The Canadian Innovation System

A scale-independent model

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Hyper Links to Background Material

- Internet
  - The European Innovation System: A scale-independent model
  - The Canadian Innovation System: A scale-independent model
  - Recognition and Innovation Systems
- Publications
  - Scale-independent Indicators and Research
    Science and Public Policy (2000)
  - The Self-Similar Science System
    Research Policy (1999)
  - Bibliometric Indicators and the Social Sciences
    ESRC Report (1999)
  - Collaborative Approaches to Research
    HEFCE Fundamental Review of Research Policy and Funding (2000)
  - Power Laws and Athletic Performance,
    J. Sports Sciences (1999)

Overview

1. Innovation Systems & Indicators
2. Power laws and Scaling
3. GERD, GDP and Power laws
4. Relative Growth Indicator
5. The Canadian Innovation System
   A scale independent model
6. Relative GERD Indicator

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1. Innovation Systems & Indicators

Hypothesis

- if our indicators are weak then our of understanding of a IS is weak.

Demonstrate a weakness

- GERD grows as a power law with GDP within and across IS
- Current indicators do not account for this non-linear behavior
- GERD values made at different GDP levels have to be adjusted to scale before they are compared
- The weakness can be removed by using scale-independent indicators (i.e. an indicator normalized to scale)

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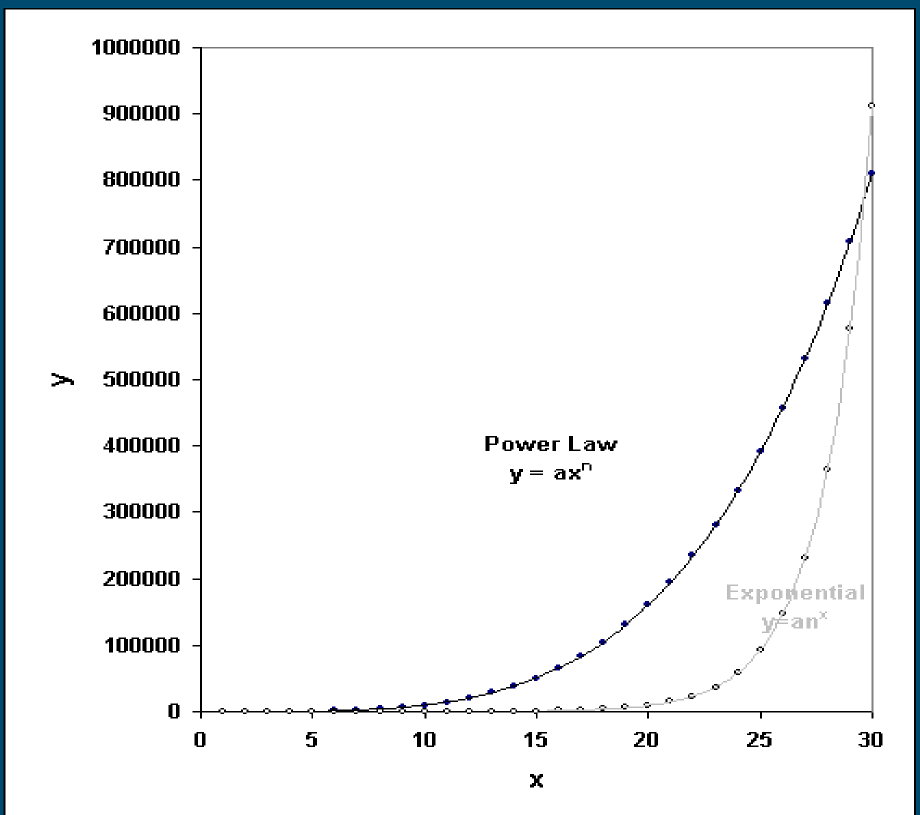
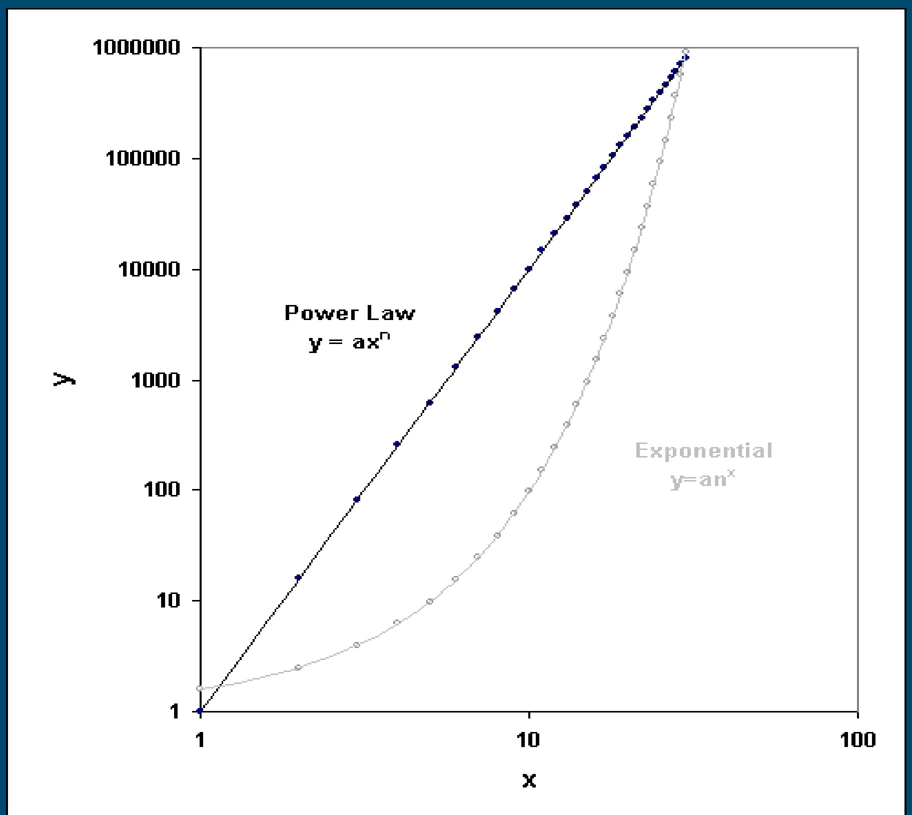
2. Power Laws and Scaling

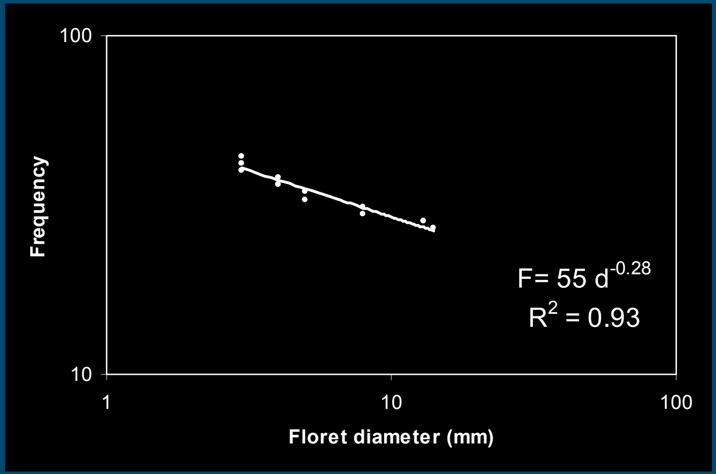
- A power law distribution is given $y = ax^n$
- The scale of a power law is given by its exponent, n





Scale-independence or Scaling

- a property that has no characteristic scale
- statistically similar at all levels from individual entities, a collection of entities or the system as a whole

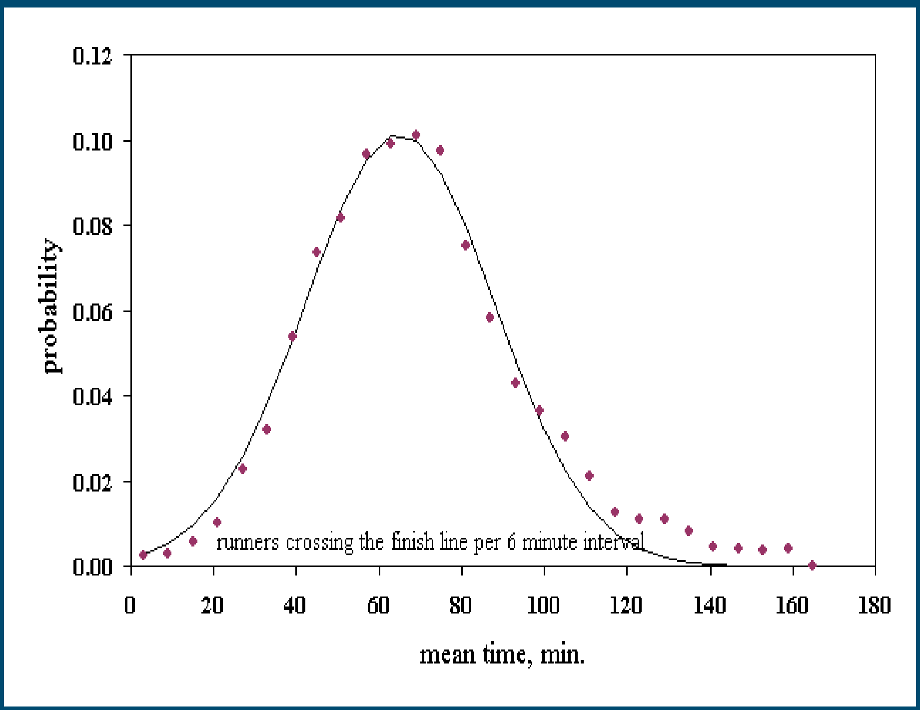


- e.g. *branchiness* of a tree & *jaggedness* of a coastline
- characterized by a power law distribution

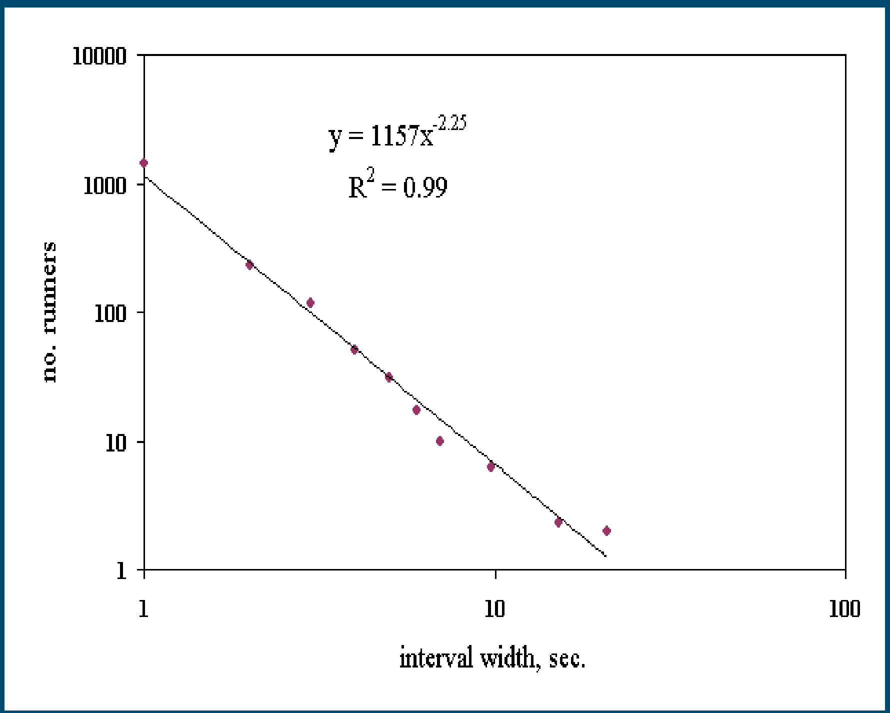
Scale-dependent & Scale-independent

A scale-dependent and a scale-independent property can co-exist

1991 Boston Marathon



Scale-dependent - has a mean



Scale-independent - doesn’t have a mean

Prevalence of Power Laws

Natural systems

- Force between masses (Newton’s law)
- Force between charges (Coulomb's law)
- Metabolic rate and mass of an organism (Kleiber's Law)
- Magnetism and temperature
- Athletic energy production over time

Social systems

- Income distribution (Pareto’s law)
- Productivity of authors (Lotka’s law)
- Use of language (Zipf’s Law)
- Distribution of sizes of communities
- Recognition and size

Financial

Pareto

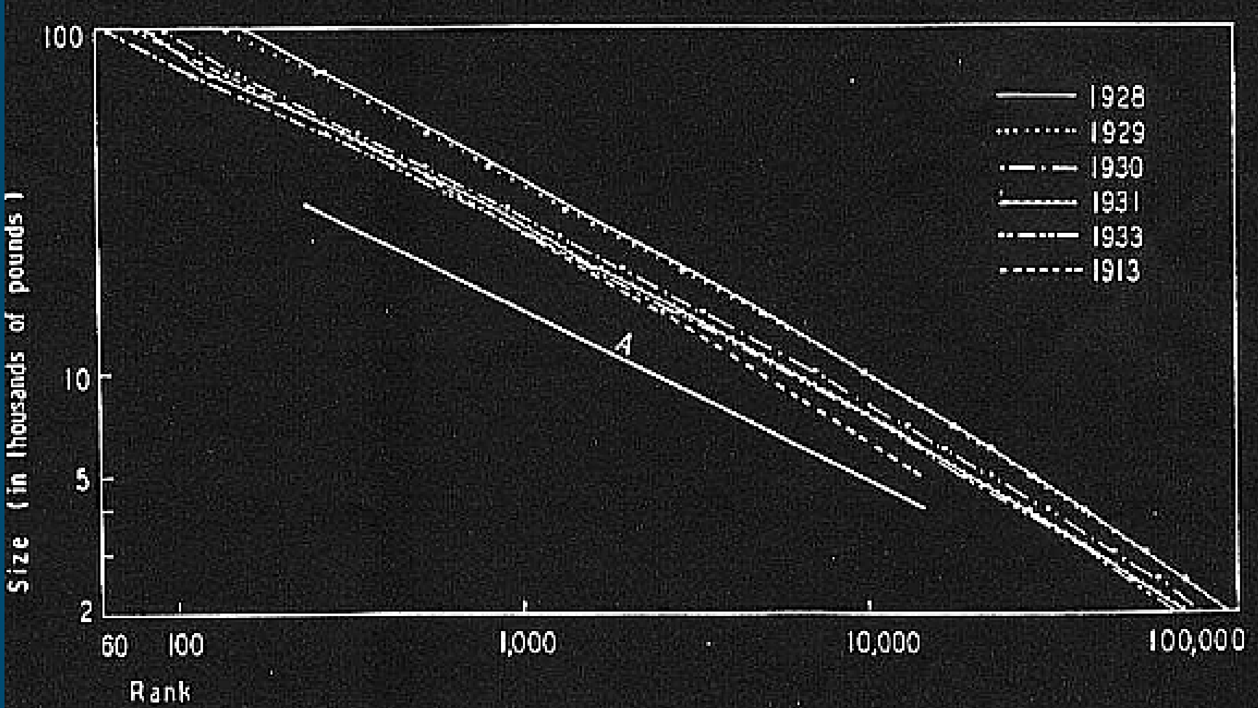


Fig. 11–1. United Kingdom: incomes for six years (for surtax). (Line A has an ideal — ½ slope.)

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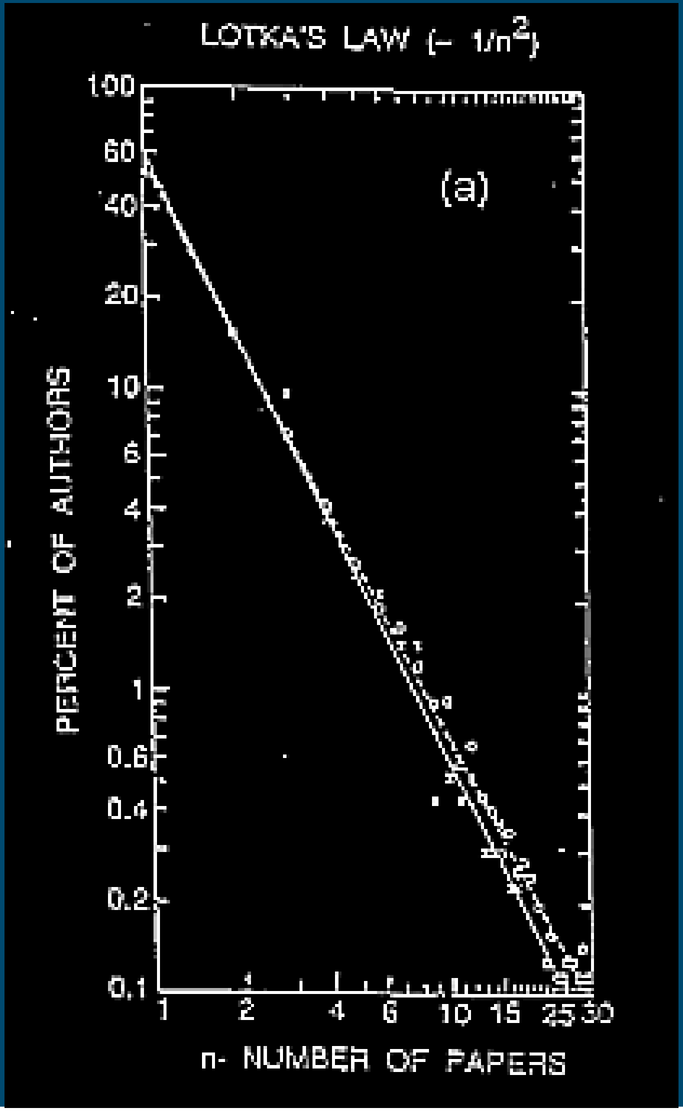
Productivity



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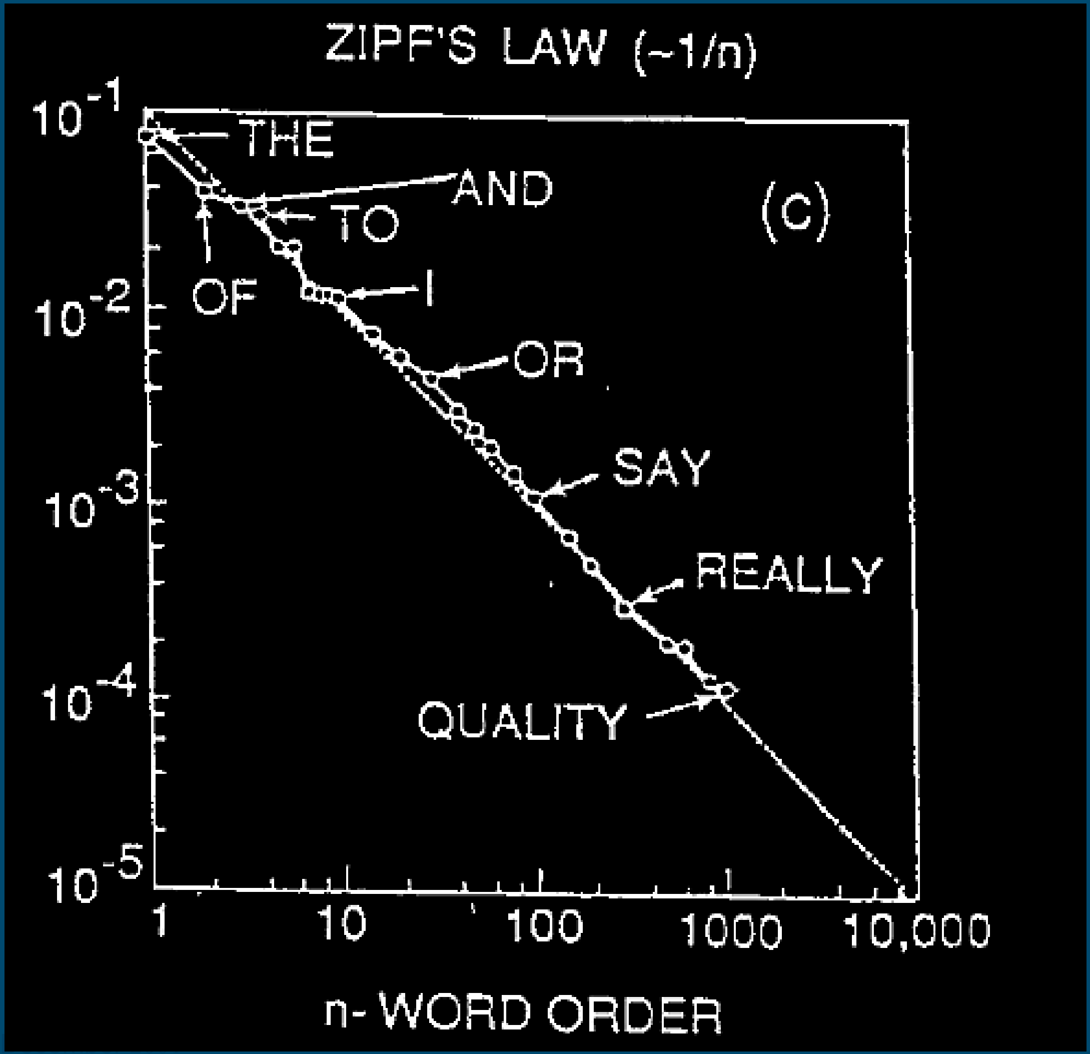
ZIPF'S LAW (~1/n)
(c)
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n- WORD ORDER

Communities

$$PR^{0.93} = 5,000,000$$

where P denoted the population of the city of rank R.

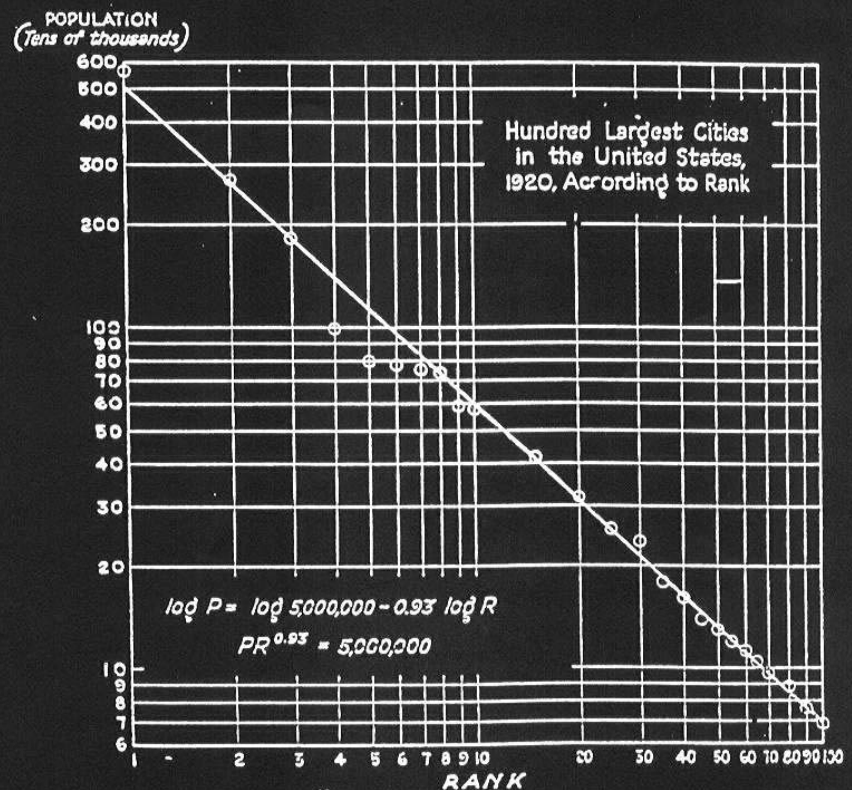
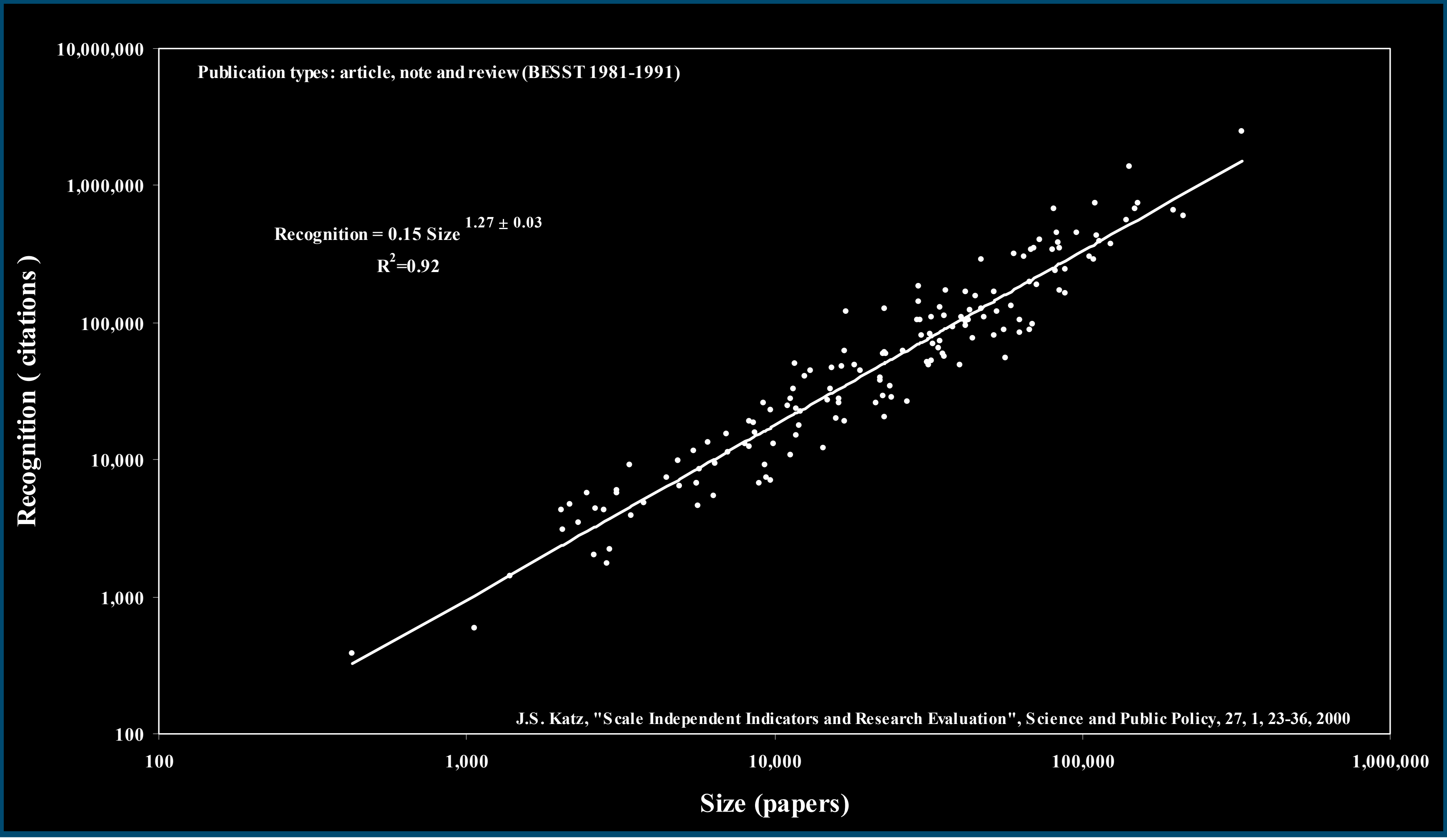


FIG. 60. LAW OF URBAN CONCENTRATION

Recognition

Matthew effect (Merton 1968)



Properties of a Power Law

- Common signature of a unique non-linear system
- Generated by deterministic, non-deterministic and mixed processes
- Has a scaling property given by the exponent, n.
- The scaling exponent, n, can be used
  - As an indicator of the processes that generated it
  - To normalize dependent variables so they can be compared over a range of independent variables.

3. GERD, GDP and Power laws

Godin (2002) *The most cherished indicator: Gross Domestic Expenditure on R&D (GERD)*

- OECD send mixed messages about our most cherished indicator
  - R&D intensity indicator is useful for international comparisons
  - warns it can vary non-linearly with per capita GNP.

Holbrook (1991) *The influence of scale effects on int'l comparisons of R&D expenditures*

- A power law relationship between GERD and GDP across OECD IS

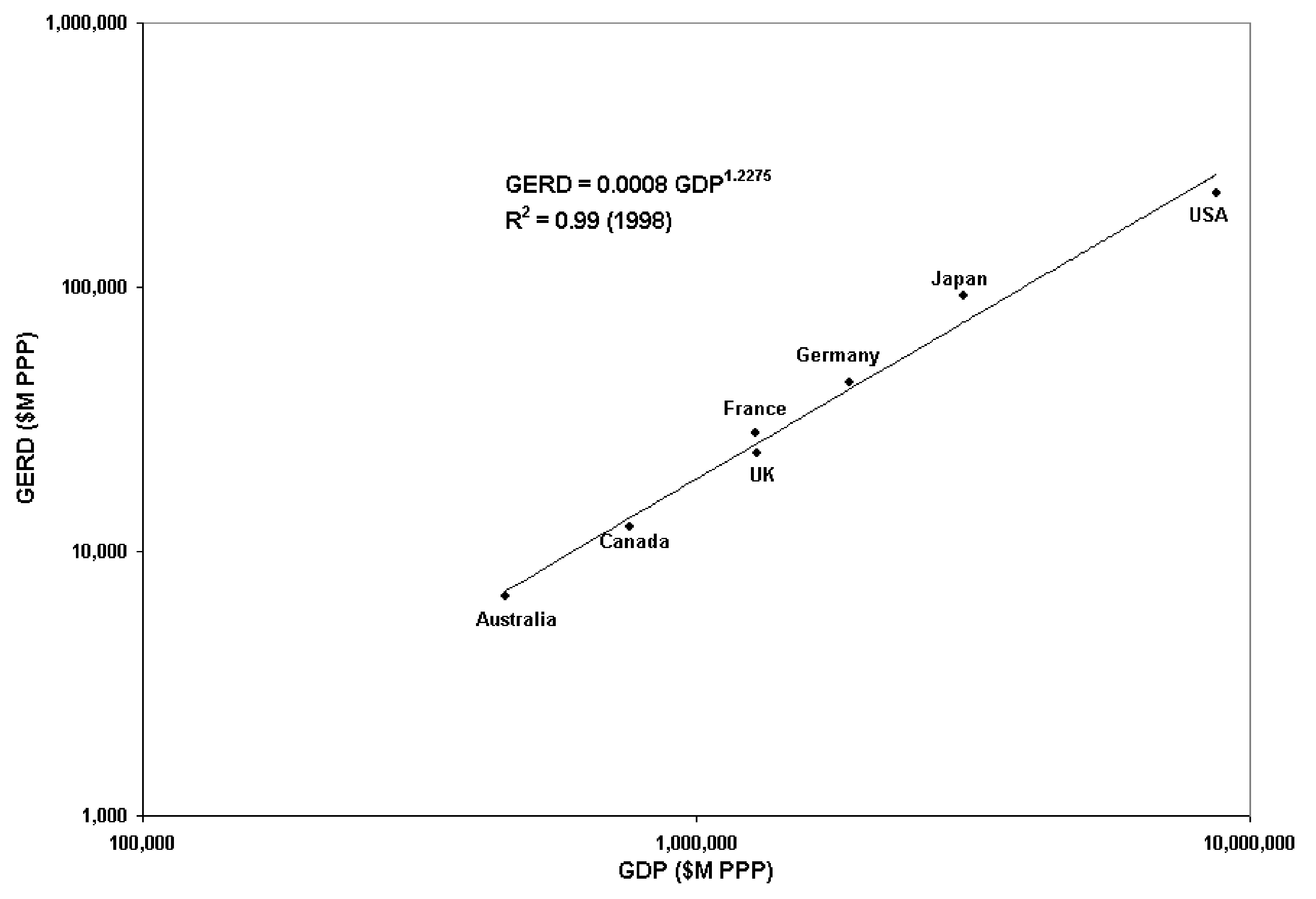
Schulz (1994) *How much should Canada Spend on R&D?*

- A power law relationship between GERD and GDP within OECD IS across time

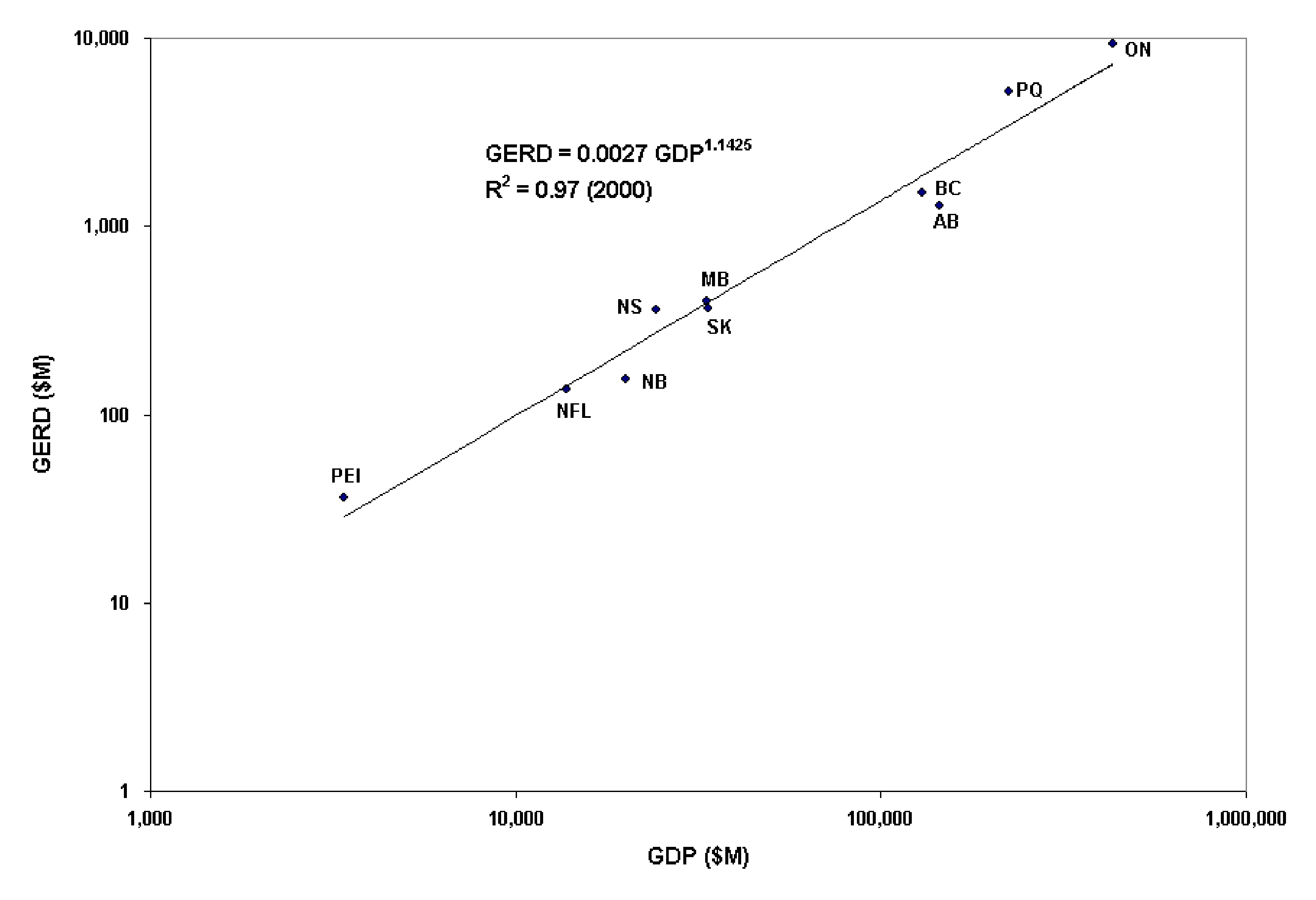
Katz (2003) *The European Innovation System: A scale independent model*

- Confirms Holbrook & Schulz findings
- The power law relationship within IS is predictably from the exponential growth rates of GERD and GDP
- Use the scaling exponent to create scale-independent indicators

GERD and GDP across IS



Provincial GERD & GDP (2000)



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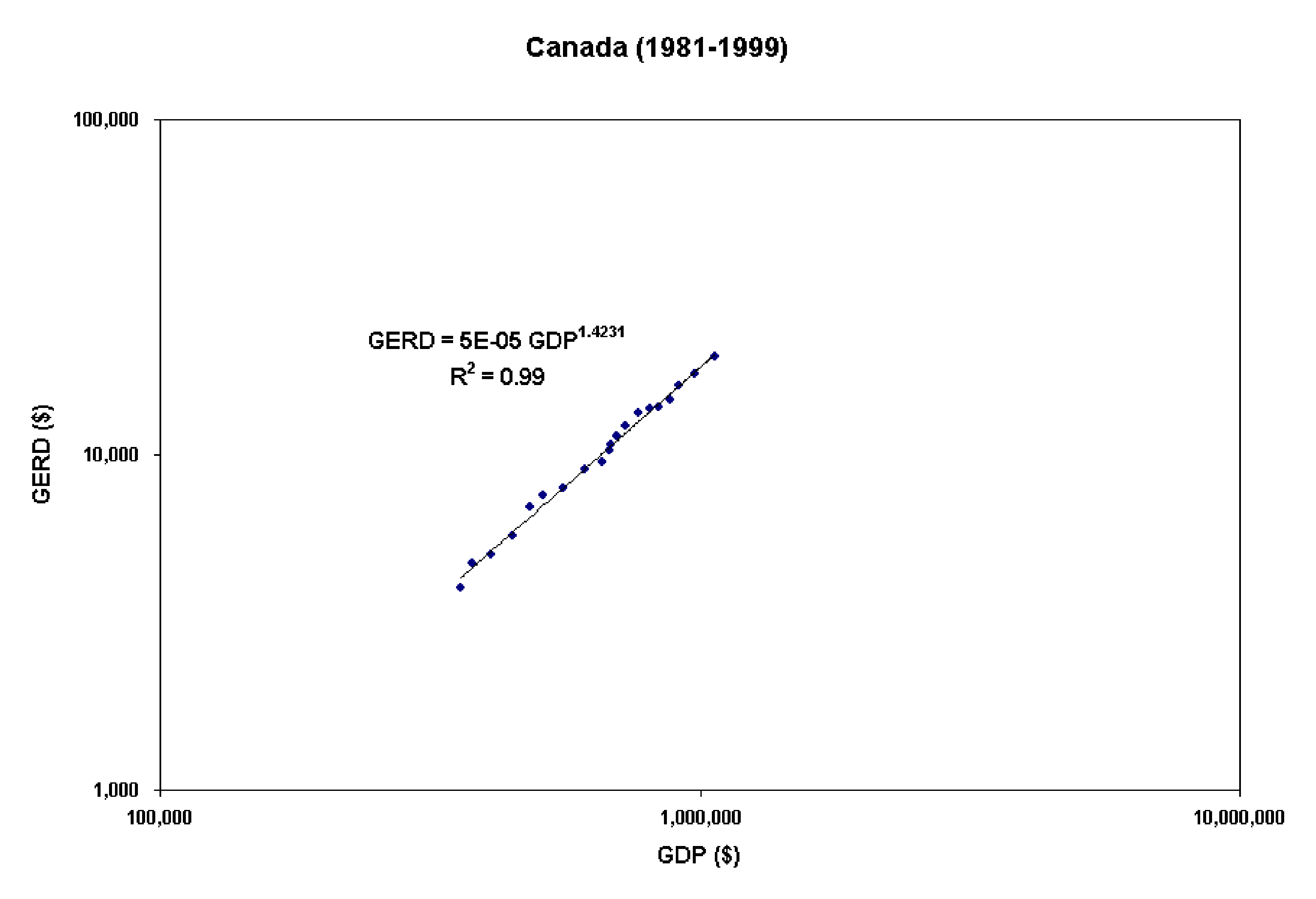
GERD & GDP within an IS



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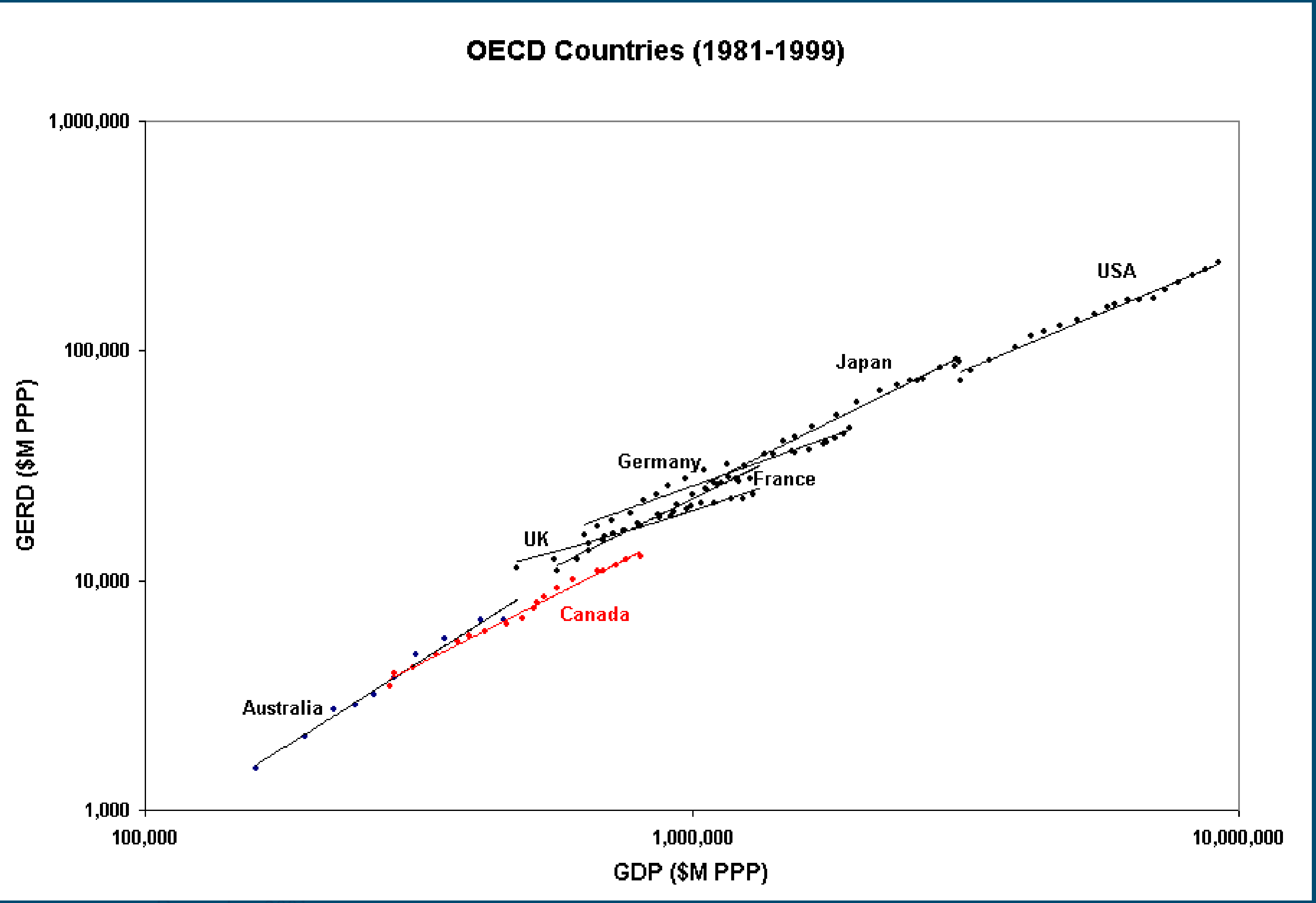
GERD & GDP within OECD IS



Coupled Exponential Process

Given any two coupled exponential processes

$x = am^{pt}$ and $y = bm^{qt}$

where

$y = sx^n$

then

$bm^{qt} = s(am^{pt})^n$

$b/s(a)^n = m^{(pn-q)t}$

Since $m^{(pn-q)t}$ is a time dependent variable and it cannot be equal to $b/s(a)^n$, a constant, unless $pn-q = 0$, therefore the power law

exponent, $n = q/p$

intercept, $s = b/a^{q/p}$

GERD & GDP within Canada

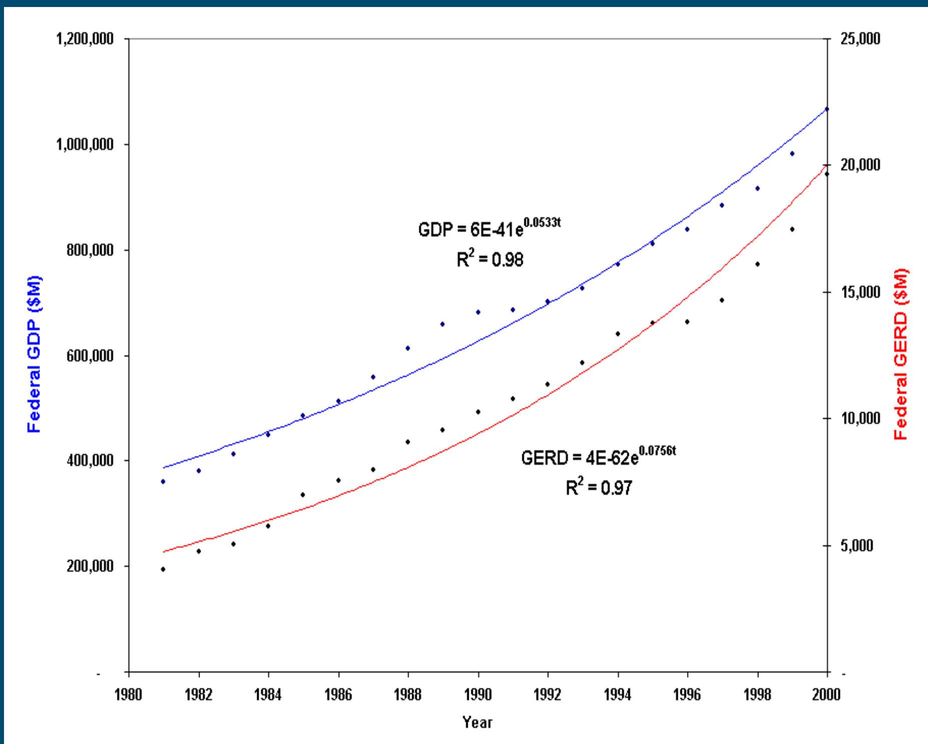
Canada (1981-2000)

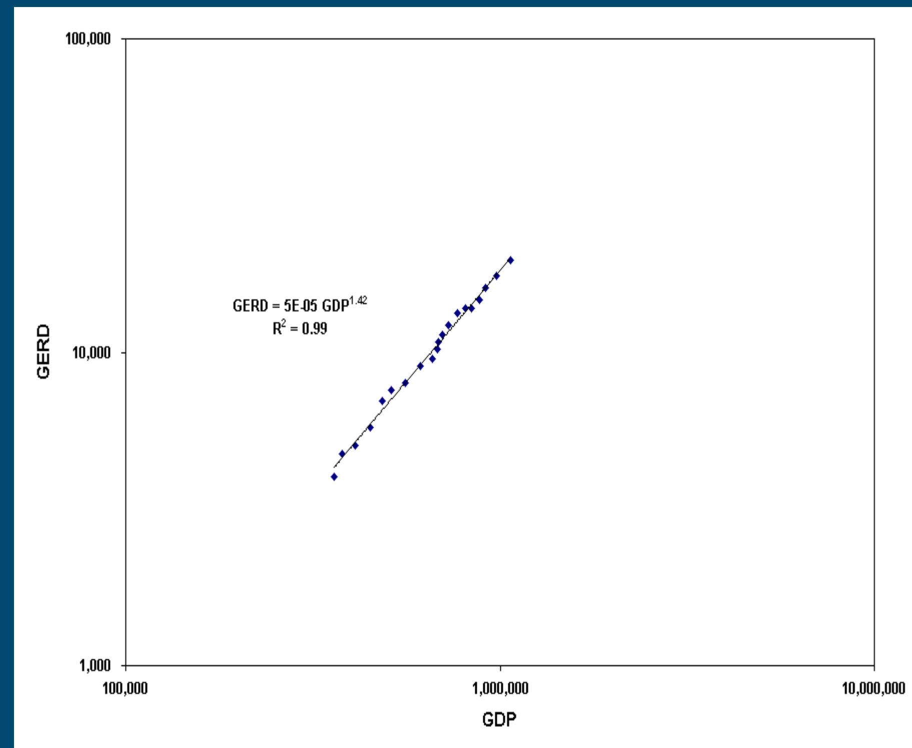
Predicted

n = 0.0756 / 0.0533 = 1.42

Measured

n = 1.42





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4. Relative Growth Indicator

The ratio between the exponents, q & p, of a pair of time coupled exponential processes

$$RGI = q/p$$

RGI = 1

q = p indicates processes growing at same rate

RGI > 1

q > p indicates q growing faster than p

RGI < 1

q < p indicates p growing faster then q

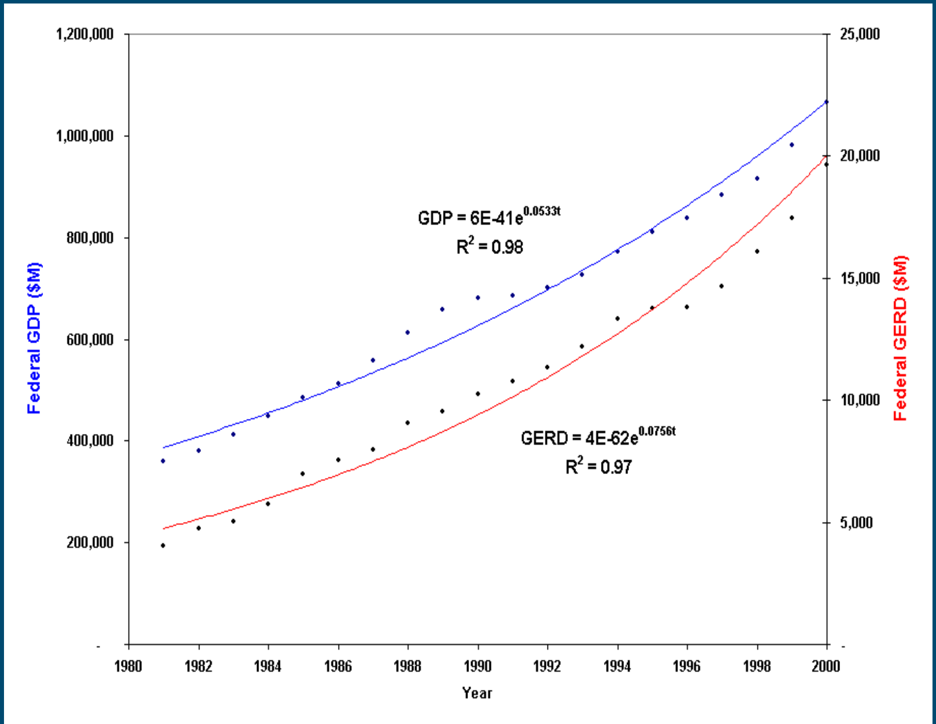
OECD 1981-1999

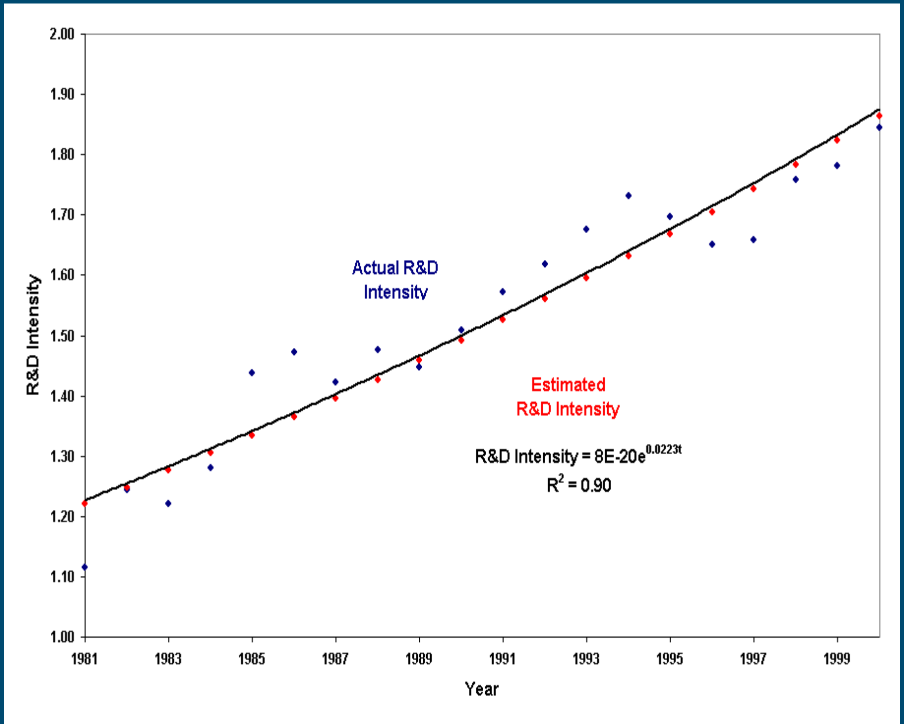
Country	Measured	R^2	Predicted	% Error
Australia	1.511	0.98	1.488	1.5
Austria	1.404	1.00	1.410	-0.4
Belgium	1.176	1.00	1.227	-4.3
Denmark	1.659	1.00	1.660	-0.1
Finland	1.926	0.99	1.930	-0.2
France	1.175	0.99	1.185	-0.9
Germany	0.848	0.96	0.857	-1.0
Greece	2.124	0.98	2.163	-1.9
Iceland	2.147	0.98	2.162	-0.7
Ireland	1.560	0.99	1.519	2.6
Italy	1.097	0.90	1.000	8.9
Japan	1.183	0.99	1.227	-3.7
Netherlands	1.004	0.98	1.011	-0.7
Norway	1.319	0.98	1.315	0.3
Portugal	1.657	0.98	1.719	-3.7
Spain	1.694	0.98	1.673	1.3
Sweden	1.511	0.99	1.571	-4.0
Switzerland	1.295	0.96	1.350	-4.3
UK	0.767	0.98	0.757	1.3
USA	0.996	0.98	0.990	0.6

5. Canadian Innovation System

- 1981-2000 (20 yr policy window)
  - Canadian GERD has grown faster than Canadian GDP (RGI = 1.42)
  - Canadian R&D Intensity indicator is growing exponentially

$$q - p = 0.0756 - 0.0533 = 0.0223$$





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Scale-independent Indicators

Relative Growth Indicators

- Total Provincial GERD vs. Provincial GDP
- Business GERD vs. Provincial GDP
- Higher Education GERD vs. Provincial GDP
- Provincial GERD vs. Provincial GDP

Data Source – Statistics Can

P_{tot} GERD vs. P GDP

Province	RGI	R^2
PQ	1.84	0.99
BC	1.40	0.97
NB	1.36	0.85
SK	1.35	0.88
ON	1.33	0.98
NFL	1.21	0.90
NS	1.14	0.94
PEI	1.09	0.71
AB	1.09	0.91
MB	1.06	0.92

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Bc GERD vs. P GDP

Province	RGI	R^2
NB	2.41	0.75
NS	2.18	0.87
MB	2.12	0.85
PQ	2.08	0.98
NFL	1.92	0.57
BC	1.64	0.96
SK	1.25	0.75
ON	1.21	0.95
AB	1.07	0.79
PEI	na	na

HEc GERD vs. P GDP

Province	RGI	R^2
NFL	2.75	0.86
NS	2.52	0.88
PQ	2.30	0.94
MB	2.16	0.80
ON	2.11	0.94
BC	2.06	0.89
SK	1.86	0.90
PEI	1.85	0.74
AB	1.24	0.63
NB	na	na

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Pc GERD vs. P GDP

Province	RGI	R^2
NS	2.25	0.87
SK	1.58	0.70
NB	1.42	0.73
MB	1.23	0.64
PQ	1.21	0.84
BC	1.12	0.89
ON	1.11	0.88
AB	0.32	0.24
NFL	na	na
PEI	na	na

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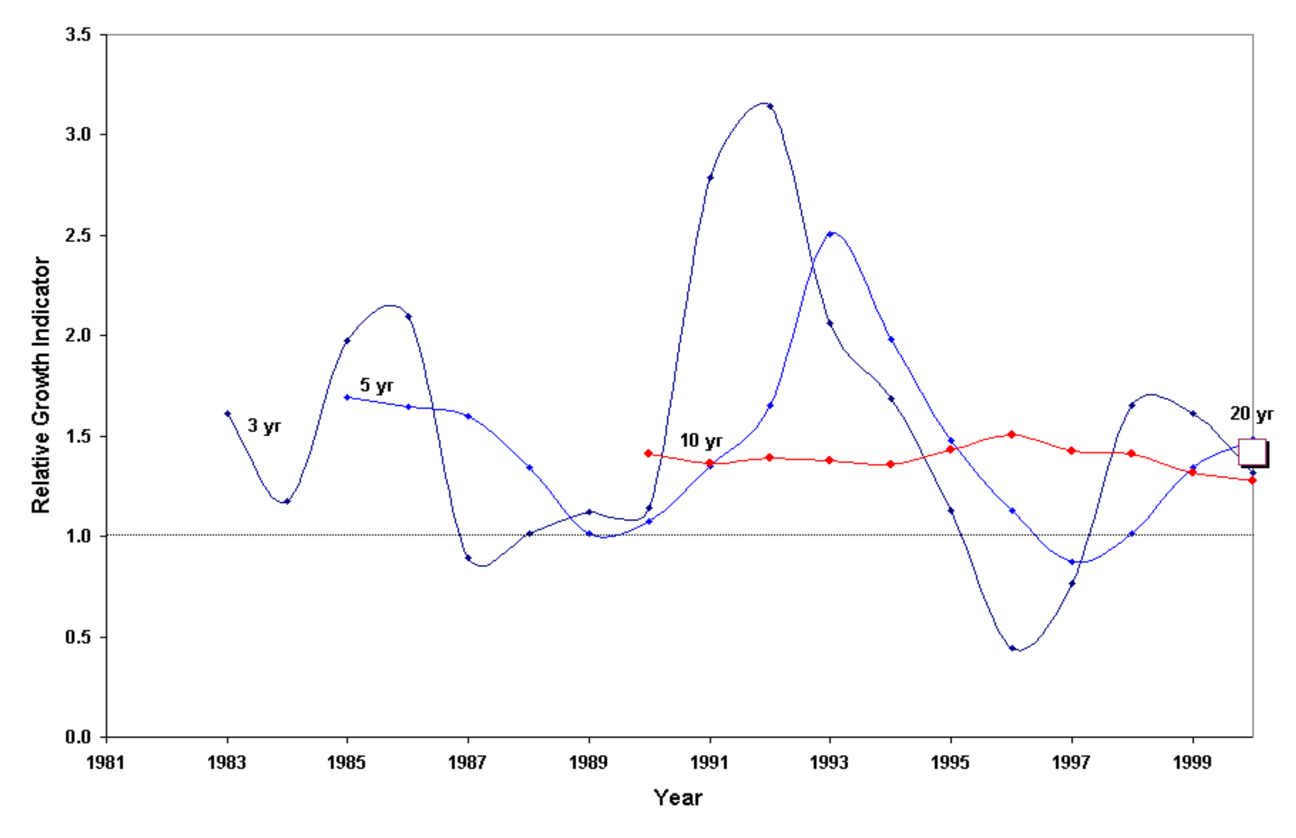
Policy Window

Varying the size of the policy window

varies our view of an innovation system



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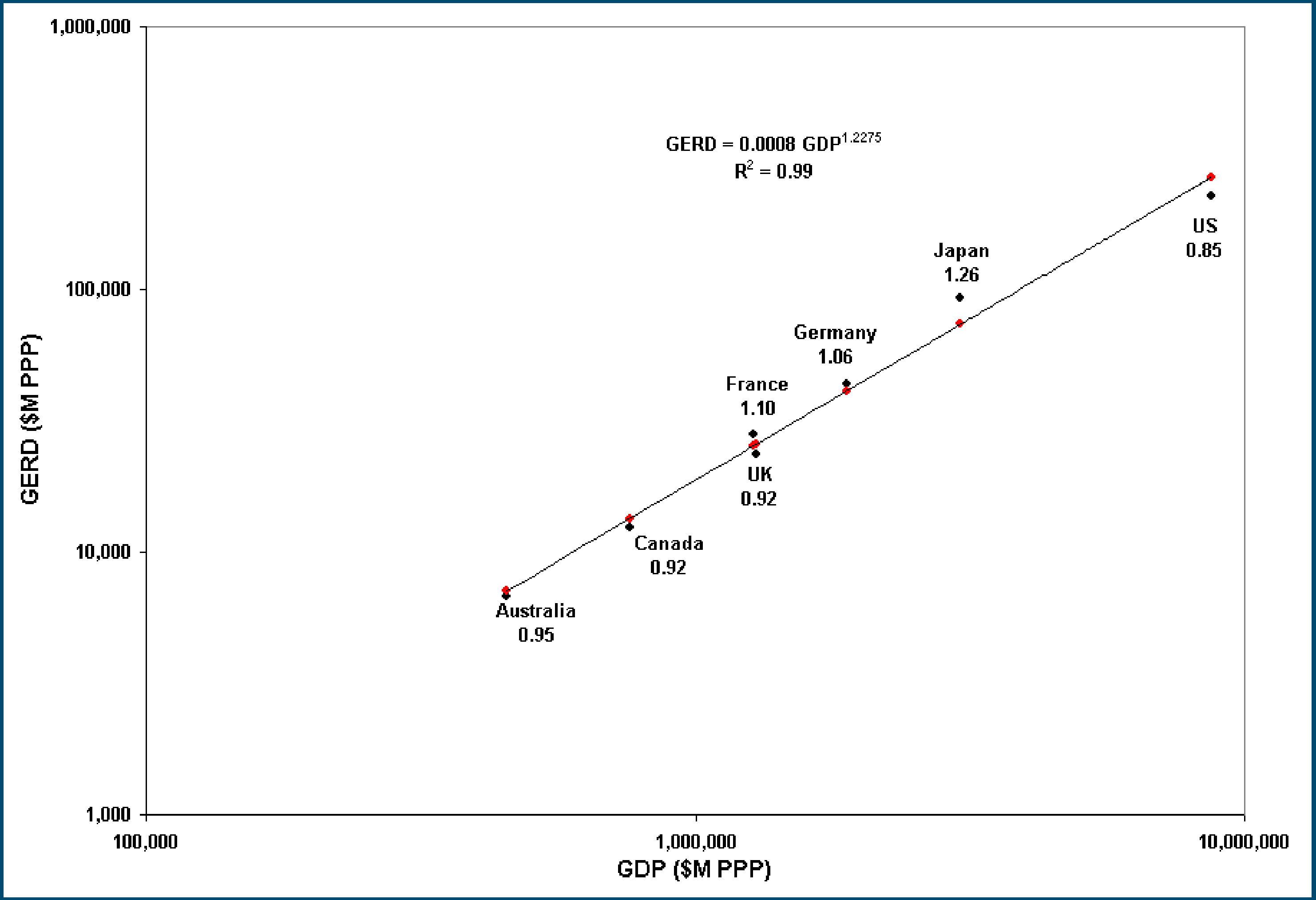
6. Relative GERD Indicator



Data source – OECD 1998

Relative Provincial GERD

Province	RPG (2000)
PQ	1.50
NS	1.32
ON	1.27
PEI	1.25
MB	1.03
NFL	0.95
SK	0.93
BC	0.81
NB	0.71
AB	0.61

Data Source – Statistics Canada

Summary

GERD and GDP can have a power law, scale-independent, relationship

- within an IS across time
- across IS at a point in time

Within IS

- GERD vs. GDP power law generated by coupled exponential processes
- The scaling exponent, n,
  - predicted from the exponential growth parameters for GERD and GDP
  - a measure of the processes that generated it

Across IS

- GERD vs. GDP power law is generated by a mixed process
- The scaling exponent, n,
  - cannot be predicted -- can be estimated
  - used to normalize GERD values for different levels of GDP

Observation

A fundamental weakest in IS indicators can be removed through the use of scale-independent indicators