Global Nanotechnology Development: Nano 1 (2000-2010) vs. Nano 2 (2011-2014) (NSF CMMI-1442116)

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❖ Introduction

- Nanotechnology—Science for control and restructuring of matter at the atomic, molecular, and supramolecular levels, in order to create materials, devices, and systems for innovative functions (Roco et al., 2010)
  - An indicator of a country's technology competence and a national priority for many industrialized countries
- **Nano 1:** The first decade (2000-2010) of nanotechnology development since National Nanotechnology Initiative (NNI) was announced
- **Nano 2:** A vision of nanotechnology development in the next decade (2011-2020) (Roco et al. 2011)

- Four years have passed since Nano 2. We need a longitudinal evaluation of the nanotechnology development progress in comparison with Nano 1.
- According to the Presidential Council of Advisors on Science and Technology (PCAST) report (2014), United States, EU, Japan, and China were international leaders in published nanotechnology papers and patents. We focused on these four countries (regions) to obtain better understanding of global nanotechnology development.
- In this research, we evaluate global nanotechnology development in the first four years of Nano 2 and compare the progress with Nano 1.

- To better understand nanotechnology development, two sets of keywords defined by NSF were adopted (Table 1).
  - The **Original Keywords** (7) to be used for all NSF searches in 2000-2010 (Nano 1)
  - To capture emerging topics in nanotechnology, the **Combined Keywords** (original 7 keywords + update for quantum + 18 new terms) are used for all NSF searches in 2011-2014 (Nano 2).
  - We use **New Keywords** to denote the difference between Combined Keywords and Original Keywords, which are 18 new terms and 1 updated term.

Combined Keywords (Nano 2)

7 Original Keywords (Nano 1)

1. selfassembl* | self assembl* | self-assembl*
2. atom* model* | atom* simulat* | atomistic* system* | atomistically-based model*
3. molecular model* | molecular simulat*
4. scanning tunnel* | scanning tunneling microscop* | STM | atomic force * | atomic force microscop* | AFM
5. molecular motor* | molecular biomotor* | biomolecular motor*
6. quantum dot*
7. nano*electromechanical system* | nanoelectromechanical system* | nano*electromechanical device* | nanoelectromechanical device* | nano*electromechanical resonator* | NEMS | nanoelectromechanical resonator*

Term Update

quantum dot* -> quantum dot* | quantum comput* | quantum device* | quantum electronic* | quantum well*

18 Additional Terms

1. plasmonic*
2. meta-material* | metamaterial*
3. spintronic*
4. molecular system*
5. supramolecul*
6. fullerene*
7. dendrimers*
8. graphen*
9. two-dimensional material* | atom* thick layer* | 2D AND material
10. atom* layer deposition* | ALD
11. artificial photosynthes*
12. cellulose fiber* | cellulose tube*
13. optoelectronic* | opto-electronic*
14. bio-photonics* | biophotonic*
15. opto-genetic* | optogenetic*
16. DNA computing* | DNA assembling*
17. proteomic*
18. synthetic biolog*

Table 1. Nano keywords defined by NSF

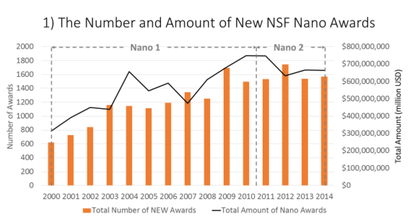
❖Research Framework

- **Descriptive Analysis**
  - Compare the evolution of the numbers of nanotechnology-related NSF awards, patents, and papers in Nano 1 (2000-2010) and the first few years of Nano 2 (2011-2014)
  - Compare the evolution of the numbers of patents and papers queried with Original Keywords and Combined Keywords in the first four years of Nano 2 (2011-2014)
- **Statistical Tests**
  - ANOVA tests and Post-hoc Tukey's tests to compare the growth rates:
    - Compare Nano 1 vs Nano 2
    - Between regions
  - The aim is to better understand the development speed and region difference of nanotechnology development.

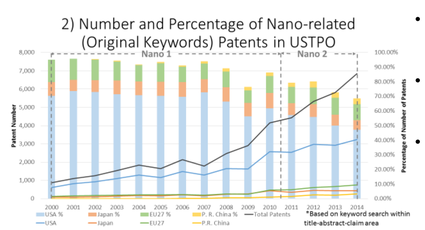
❖ Research Testbeds

- **Award Data**
  - We obtained award data from NSF. **Original keywords** were used to retrieve NSF award data up to 2010. For 2011-2014, **combined keywords** were used.
- **Patent Data**
  - For consistency across years, we collected USPTO based on the title, abstract, and claim of patents using **original keywords** for all years.
  - To perform a comparison between the original keywords and the combined keywords in 2011-2014, **combined keywords** were also used to query patent data in 2011-2014.
- **Publication Data**
  - For consistency, nano-related publication data was queried from Thomson Reuters ISI database using **original keywords** for all years.
  - To perform a comparison between the original keywords and the combined keywords in 2011-2014, **combined keywords** were also used to query publication data in 2011-2014.

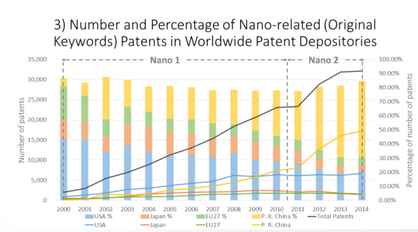
❖ Results



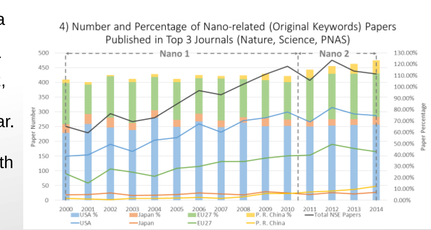
- The NSF funding for nanotechnology increased in Nano 2 compared to Nano 1 in terms of both the number of awards and the total amount funded.



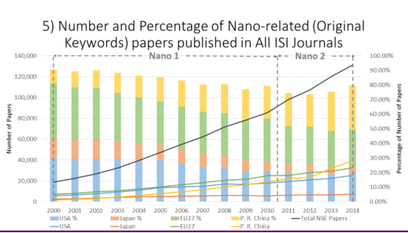
- US still has the dominant number of patents in USPTO.
- China has an increasing share of patents in USPTO.
- No significant difference between growth rates across regions and time-periods.



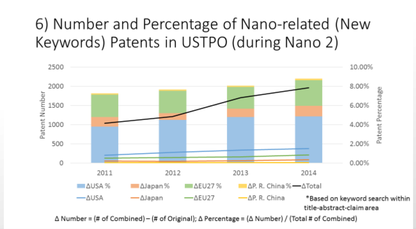
- China experienced a great increase in terms of the number of patents in Nano 2, and its share is increasing every year.
- A follow-up Tukey's test shows the growth rate in Nano 2 is significantly lower than Nano 1.



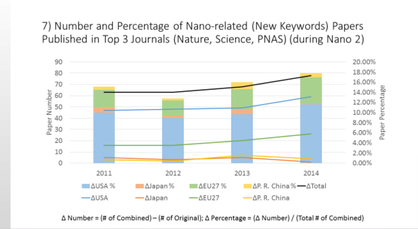
- EU and China are gaining more shares in the top 3 journals.
- No significant difference between growth rates across regions and time-periods.



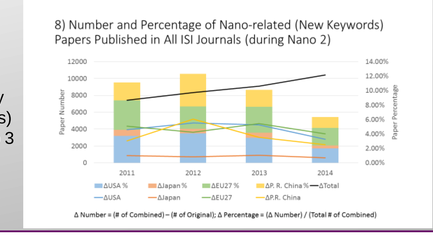
- China exceeded US in 2010, and exceeded EU in 2013.
- Tukey's test shows China's growth rate is significant higher than other regions in two time periods.



- The patent shares of US, EU, and Japan indicate that those regions are leading the development in the new area.
- China is not yet competitive in this area from the patent perspective.



- New-Keywords-related papers took up 11%~15% of all the nano-related papers (searched by Combined Keywords) published in the Top 3 journal.
- US is the dominant publishing region.



- Unlike the less competitive role from the patents' perspective, China was playing an active role in this research area from paper publishing perspective.

❖ Conclusions

- In Nano 2, USPTO patents increased by 15.7% per year, WIPO patents increased by 11.3% per year, Top-3 Journal publications increased by 1.8% per year and all ISI journal publications increased by 10.2% per year.
- The annual growth rates of patents in WIPO (11.3%) and papers in ISI All Journal (10.2%) were lower than the corresponding rates in Nano 1, which were 27.5% and 16.2%.
- US is still the dominant player in terms of the number of patents in USPTO and the number of publications in top 3 journals, but its share is decreasing.

- China is experiencing a significant growth in terms of the number of patents in worldwide patent depositories, and the number of publications both in top 3 journals and all ISI journals. Its share in these areas are also increasing.
- In areas identified by New Keywords, US and EU are the leading countries in both papers and patents perspective. Although China has not yet established its position in USPTO patent publication, its number of published papers in ISI All Journals still takes up a relatively high portion.

❖Next Steps

- We noticed from the research that Japan's share in nanotechnology research is decreasing while China is playing more active role in this area. A follow up study on Japan and China's different development patterns will bring us insights into East Asia's nanotechnology market.
- Since Nano 2, nanotechnology applied to numerous fields and commercialization. The rapid development of nanotechnology brings environmental health and safety (EHS) risks. Identifying potential EHS risks is the first steps towards understanding and mitigating their negative impacts. We are going to approach this question by following steps:
  - Crawling online contents (e.g., news and comments, forum posts, social media messages and etc.) to construct a multi-source data collection.
  - Applying text mining techniques to extract named entities related with nanotechnology's EHS risks and to capture the sentiments of the public towards the risks.
  - Analyzing the potential EHS risk.

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