Toward a leading indicator of catastrophic shifts in complex systems: Assessing changing conditions in nation states

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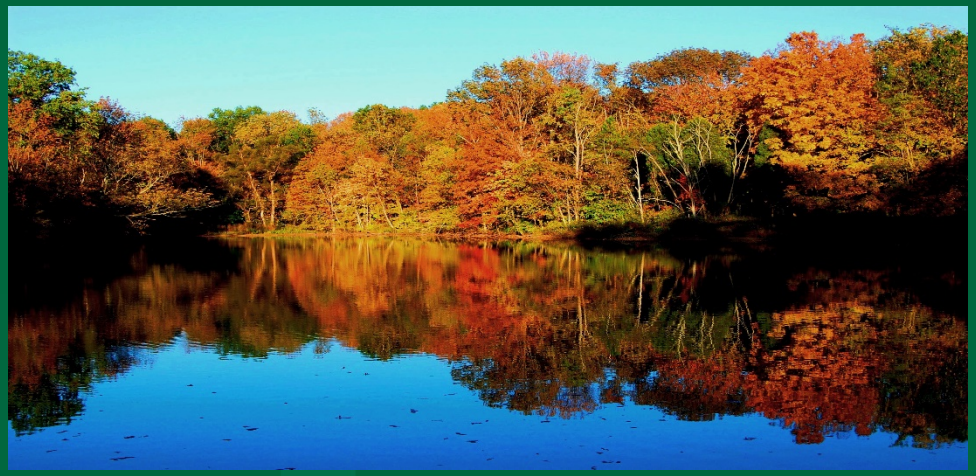

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Outline

- Sustainability
- Fisher Information
- Data
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- Results: Bayes' Theorem
- Summary

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Sustainability

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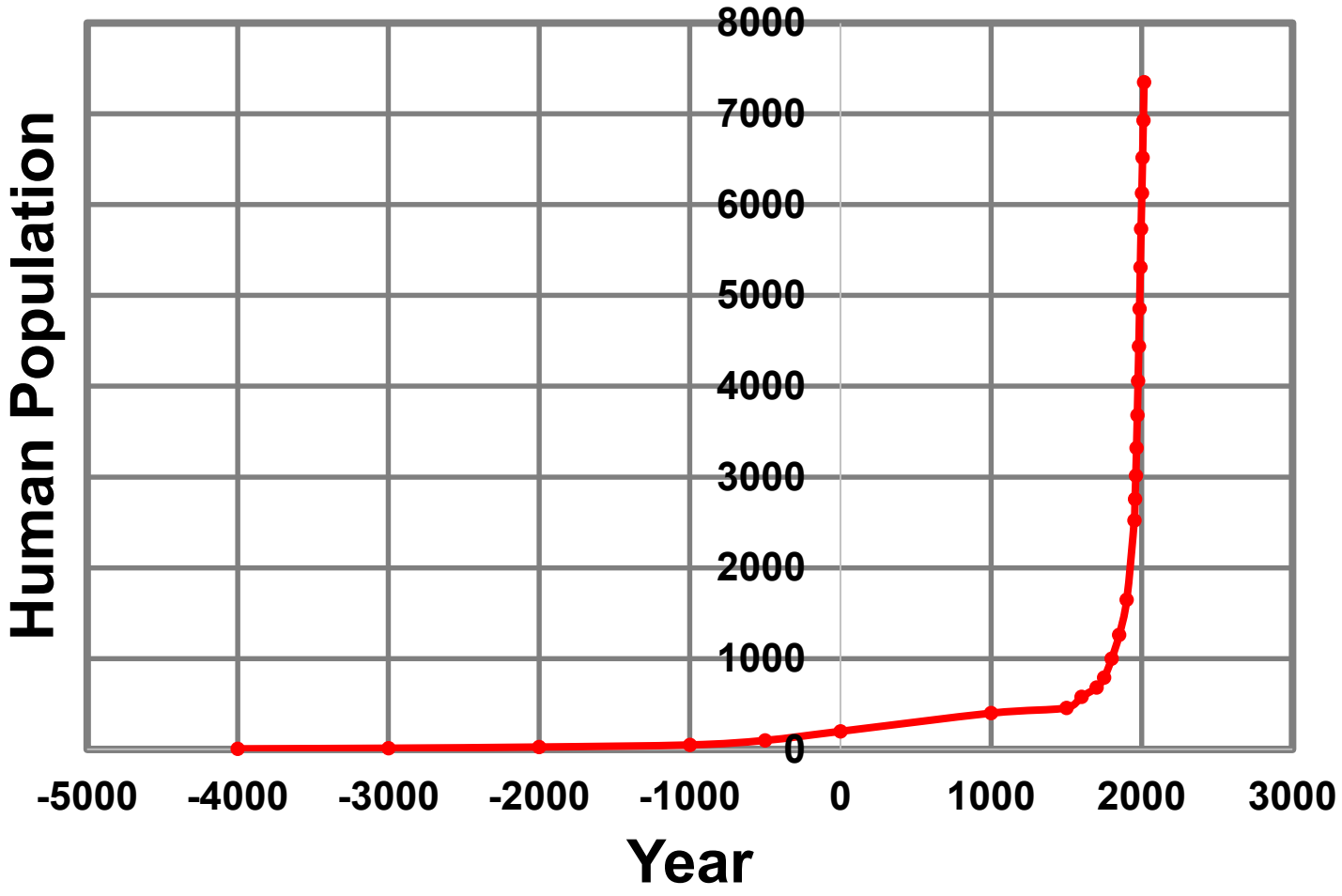
Historical World Population

(https://en.wikipedia.org/wiki/World_population)



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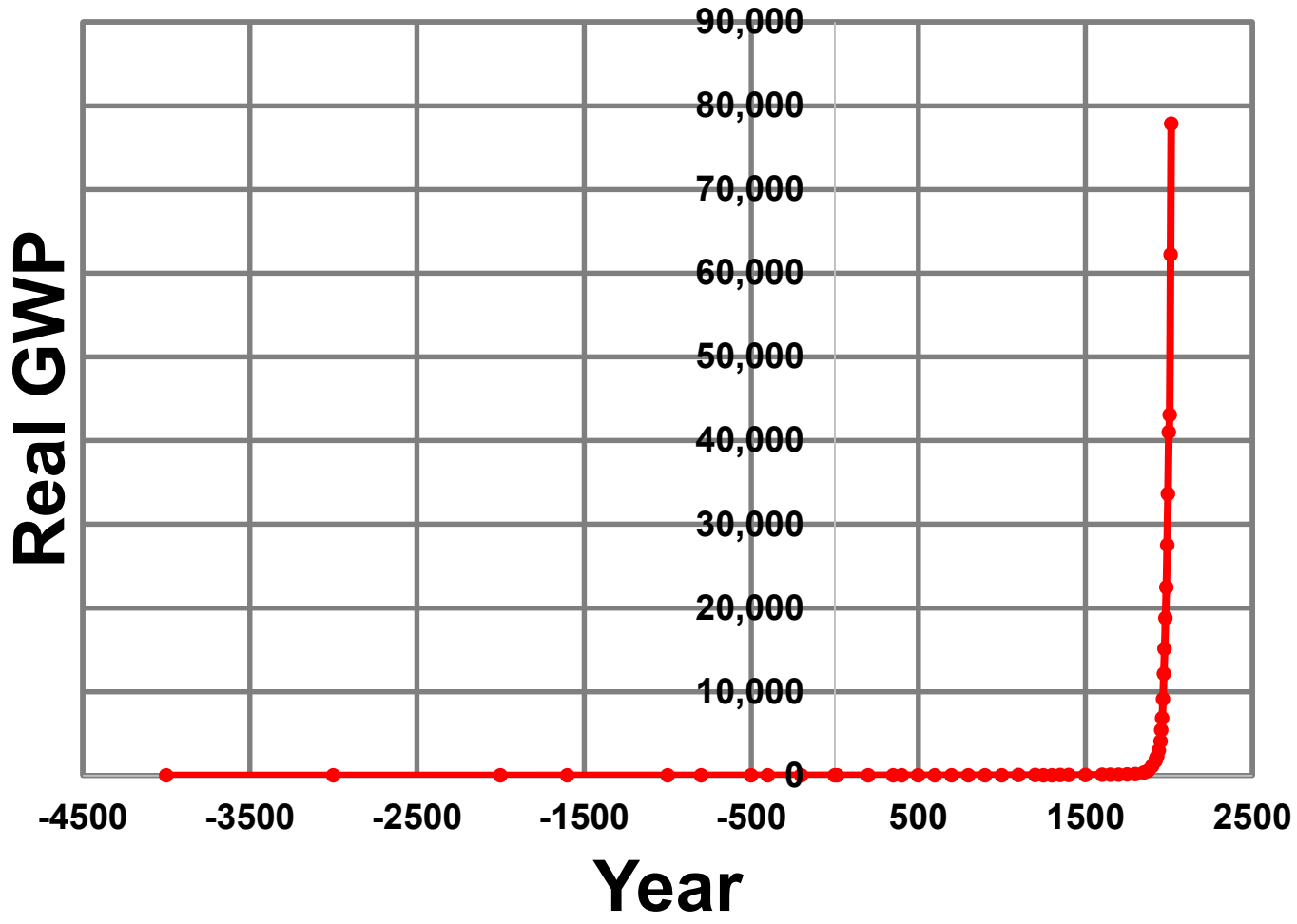
Real Gross World Product

(https://en.wikipedia.org/wiki/Gross_world_product)
($US billions, 1990 intl $US)



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Fisher Information

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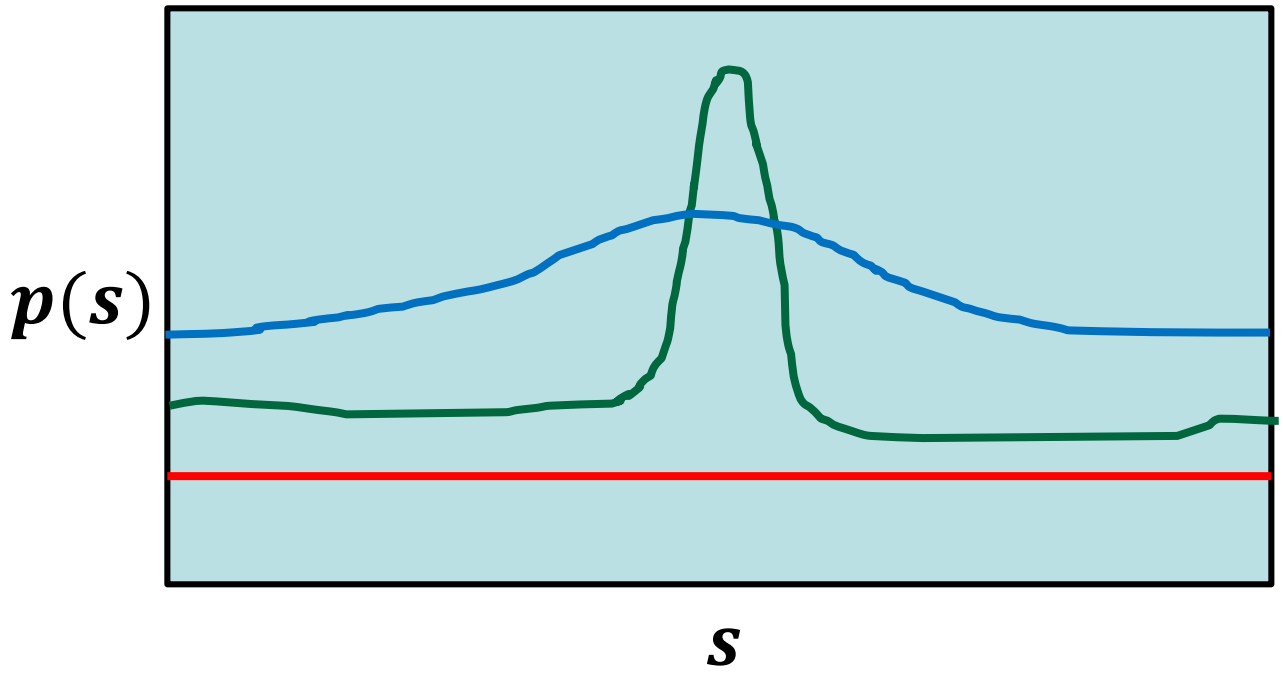
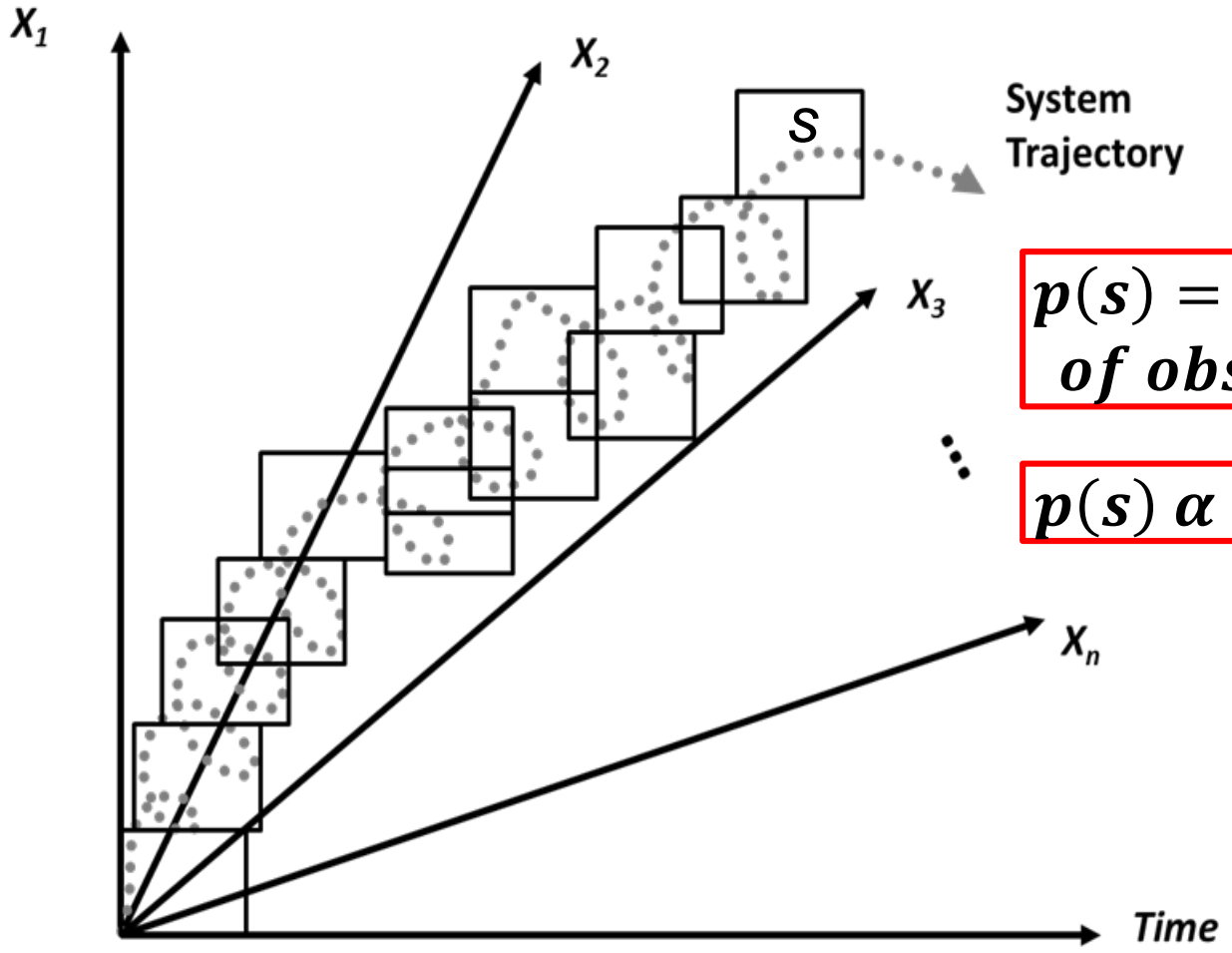
What is Fisher Information?



$$I = Fisher\ Information = \int \frac{ds}{p(s)} \left[\frac{dp(s)}{ds}\right]^2$$

$$I\ \alpha \left[\frac{dp(s)}{ds}\right]^2$$

Phase Space



$p(s) = the\ probability\ of\ observing\ state\ s.$

$p(s)\ \alpha\ (\#\ points\ in\ s)$

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Fisher Information: Expressions

$$I = \int \frac{ds}{p(s)} \left[\frac{dp(s)}{ds}\right]^2 \quad \& \quad q(s) \equiv \sqrt{p(s)}$$

$$I = 4 \int \left[\frac{dq(s)}{ds}\right]^2 ds \cong 4 \sum_s \left[\frac{q(s) - q(s+1)}{s - (s+1)}\right]^2$$

$$\mathbf{I} \cong 4 \sum_s [q(s) - q(s+1)]^2$$

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Data

Study Variables:1900 – 2000

COMPONENT	CATEGORY	VARIABLES
SOCIAL (SOC)	*Population*	Total Population - Census
	Labor Force	Labor - Ag/Forestry/Fishing (000)
		Labor - Extractive (000)
		Labor - Manufacturing (000)
		Labor - Construction (000)
		Labor - Commerce/Finance/etc. (000)
		Labor - Transport/Communications (000)
		Labor - Services (000)
		Workers Involved (000)
	Education	Pupils in Schools (000)
		Students in Universities (000)
ECONOMIC (ECO)	*Industry*	Coal output Bituminous (000 mt)
		Crude Steel output (000 mt)
		Sulphuric Acid (000 mt)
	External Trade	Imports (mill $)
	Transport/Communication	Length of open railroad lines (km)
		RR traffic (mil passenger km)
	Finance	Currency in Circulation (mill)
		Central govt. revenue total (mill)
	Prices	Consumer price indices

Study Variables (2): 1900 - 2000

COMPONENT	CATEGORY	VARIABLES
ENVIRONMENTAL (ENV)	*Agricultural Crops*	Arable Cropland (000 ha) - wheat
		Arable Cropland (000 ha) - barley
		Arable Cropland (000 ha) - oats
		Arable Cropland (000 ha) - rye
		Arable Cropland (000 ha) - potatoes
		Crops (000 mt) - wheat
		Crops (000 mt) - barley
		Crops (000 mt)- oats
		Crops (000 mt) - rye
		Crops (000 mt) - potato
	Livestock	Horses (000)
		Cattle (000)
		Pigs (000)
		Sheep (000)

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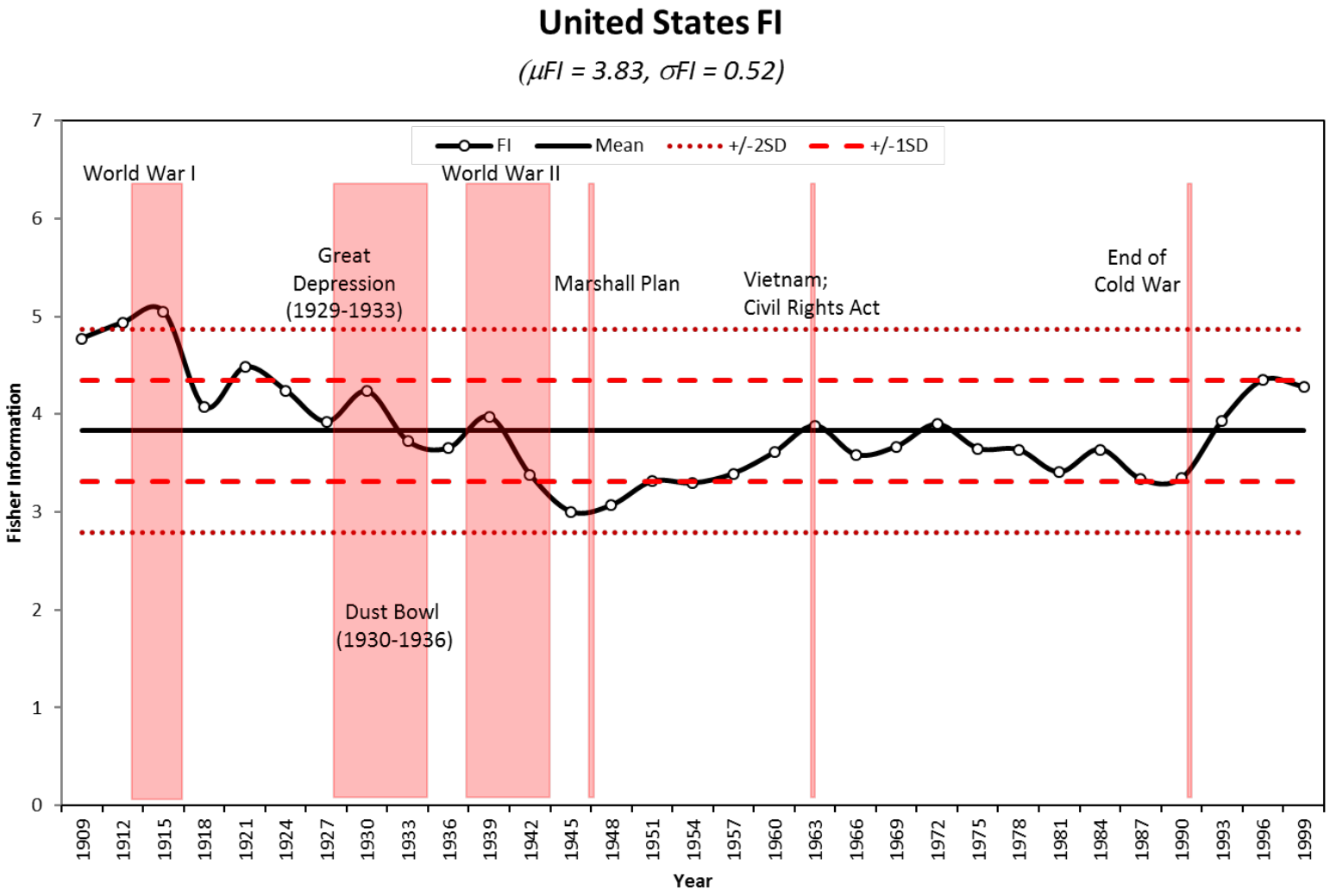
Results: Fisher Information

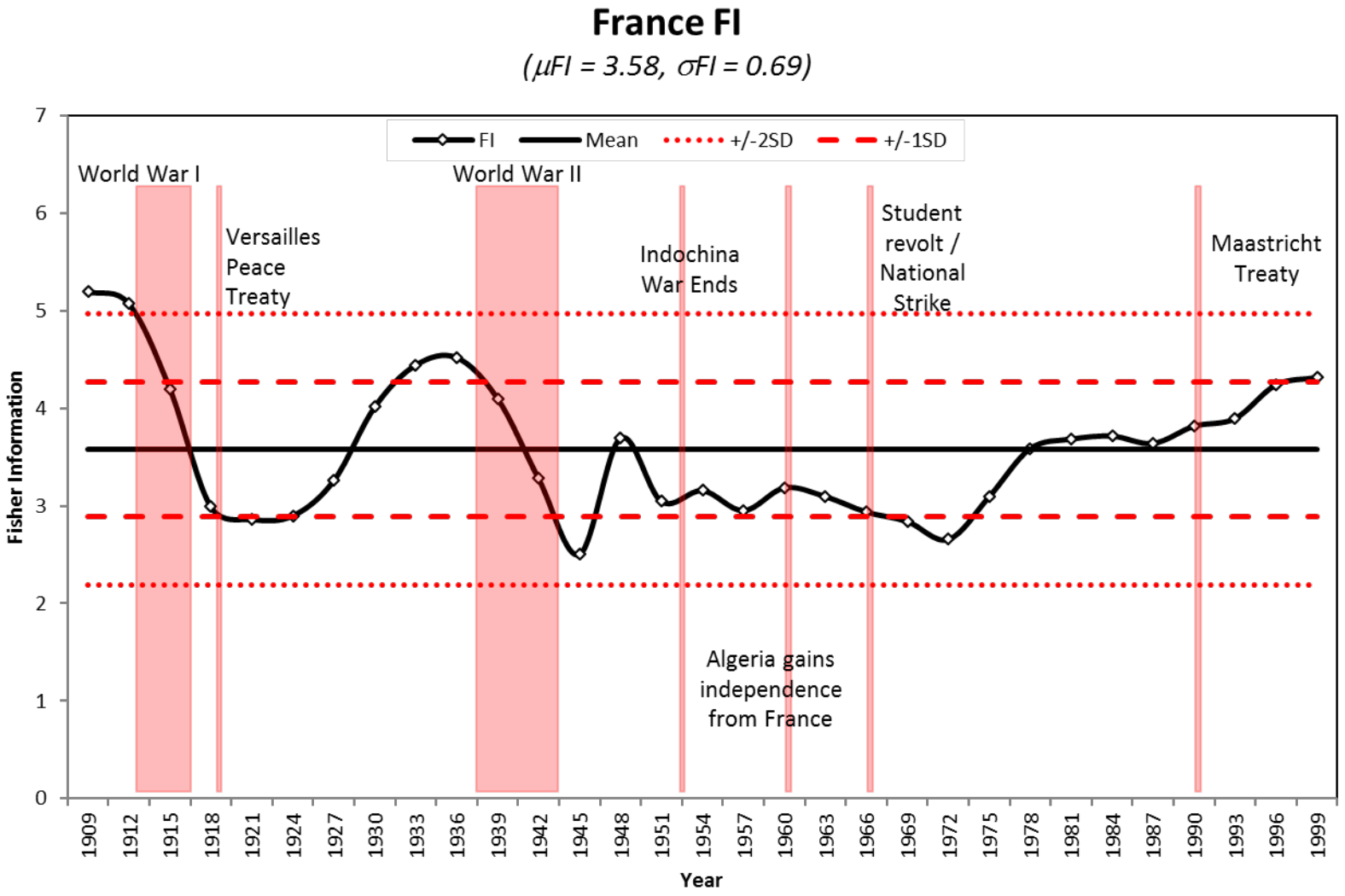
Regime Shifts (RS)

- Regimes shifts are major changes in the observable and stable behavior of dynamic systems.
- Examples:
  - Laminar Flow ⇔ Turbulent Flow
  - Economic Expansion ⇔ Economic Recession
  - Oligotrophic Lake ⇔ Eutrophic Lake
- Regime shifts involve a loss of dynamic order and are detectable from Fisher information analysis.

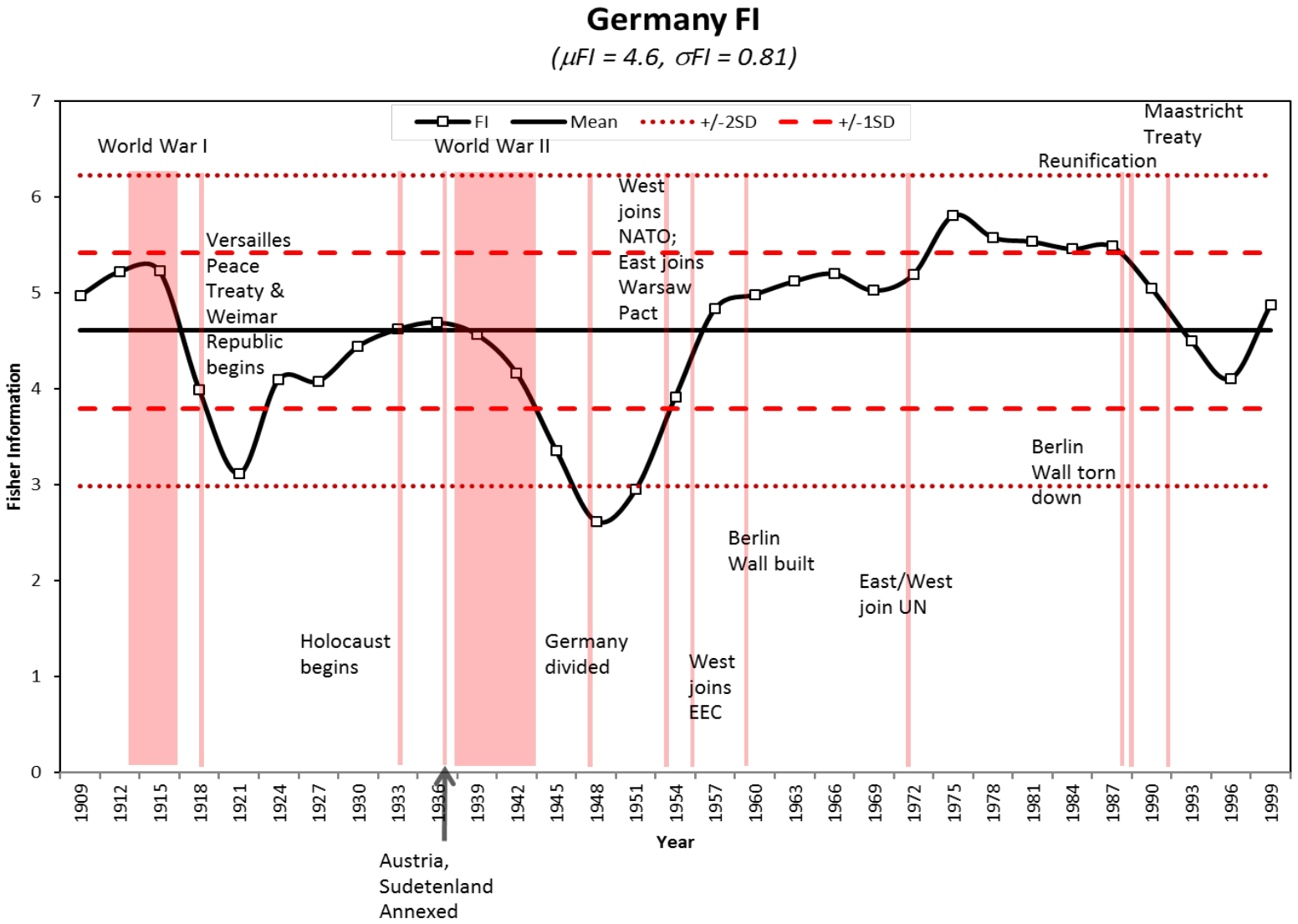
Fisher Information: USA



Fisher Information: France



Fisher Information: Germany



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Results: Bayes' Theorem

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Bayes' Theorem

$$p(a|b) = \frac{p(a)p(b|a)}{p(b)}$$

$p(a|b) \equiv probability\ of\ obersving\ event\ a$
$in\ the\ presence\ of\ event\ b.$

$p(a) \equiv probability\ of\ obersving\ event\ a.$

$$p(RS|D1) = \frac{p(RS)p(D1|RS)}{p(D1)} \qquad p(RS|D2) = \frac{p(RS)p(D2|RS)}{p(D2)}$$

$RS \equiv Regime\ Shift$
$D1 \equiv one\ time\ step\ decline\ in\ FI$
$D2 \equiv two\ consecutive\ time\ step\ declines\ in\ FI$

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Statistics for Declines in Fisher Information

Statistic	Description	France	Germany	USA
NumD1	Number of single declines in FI	14	14	14
NumD2	Number of FI declines over two points sequentially	8	8	5
$\mu D'$	Mean slope of declines	-0.1290	-0.1360	-0.0950
$\sigma D'$	Standard deviation of decline slopes	0.1260	0.1230	0.0870
P(D1)	Probability of a single decline: NumD1/PNumD1	48.3%	48.3%	48.3%
P(D2)	Probability of a double decline: NumD2/PNumD2	28.6%	28.6%	17.9%

Likelihood of Significant Events: Bayes' Theorem

Probability	Description	France	Germany	USA
P(RS@RS_CP1|D1)	Probability of regime shift at RS_CP1 if there are single declines in FI.	20.71%	13.81%	6.90%
P(RS@RS_CP2|D1)	Probability of regime shift at RS_CP2 if there are single declines in FI.	0.00%	6.90%	0.00%
P(RS@RS_CP1|D2)	Probability of regime shift at RS_CP1 if there are double declines in FI.	35.00%	23.33%	18.67%
P(RS@RS_CP2|D2)	Probability of regime shift at RS_CP2 if there are double declines in FI.	0.00%	11.67%	0.00%
P(SDE@SDE_CP1|D1)	Probability of severe decline event based on SDE_CP1 if there are single declines in FI.	27.62%	20.71%	13.81%
P(SDE@SDE_CP2|D1)	Probability of severe decline event based on SDE_CP2 if there are single declines in FI.	6.90%	6.90%	6.90%

Note: If a regime shift has been identified, there is a 100% probability that a decline has occurred; hence, P(D1/RS) or P(D2/RS) at any cut-off point = 100%.

Severe declines involve at least one decline event.

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Summary

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Summary

- Why is this important? Because a stable, orderly, and well-functioning social-environmental-economic regime is a prerequisite to sustainability.
- Stable, orderly, and well-functioning social-environmental-economic systems can have much variability but rarely regime shifts.
- It is important to know whether the system has had regime shifts and when and under what conditions.
- It is important to have an estimate of the likelihood that the system is moving to a regime shift so plans can be made accordingly.
- Fisher information analysis can give reasonably accurate answers to these and other questions.

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