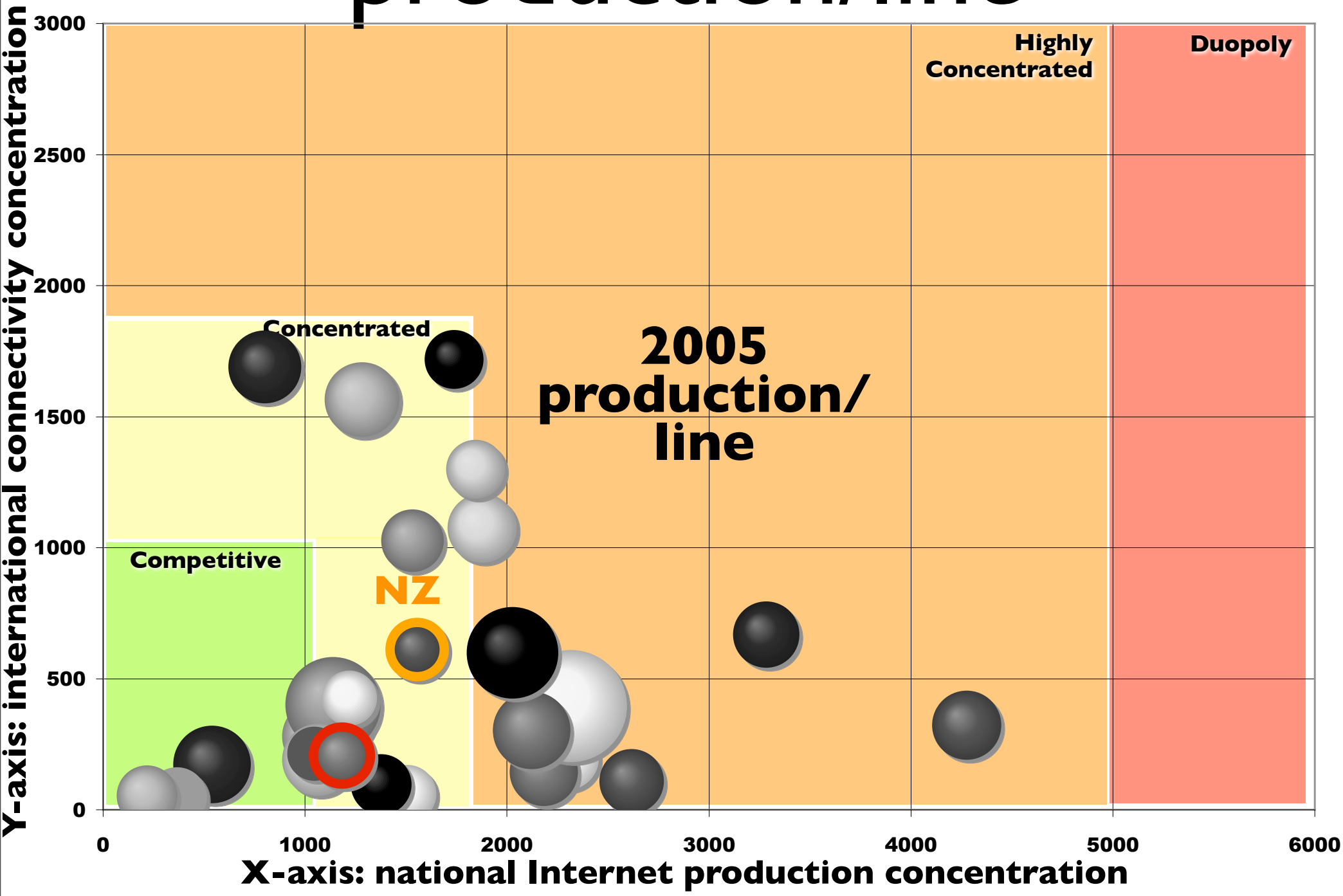



| | | | |
|---|---|---|---|
| SWITZERLAND | 0.75 | KOREA | 0.17 |
| CANADA | 0.72 | SWEDEN | 0.15 |
| JAPAN | 0.67 | AUSTRIA | 0.15 |
| NEW ZEALAND | 0.65 | CZECH REPUBLIC | 0.15 |
| AUSTRALIA | 0.57 | DENMARK | 0.14 |
| FINLAND | 0.54 | IRELAND | 0.09 |
| SPAIN | 0.53 | BELGIUM | 0.09 |
| ICELAND | 0.45 | POLAND | 0.07 |
| NORWAY | 0.33 | MEXICO | 0.05 |
| NETHERLANDS | 0.30 | PORTUGAL | 0.04 |
| UNITED KINGDOM* | 0.30 | SLOVAKIA | 0.03 |
| TURKEY | 0.29 | UNITED STATES | 0.03 |
| FRANCE | 0.23 | ITALY | 0.03 |
| GERMANY | 0.19 | LUXEMBOURG | -0.32 |
| HUNGARY | 0.17 | | |

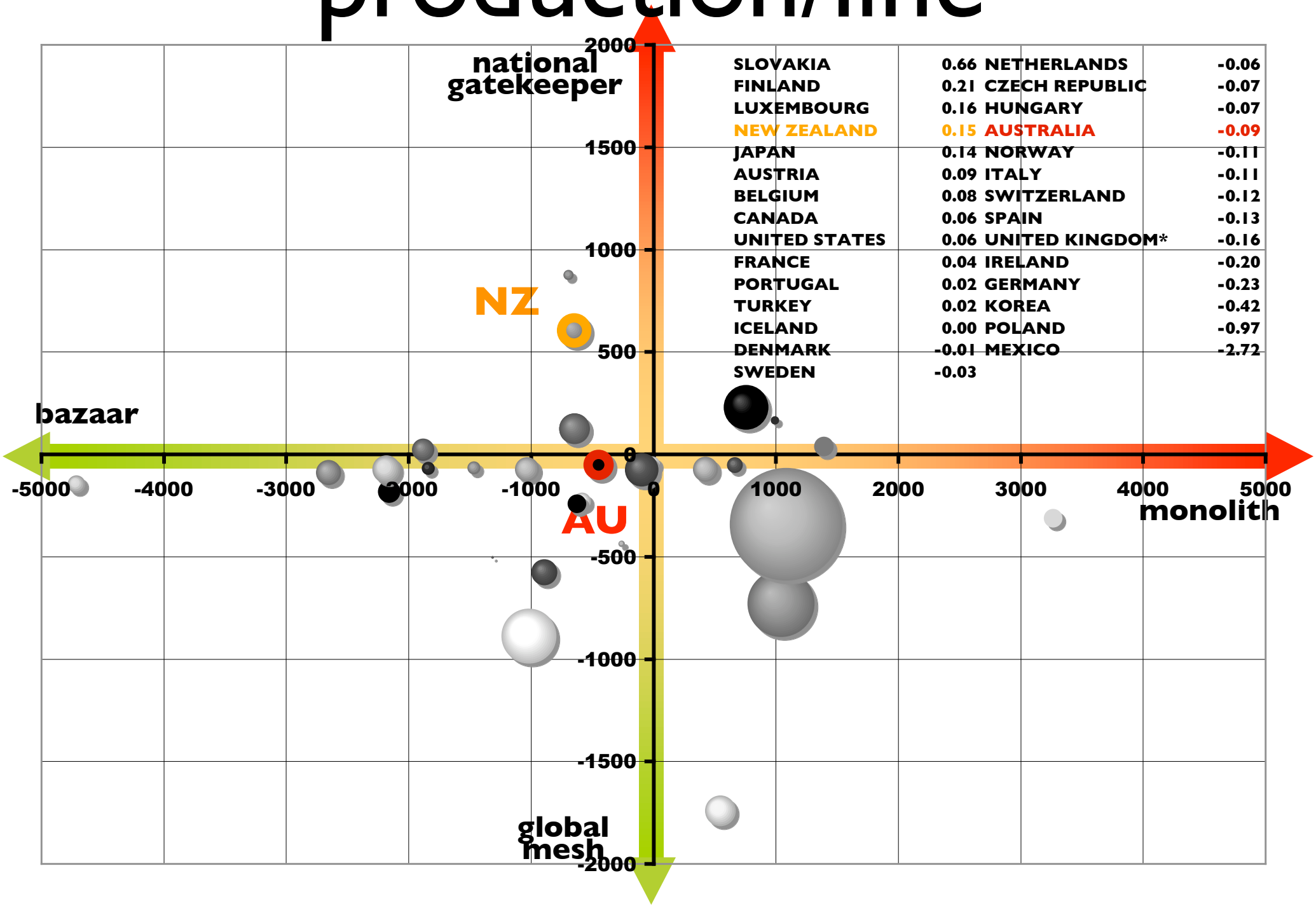
# production/line



# production/line



# production/line



# preliminary observations

- Internet routing tables reveal interesting, familiar-looking industrial dynamics
- Macro-level market phenomena, e.g., “concentration” -- others to be identified -- may have significant independent effects on growth trends and other important features of Internet evolution
- Macro-economic approach to Internet measurement can provide decision support value to policy makers, just as macro-economic analysis of financial data currently informs a many important decisions in the public and private sector

# In the works

- Bayes factor analysis of national time series
- Changing distribution of "single-homers" by country and upstream provider, 1997-2005
- Aggregation of ARIN ASes by org-id, to better (?) reflect true market structure
- Aggregation of CN ASes by parent institution (CT, CNC, CM), to better (!) reflect true market structure
- Comparison of Internet production metrics to measurable infrastructure inputs and other benchmarks -- testing the "logical multiplexing" thesis

治大「网路」若烹小鮮

# Questions?

Tom Vest
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**23 March 2006**