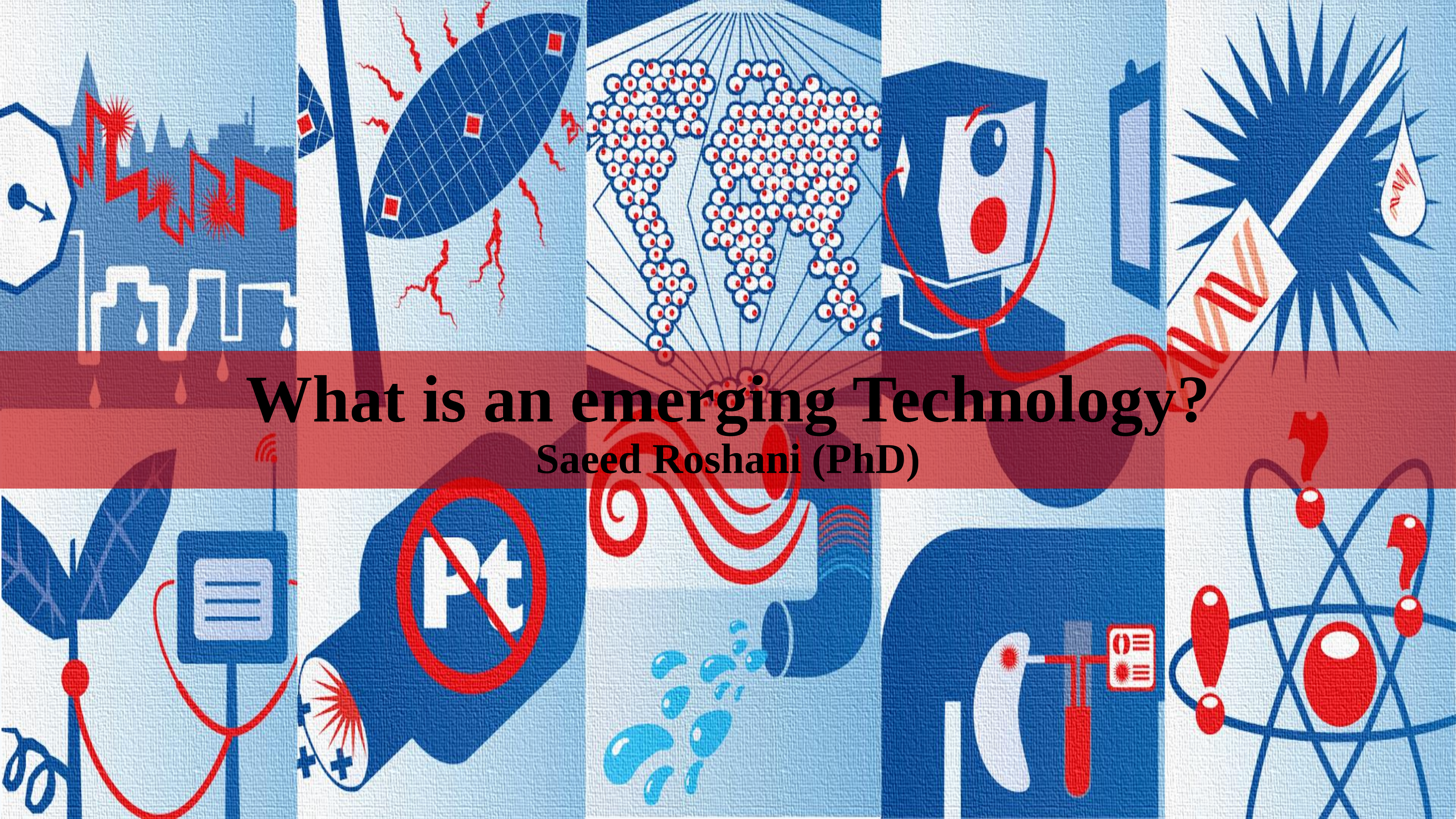


What is an emerging Technology?

Saeed Roshani (PhD)

ELSEVIER

Research Policy

Volume 44, Issue 10, December 2015, Pages 1827-1843

What is an emerging technology?

Daniele Rotolo [a] [b], Diana Hicks [b], Ben R. Martin [a] [c]

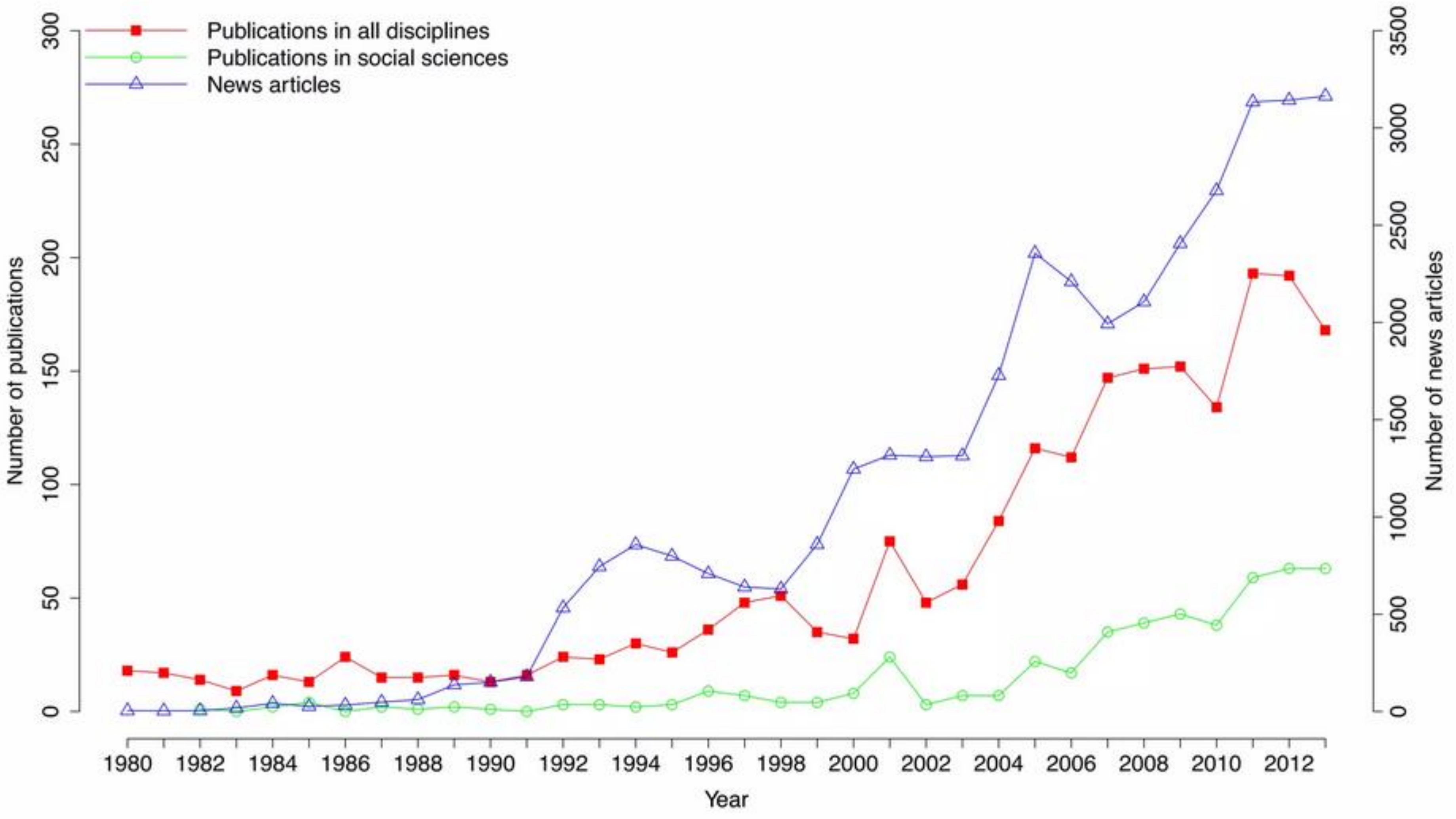
[a] SPRU – Science Policy Research Unit, University of Sussex, Brighton BN1 9SL, United Kingdom

[b] School of Public Policy, Georgia Institute of Technology, Atlanta 30332-0345, United States

[c] Centre for Science and Policy (CSAP) and Centre for Business Research, Judge Business School, University of Cambridge, Cambridge CB2 1QA, United Kingdom

Received 11 December 2014, Revised 15 June 2015, Accepted 16 June 2015, Available online 9 August 2015, Version of Record 9 August 2015.

The growing interest on emerging technologies



The problem

Growing interest, but no consensus on what qualifies a technology to be 'emergent'

- Proposed definitions overlap, but also point to different characteristics
    - extensive socio-economic impact (e.g. Porter et al., 2002)
    - long term impact (15-year horizon or so) (Porter et al., 2002)
    - uncertainty (Boon & Moors, 2008)
    - novelty and growth (Small et al., 2014)

- A variety of methodological approaches has been developed, especially in scientometrics, for the detection and analysis of emergence in science and technology

- These methods however build on relatively loose definitions of emerging technologies or often no definition at all is provided – methods tend to greatly differ also with the use of the same or similar techniques

2. Review of innovation studies

- We searched for "emerg* technolog*", "tech* emergence", "emergence of* technolog*" or "emerg* scien* technol*" in publication titles (SCOPUS)
- 2,201 publications were identified of which 501 in social science domains
- ~ 50% of these were not relevant (focus on specific industrial context or on the educational sector)
- A <u>core set of 12 studies</u> that contributed to the conceptualisation of technological emergence was identified

Study	Domain	**Definition** (elaborated or adopted)
Martin (1995)	S&T policy	"A 'generic emerging technology' is defined [...] as a technology the exploitation of which will yield benefits for a wide range of sectors of the economy and/or society" (p. 165)
Day and Schoemaker (2000)	Management	"emerging technologies as science-based innovation that have the potential to create a new industry or transform an existing ones. They include discontinuous innovations derived from radical innovations [...] as well as more evolutionary technologies formed by the convergence of previously separate research streams" (p. 30)
Porter et al. (2002)	S&T policy	"Emerging technologies are defined here as those that could exert much enhanced economic influence in the coming (roughly) 15-year horizon." (p. 189)
Corrocher et al. (2003)	Evolutionary economics	"The emergence of a new technology is conceptualised [...] as an evolutionary process of technical, institutional and social change, which occurs simultaneously at three levels: the level of individual firms or research laboratories, the level of social and institutional context, and the level of the nature and evolution of knowledge and the related technological regime." (p. 4)
Hung and Chu (2006)	S&T policy	"Emerging technologies are the core technologies, which have not yet demonstrated potential for changing the basis of competition" (p. 104)
Boon and Moors (2008)	S&T policy	"Emerging technologies are technologies in an early phase of development. This implies that several aspects, such as the characteristics of the technology and its context of use or the configuration of the actor network and their related roles are still uncertain and non-specific" (p. 1915)
Srinivasan (2008)	Management	"I conceptualize emerging technologies in terms of three broad subheads: their sources (where do emerging technologies come from?), their characteristics (what defines emerging technologies?) and their effects (what are the effects of emerging technologies on firms' strategies and outcomes?)." (p. 634)
Cozzens et al. (2010)	S&T policy	"Emerging technology — a technology that shows high potential but hasn't demonstrated its value or settled down into any kind of consensus." (p. 364) "The concepts reflected in the definitions of emerging technologies, however, can be summarised four-fold as follows: (1) fast recent growth; (2) in the process of transition and/or change; (3) market or economic potential that is not exploited fully yet; (4) increasingly science-based." (p. 366)
Stahl (2011)	S&T policy	"[...] emerging technologies are defined as those technologies that have the potential to gain social relevance within the next 10 to 15 years. This means that they are currently at an early stage of their development process. At the same time, they have already moved beyond the purely conceptual stage. [...] Despite this, these emerging technologies are not yet clearly defined. Their exact forms, capabilities, constraints, and uses are still in flux" (p. 3-4)
Alexander et al. (2012)	S&T policy	"Technical emergence is the phase during which a concept or construct is adopted and iterated by [...] members of an expert community of practice, resulting in a fundamental change in (or significant extension of) human understanding or capability." (p. 1289)
Halaweh (2013)	Management	Characteristics of (IT) emerging technologies "are uncertainty, network effect, unseen social and ethical concerns, cost, limitation to particular countries, and a lack of investigation and research." (p. 108)
Small et al. (2014)	Scientometrics	"[...] there is nearly universal agreement on two properties associated with emergence — novelty (or newness) and growth." (p. 2)

2. Review of innovation studies

Attributes of emergence

We analysed the textual content of the proposed definitions to extract all the <u>component concepts</u> and grouped those into attributes of emergence

	Innovation studies defining emerging technologies											
Attribute of emergence	Martin (1995)	Day and Schoemaker (2000)	Porter et al. (2002)	Corrocher et al. (2003)	Hung and Chu (2006)	Boon and Moors (2008)	Srinivasan (2008)	Cozzens et al. (2010)	Stahl (2011)	Alexander et al. (2012)	Halaweh (2013)	Small et al. (2014)
Radical novelty		x									x	x
Relatively fast growth							x	x				x
Coherence		x					x		x	x		
Prominent impact	x	x	x	x	x		x	x	x	x		
Uncertainty and ambiguity		x	x		x	x		x	x		x	

Radical novelty

- Included in 2/12 definitions: "novelty (or newness)" (Small et al., 2014),"discontinuous innovations derived from radical innovations" (Day & Schoemaker, 2000)

- To achieve a new or a changed purpose/function, emerging technologies build on different basic principles (e.g. cars with an internal combustion engine vs. an electric engine) (Arthur, 2007)

- Revolutionary/evolutionary technologies and radical novelty (see Adner & Levinthal, 2002)
  - 'Revolutionary' – technologies with relatively limited prior developments (nano-materials, DNA sequencing)
  - 'Evolutionary' – niches and speciation process (e.g. wireless communication technology), but also incremental technological advances

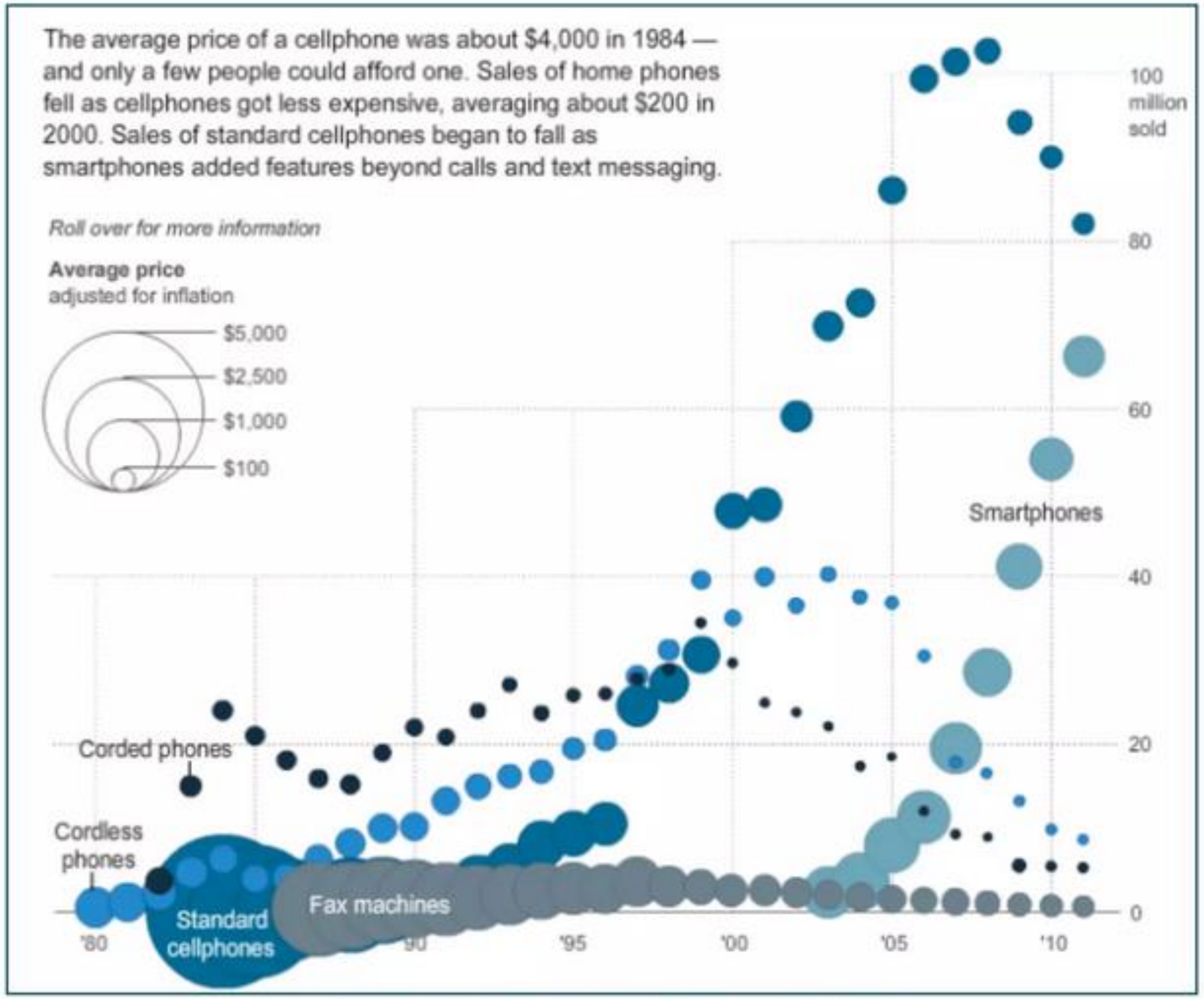
- 'Novelty' vs. 'radical novelty'

Relatively fast growth

- Included in 3/12 definitions: "fast clock speed" (Srinivasan, 2008) or "fast growth" (Cozzens et al., 2010), or "growth" (Small et al., 2014)

- Growth may be observed across a number of dimensions (e.g. actors, public and private funding, publications, patents, prototypes, products)

- The context matters: A technology may grow rapidly in comparison with other technologies in the same domain(s) which may be growing at a slower pace



Source: Consumer Electronic Association (2011)

Coherence

- Included in 4/12 definitions: "convergence of previously separated research streams" (Day & Schoemaker, 2000), "convergence in technologies" (Srinivasan, 2008), technologies that "have already moved beyond the purely conceptual stage" (Stahl, 2011)

- Also as arising of "an expert community of practice" that adopts and iterates the concepts or constructs" (Alexander et al., 2012)

    - Both a <u>number of people and a professional connection between those people</u> are necessary – *coherence refers to internal characteristics of a group such as 'sticking together', 'being united', 'logical inter- connection' and 'congruity'*

    - <u>The status of external relations</u> is also important – the emerging technology must detach itself from its technological 'parents' to some degree to merit a separate identity (Glanzel and Thijs, 2012)

Prominent impact

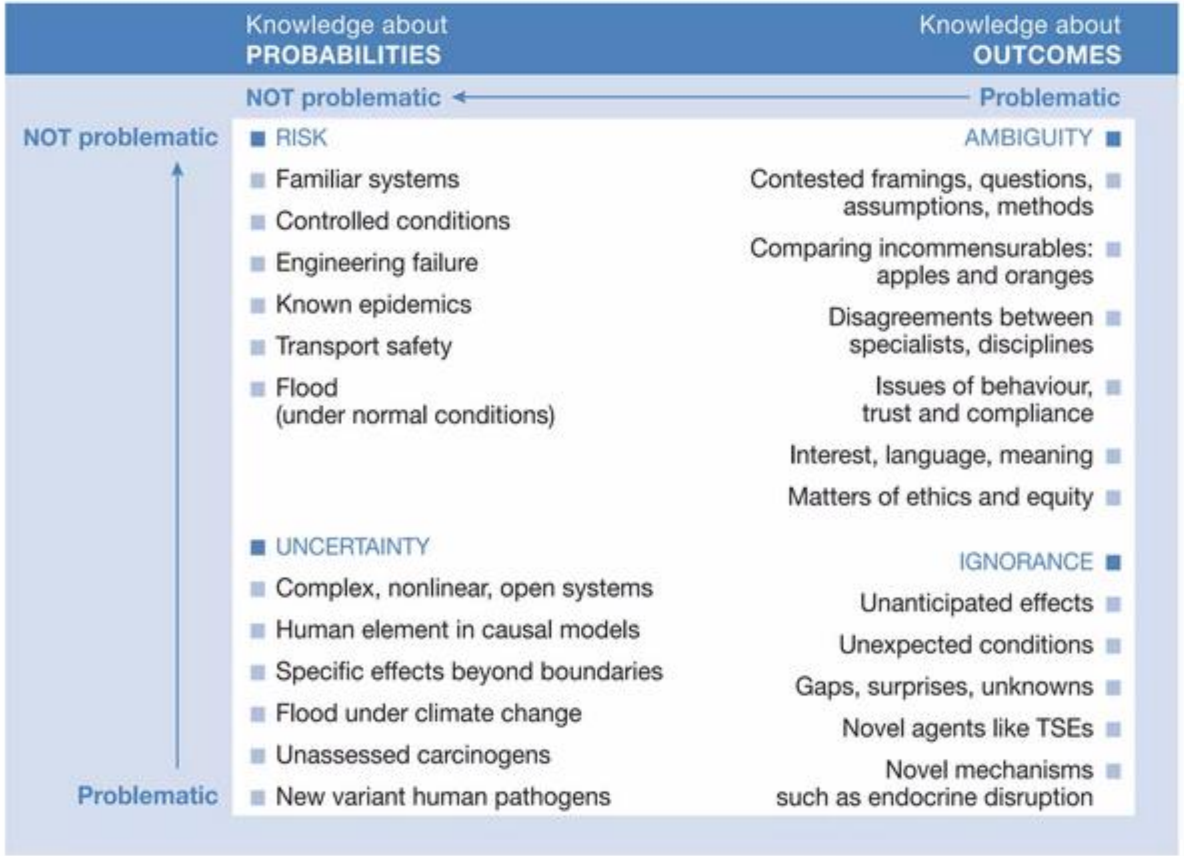
- Included in 9/12 definitions: ”benefits for a wide range of sectors” (Martin, 1995), ”create new industry or transform existing ones” (Day & Schoemaker, 2000), or change ”the basis of competition” (Hung & Chu, 2006), etc.

- This conceptualisation inevitably excludes technologies that may still exert a prominent impact within specific domains

- ‘Scope’ of a technology: few vs. many domains (‘GPT’) of applications

Uncertainty and ambiguity

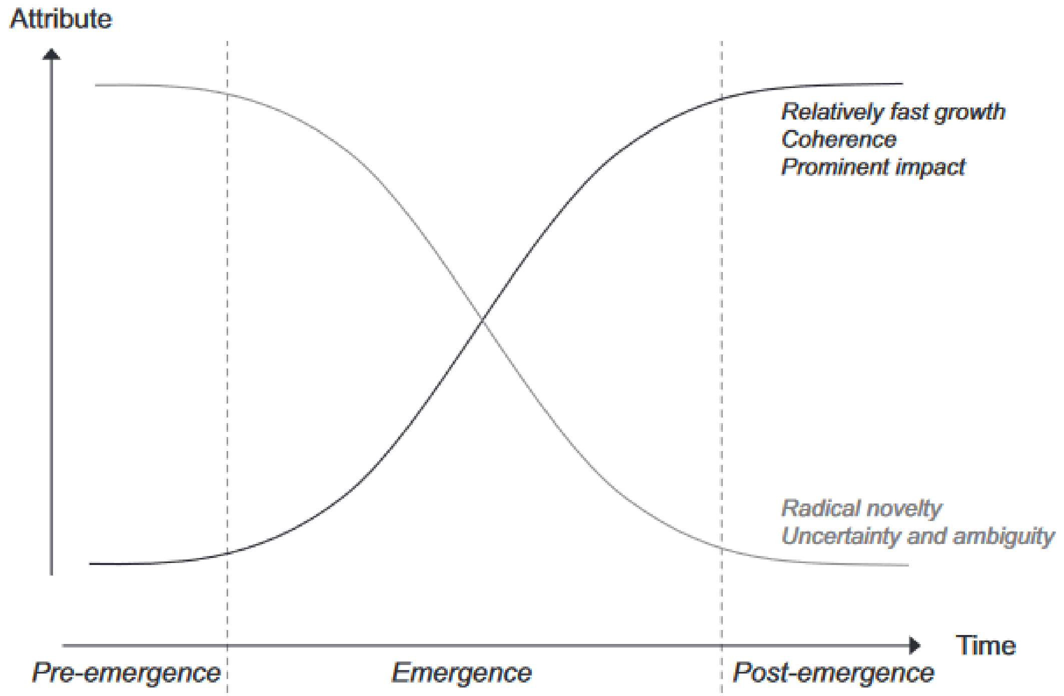
- 'Uncertainty' (identified in 6/12 definitions) is generally expressed in terms of the 'potential' that emerging technologies have for changing the existing 'ways of doing things' (e.g. Boon & Moors, 2008; Cozzens et al., 2010)



Source: Stirling (2007)

An **Emerging Technology** is a **radically novel** and **relatively fast growing** technology characterized by a certain degree of coherence persisting over time and with the potential to exert a considerable impact on the socio-economic domain(s) which is observed in terms of the composition of actors, institutions and patterns of interactions among those, along with the associated knowledge production processes.

Its most prominent impact, however, lies in the future and so in the emergence phase is still somewhat uncertain and ambiguous.



	Contemporary analysis	*Retrospective analysis*
Radical novelty	Content analysis of • news articles • editorials • reviews	Citation and co-word analyses • New clusters linking otherwise weakly connected clusters (e.g. Furukawa et al., 2015) or citing more recent clusters (e.g. Morris et al., 2003) • Clusters that are new to both the co-citation and the direct citation model (Small et al., 2014) Overlay mapping • Use of new knowledge bases (Rafols et al., 2010)
Relatively fast growth	*Not yet observed in scientometric data*	Indicators and trend analysis • Yearly count of documents (including modelling) • 'Bursts of activity' (Kleinberg, 2002) • Increasing number of authors (Bettencourt et al., 2008) Citation and co-word analyses • Growth of clusters (e.g. Ohniwa et al., 2010)
Coherence	Indicators and trend analysis • Appearance of abbreviations (Reardon, 2014) and categories (Cozzens et al., 2010) • Creation of conference tracks, journal SI, and new journals (Leydesdorff et al., 1994)	Indicators and trend analysis • Entropy measures (e.g. Watts & Porter, 2003) • Dense sub-graphs in co-authorship networks (e.g. Bettencourt et al., 2009) Citation and co-word analyses • Dense sub-graphs citation/co-word networks (e.g. Yoon et al, 2010, Furukawa et al., 2015)
Prominent impact	*Not yet observed in scientometric data*	*Impact seems to be taken for granted*
Uncertainty & ambiguity	*Measurement challenges*	*Efforts in measuring uncertainty reduction with Triple-Helix models (Lucio-Arias & Leydesdorff, 2009), but this area remains largely unexplored*

"Discovering Cutting-Edge Technologies:

A Guide to Identifying Emerging Trends."

Step 1: Extract the most prominent technologies through co-word analysis.

Extract the key technologies that you identified through word co-occurrence analysis from the original dataset. In this step, you may need to search for and combine several words based on the word guide you created in the previous step.

```python
# Create a list of keywords to search for
keywords_to_search = ['deep learning', 'machine learning', 'videomicroscopy', 'biosensor', 'imaging', 'digital pathology', '2D-barcode', 'digital imaging', 'image processing', 'neural network']
```

Step 2: Extract the refined Excel file that includes your keywords and clean it manually.

Combine all keywords that fall into one group. For example, if you have supervised learning, unsupervised learning, and machine learning, you need to merge their values.

Year	2D-barcode	deep learning	digital imaging	digital pathology	image processing	imaging	machine learning	neural network	videomicroscopy
1995	0	0	0	0	0	0	0	0	1
1996	0	0	1	0	0	0	0	0	5
1997	0	0	1	0	0	0	0	0	10
1998	0	0	1	0	2	0	0	0	6
1999	0	0	3	0	0	1	0	0	5
2000	0	0	2	0	2	0	0	0	11
2001	0	0	0	0	0	0	0	0	10
2002	0	0	1	0	1	0	0	1	9
2003	0	0	1	0	2	1	0	0	5
2004	0	0	2	0	3	0	0	0	14
2005	0	0	0	0	1	0	0	1	6
2006	0	0	2	2	1	2	0	0	6
2007	0	0	0	1	0	0	0	0	6
2008	0	0	0	2	2	1	0	0	7
2009	0	0	0	4	1	0	0	0	2
2010	0	0	2	2	2	0	0	0	1
2011	0	0	1	3	2	0	0	0	1
2012	0	0	3	9	1	0	0	0	2
2013	0	0	1	6	1	1	1	0	1
2014	0	0	2	13	0	0	0	0	2
2015	0	0	0	8	1	0	1	0	0
2016	0	1	1	11	1	0	0	0	0
2017	0	0	1	23	2	0	1	0	1
2018	0	2	2	25	1	2	3	0	0
2019	0	11	0	47	0	0	5	0	1
2020	0	25	0	49	2	2	12	0	0
2021	1	42	0	104	3	1	20	0	2
2022	0	44	1	97	2	1	22	1	2

Step 3-1: Calculating “CAGR” and “Share of technologies”

In this step, you will calculate the Compound Annual Growth Rate (CAGR) and the share of technologies in order to determine the technological landscape.

$$CAGR = \left(\frac{\text{Ending Value}}{\text{Beginning Value}}\right)^{\left(\frac{1}{\text{\# of years}}\right)} - 1$$

The Compound Annual Growth Rate (CAGR) is a measure used in technology forecasting and other fields to represent the average annual growth rate of a quantity over a specified period of time, taking into account the compounding effect. It is commonly used to estimate the future growth of technologies, products, or markets based on historical data.

```python
# Calculate CAGR for each keyword
result_cagr = pd.DataFrame(index=new_df.columns, columns=['CAGR'])
for keyword in new_df.columns:
    start_value = new_df[keyword].loc[new_df[keyword].ne(0).idxmax()]  # First non-zero value
    end_value = new_df[keyword].iloc[-1]  # Value in the last row
    n = new_df[keyword].ne(0).sum()  # Number of non-zero values
    cagr = (end_value / start_value)**(1 / n) - 1  # Calculate CAGR
    result_cagr.at[keyword, 'CAGR'] = cagr if cagr != np.inf else np.nan
```

Step 3-2: Calculating “CAGR” and “Share of technologies”

In this step, you will calculate the Compound Annual Growth Rate (CAGR) and the **share of technologies** in order to determine the technological landscape.

The purpose of this criteria is to calculate and store the share of keywords based on the sum of values for the last two years compared to the total sum of values in a specific column, expressed as a percentage.

```
# Calculate share of keywords
result_share = pd.DataFrame(index=df.columns, columns=['Share'])
for keyword in new_df.columns:
    last_two_years_sum = new_df[keyword].iloc[-2:].sum()  # Sum of values for last two years
    total_sum = new_df[keyword].sum()  # Sum of all years
    share = (last_two_years_sum / total_sum) * 100  # Calculate share as percentage
    result_share.at[keyword, 'Share'] = share
```

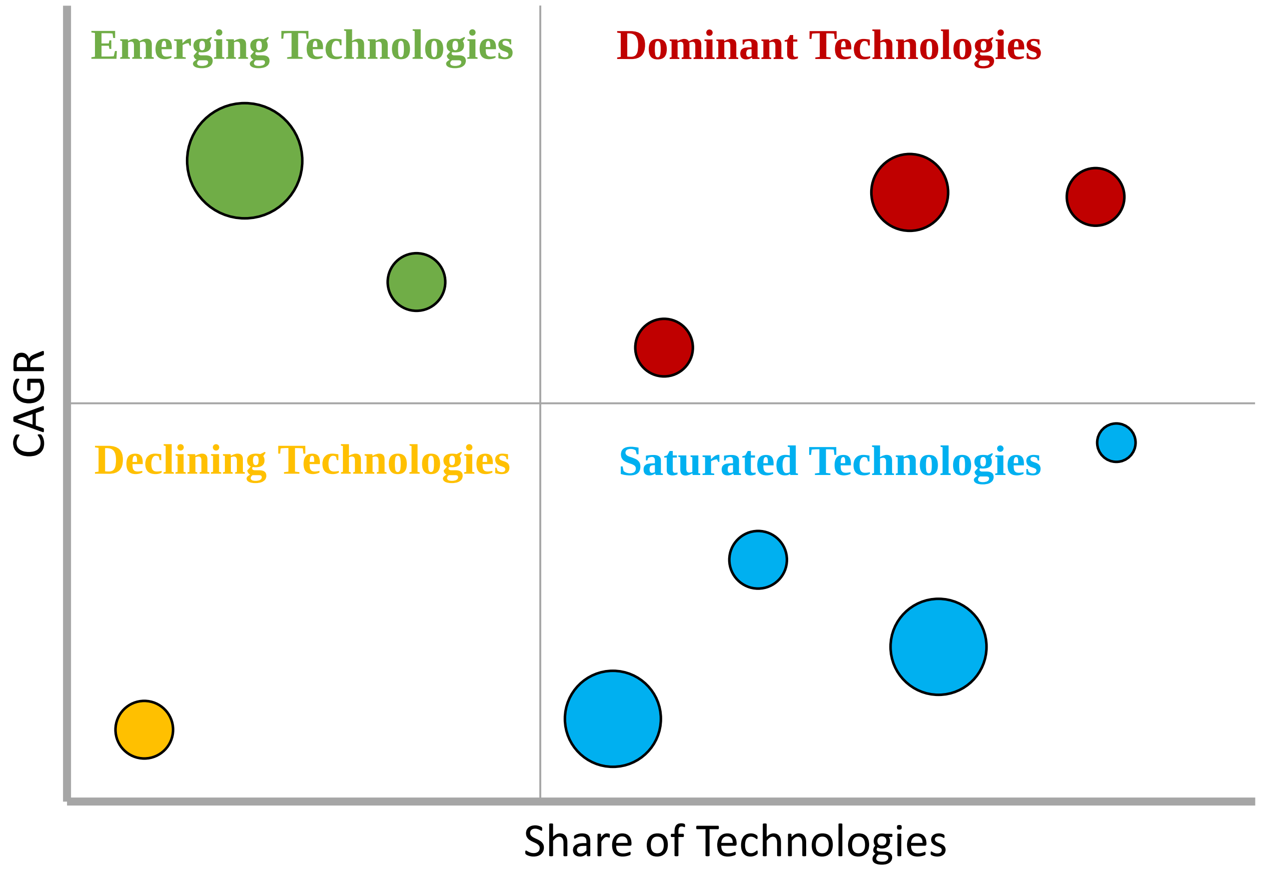
Step 4: Mapping Technological Landscape

Using Compound Annual Growth Rate (CAGR) and the share of technologies, you can map the status of technologies.

1- You need to place CAGR on the y-axis and the share of technologies on the x-axis of a scatter plot.

2-Split the x-axis using the average of the share of technologies and 0 for CAGR.

3- By employing this method, you will have four quadrants.



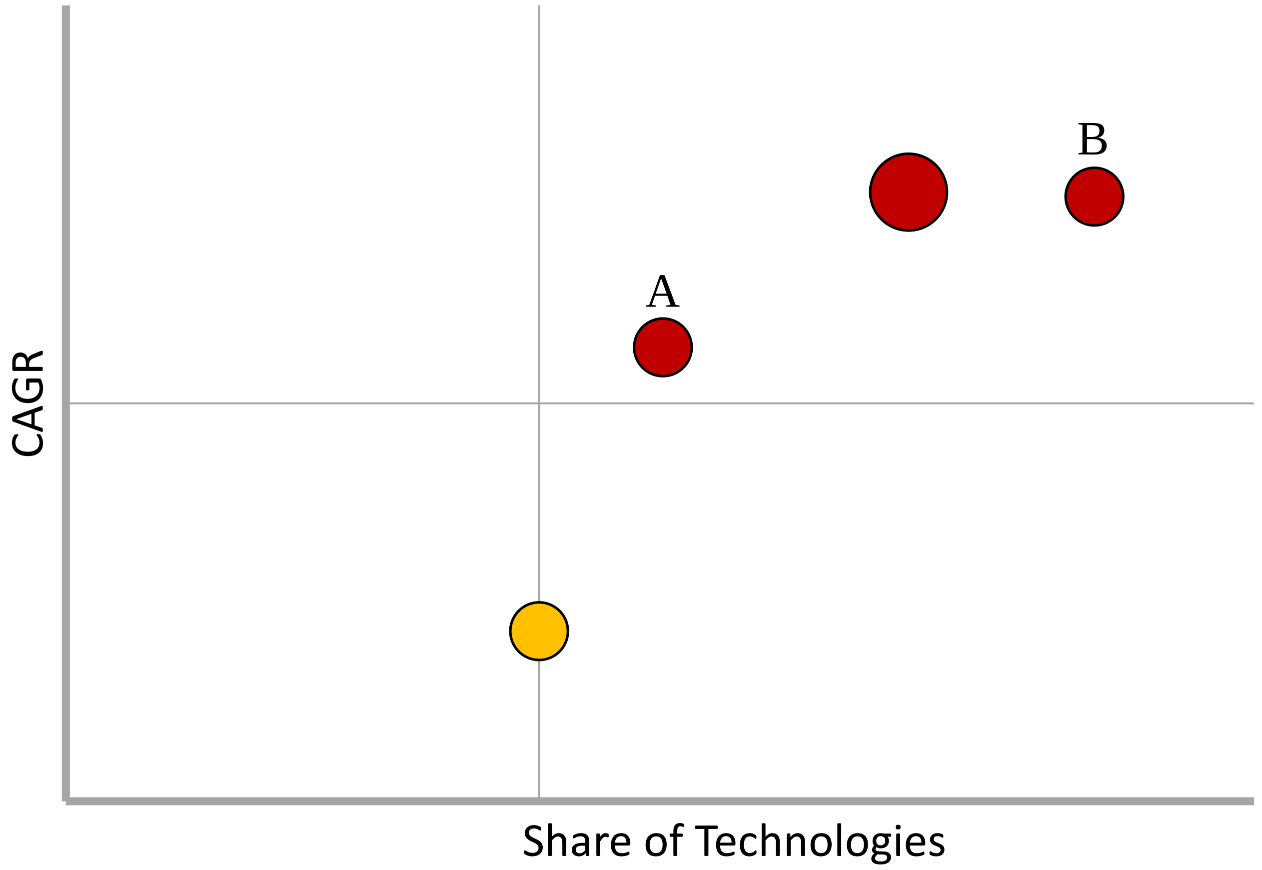
If CAGR $>$ 0 and Share $<$ mean()

If CAGR $>$ 0 and Share $>$ mean()

If CAGR $<$ 0 and Share $>$ mean()

If CAGR $<$ 0 and Share $<$ mean()

What are the differences Between Technology A and B?



What happens if technology D falls across the border?

The **Mann-Kendall** test is a statistical test used to determine the presence of **trend** (either **increasing** or **decreasing**) in a dataset over time. It is a non-parametric test, meaning it does not assume any specific distribution for the data, making it suitable for analyzing data with unknown or non-normal distributions.

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1} \text{sign}(x_j - x_k)$$

$$\text{sign}(x_j - x_k) = \begin{cases} 1 \text{ if } x_j - x_k > 0 \\ 0 \text{ if } x_j - x_k = 0 \\ -1 \text{ if } x_j - x_k < 0 \end{cases}$$

sgn() is the sign function, which returns -1 for negative values, 0 for zero, and 1 for positive values.
Xi and Xj are the values of the dataset at positions i and j, respectively.
n is the total number of data points in the dataset.

The test statistic S represents the sum of signs of the differences between pairs of data points in the dataset. It measures the number of concordant pairs (where the signs of the differences are consistent) and discordant pairs (where the signs of the differences are inconsistent).

$$Var(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{n} t_i(i)(i-1)(2i+5)}{18}$$

where:
tj is the number of tied groups of data points with a tie of j.
∑tj represents the sum of tj over all values of j.

Once the test statistic S and the variance Var(S) are calculated, the z-score can be calculated as:

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} & for \quad S > 0 \\ 0 & for \quad S = 0 \\ \frac{S+1}{\sqrt{Var(S)}} & for \quad S < 0 \end{cases}$$

The z-score is used to calculate the p-value, which can be compared to a chosen significance level (e.g., 0.05) to determine the statistical significance of the test result. If the p-value is smaller than the chosen significance level, the null hypothesis of no trend is rejected, indicating the presence of a significant trend in the dataset.

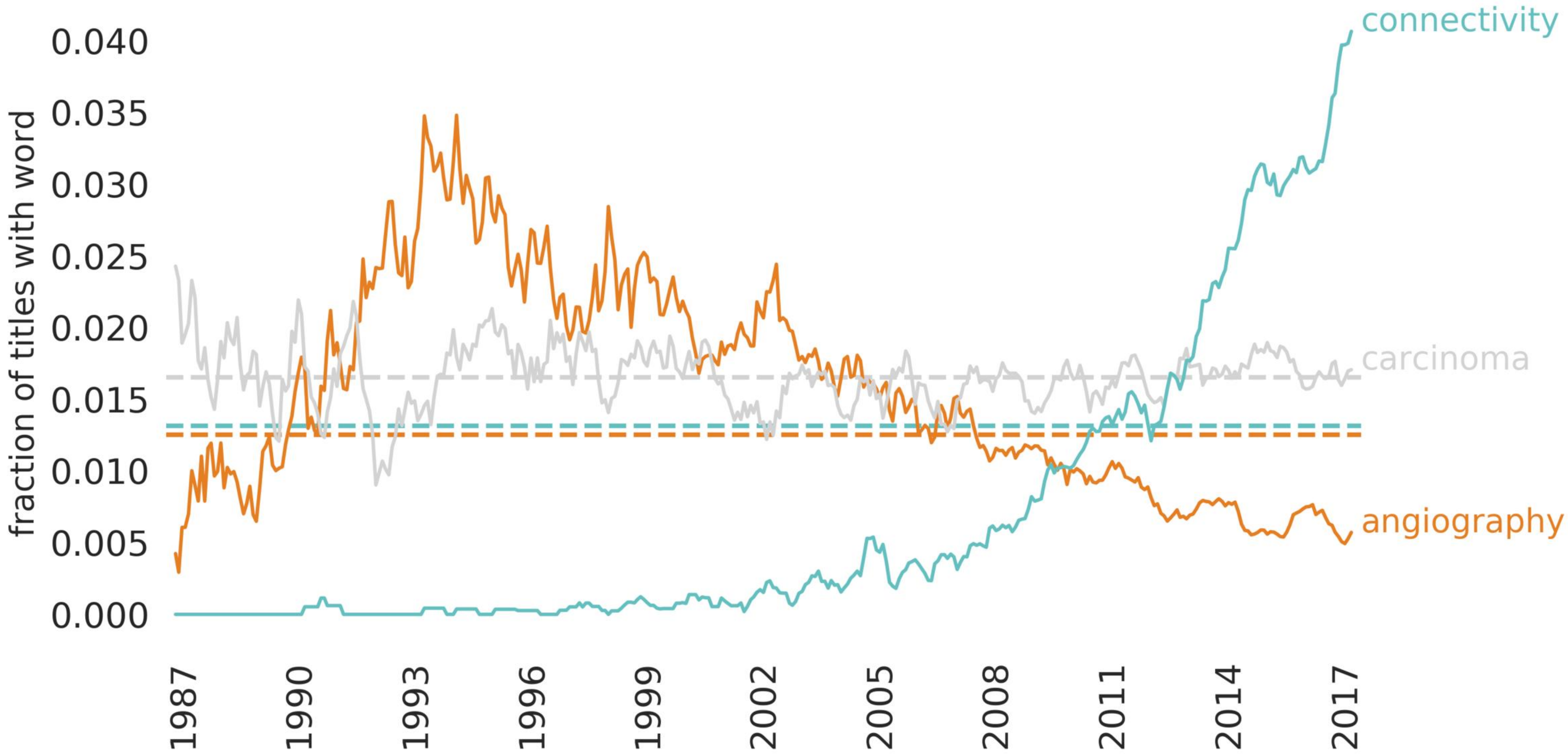
Check Excel File for Calculations

```python
# Save the results DataFrame to a CSV file
results_df.to_csv('Kendal.csv', index=False)
```

Keyword	Test Statistic	p-value	Trend	h	z	Tau	s	var_s	slope
2D-barcode	no trend	FALSE	0.137395	1.485563	0.066138	25	261	0	0
deep learning	increasing	TRUE	6.69E-05	3.987202	0.383598	145	1304.333	0	0
digital imaging	no trend	FALSE	0.571991	-0.56512	-0.07407	-28	2282.667	0	1
digital pathology	increasing	TRUE	5.88E-10	6.19357	0.804233	304	2393.333	0.922619	-10.4554
image processing	no trend	FALSE	0.096132	1.663901	0.214286	81	2311.667	0	1
imaging	no trend	FALSE	0.100389	1.642972	0.18254	69	1713	0	0
machine learning	increasing	TRUE	9.06E-06	4.438457	0.473545	179	1608.333	0	0
neural network	no trend	FALSE	0.823664	0.222834	0.018519	7	725	0	0
videomicroscopy	decreasing	TRUE	0.000574	-3.44345	-0.45767	-173	2495	-0.28571	5.857143

trend: tells the trend (increasing, decreasing or no trend)
h: True (if trend is present) or False (if the trend is absence)
p: p-value of the significance test
z: normalized test statistics
Tau: Kendall Tau
s: Mann-Kendal's score
var_s: Variance S
slope: Theil-Sen estimator/slope

Now Look at this graph….
What is the differences between these lines?




Standard Deviation (m³/h)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0:00
4:00
8:00
12:00
16:00
20:00
23:45
Time