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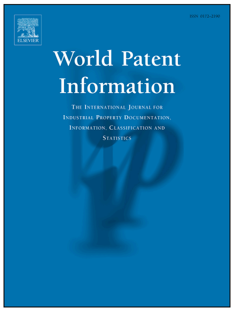

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Patenting Activity in the Food Safety Sector

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Abstract

Research on science and technology policy has heavily relied on patent data. However, relatively few studies of food safety patent activity appear in scholarly literature. This paper provides a discussion on patents as a measure of new knowledge generation in the food safety sector. In so doing, there are inherent challenges to identifying a research taxonomy for this multidisciplinary area. To overcome these challenges, the paper uses a natural language approach that can be applied to other research areas where boundaries of fields are not well defined.

Keywords: food safety; patent; machine learning; research taxonomy

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Patenting Activity in the Food Safety Sector

1. Introduction

Food safety is a national priority in the United States and around the world. In a 2010 report [1], the Centers for Disease Control and Prevention stated that one in every six people in the United States gets sick from foodborne illness, 128,000 cases of foodborne illness require medical treatment, and approximately 3,000 people die every year in the United States from foodborne illness. Outbreaks of foodborne illnesses occur with surprising frequency and more than $2 billion are spent annually on food-safety research and development (R&D) at the U.S. Department of Agriculture (USDA) [National Institute of Food and Agriculture (NIFA), Agricultural Research Service (ARS) and Economic Research Service (ERS)], and the U.S. Department of Health and Human Services [Food and Drug Administration (FDA) and the National Institutes of Health (NIH)]. Other federal agencies, such as the National Science Foundation (NSF), sponsor research that informs biological solutions and practices in the food-safety sector. Health outcomes are typically the focus of studies on impacts related to investments in research and development (R&D) related to food safety. But preceding those outcomes are outputs, such as human capital produced during training on research projects (e.g., graduate students), papers published on findings from the research, and patents granted to protect the intellectual property embodied in products and processes produced as a result of the research. It is this latter output—patents—that we seek to examine in this paper.

The scope of food-safety research spans from farm-to-fork. Husbands Fealing et al. [2][1] discuss ways in which the impact of food-safety research is evident throughout the entire supply chain of food production and distribution: agricultural inputs, pre-harvest environmental factors, harvest-related and postharvest factors, manufacturing techniques, storage and transportation

[1] The scope of food-safety research is a well-illustrated in Figure 2.1(page 13) [1].

conditions, food-processing factors, retail and consumer handling, and surveillance systems. Food-safety research includes all stages of research, including basic, translational, applied, and data acquisition (e.g., environmental and food sampling). Therefore, evaluating the impact of federal funding on food-safety research requires examining the full span of food safety activities (farm-to-fork) and research at all stages of exploration.

One challenge faced when investigating the relationship between funding of food-safety research and outputs of that funding is the development of a taxonomy that defines food safety. A multidisciplinary area, food safety is difficult to define using traditional methods. The existing scientific taxonomy does not provide a comprehensive definition of food safety that includes multiple scientific domains, levels of examination, and industry sectors. Merely looking up food safety in, for example, the North American Industry Classification System codes does not yield a complete list of sectors comprising food safety.

Another challenge is that patents are not the primary currency of food-safety research. Based on the literature review, we did not find a sizable corpus of literature on food safety patents. Food scientists[2] who participated in a workshop sponsored by the research team acknowledge that outputs of their research are public goods—that is, a product or process that is not necessarily developed for private benefit. Therefore, a focus on patents underestimates the full benefit to society of food-safety research, since it is more important to get a new product or process to market to save lives than it is to delay distribution owing to the patenting process [2](p.145).

[2] A dozen food-safety experts attended the December 2015 workshop sponsored by the research team and funded by the USDA-NIFA. Two participants are also co-authors of chapter 2 of Husbands Fealing et al.: Lee-Ann Jaykus is a William Neal Reynolds Distinguished Professor in the Department of Food, Bioprocessing & Nutrition Sciences at North Carolina State University; and Laurian Unnevehr is Professor Emerita in the Department of Agricultural and Consumer Economics at the University of Illinois.

Fanfani, Lanini, and Torroni [3] showed that patents related to agriculture and food industries in Italy are a weak indicator of food innovation. They stated that it is important to consider commercialization that is not a result of patents. Therefore, although patent data are widely used as a measure of innovation in some manufacturing sectors [4–8], more recent literature shows that there is not necessarily a strong correlation between patenting and innovation [9]. For this reason, using only patent data to measure food safety innovation can be misleading. A patent is not a perfect measure of innovation, since not all commercialized products or processes are patented especially in food-safety sectors.

There is anecdotal evidence that the food safety innovation was largely driven by both private and public sector funding on Hazard Analysis and Critical Control Points (HACCP) systems to control pathogens for the U.S. meat industry [10]. On one hand, private companies play an important role in inducing agricultural biotechnology innovation [11]. On the other hand, agricultural biotechnology patenting heavily relies on public research funding [12]. However, the impact of public funding may be realized for some time in the food safety sector similar to the low-carbon technology sector [13].

Although patent data are not a perfect measure of food safety innovation, there are several research papers that use patents as a proxy of the subfield of agriculture. For example, one study found that innovators are getting clustered in the agriculture, water, food, and bioenergy innovation ecosystem in Colorado using patent data [14]. King and Schimmelpfennig [15] also relied on patents from the USDA-ERS and the Agricultural Biotechnology Intellectual Property Database to investigate the quantity, quality, and composition of agricultural biotechnology intellectual property rights of the major agricultural biotechnology firms and their subsidiaries: Dow, DuPont, Monsanto, BASF, Bayer, and Syngenta. While this is the most comprehensive report on agricultural biotechnology innovation in general, their paper does not specifically focus on food safety patent activity.

There is also literature on seed industry and intellectual property rights owing to tremendous industry consolidation in the agricultural sector [16,17] and evolving roles of intellectual property protection rights in the agricultural biosciences [18–20]. Salay, Caswell, and Roberts conducted a survey for case studies of food safety innovation, but their taxonomy of food safety was not fully specified [21].

This paper, therefore, contributes to the literature by showing how machine learning techniques can be used to develop a taxonomy on food safety and to identify food safety patents. Those identified food-safety patents are further examined to address three questions: (1) How are food-safety patents classified? (2) Which firms are actively participating in food safety patenting? (3) What are the geographical and sectoral distributions of food safety patenting? The paper is organized as follows. First, we discuss the methodological background. Second, this paper describes new data and methods used to define food-safety research, which can be further applied to other multidisciplinary sectors. Third, we validate our results. Fourth, we analyze results and then conclude.

2. Methodological Background

In this paper, we have two methodological contributions. The first methodological contribution is the application of text analysis techniques, using Wikilabeling to establish the taxonomy, which we then used to discover food-safety patents [22]. This technique is described in chapter four of the Husbands Fealing et al.[2]. Information retrieval and identification using Wikilabeling determines a group of topics based on words in documents. This process generated a list of topics within a corpus. Similarities between individual documents, such as government awards and Wikipedia webpages, were matched using the following method:

1) determine if a standalone Wikipedia article exists within the list of significant n-grams from within the corpus and an existing taxonomy;
2) evaluate the similarities between individual documents and Wikipedia webpages; and
3) identify keywords and phrases that represent the food safety sector.

The model was trained on a database of grant abstracts from NIH, NSF and USDA. The primary advantage of applying Wikilabeling is that it allowed us to derive a list of potential labels from the corpus that reflected the existing taxonomy, for example, NSF's Survey of R&D Expenditures at University and Colleges. Therefore, Wikilabeling enabled us to update and extend the existing research taxonomy.

The second key methodological contribution is the use of the U.S. Patent and Trademark Office's (USPTO) PatentsView database. This database is used to identify food safety patents and to retrieve additional data about patent assignees, inventors, their locations, and patent classifications. The most significant advantage of using the PatentsView database is accuracy of the disambiguated assignee, inventor, their locations, and patent classifications [23]. PatentsView uses a patent assignee disambiguation technique,[3] the Jaro-Winkler approach, to cluster entities. Of course, a certain amount of manual check is inevitable. Additionally, the same John M. Smith might apply for two patents with and without the middle initial. If one were looking at exact matches, then these two inventors would be considered different individuals while in fact, they reside in the same city, the patent is in the same technology area, they work for the same company, and so on. The new inventor disambiguation algorithm, authored by the research team from the University of Massachusetts at Amherst and integrated into PatentsView in 2016, uses

[3] https://www.uspto.gov/about-us/organizational-offices/office-policy-and-international-affairs/patentsview-inventor

discriminative hierarchical co-reference as a new approach to increase the quality of inventor disambiguation [24,25]. For locations—city/state/country text as it appears in source files—area algorithmically matched against a master geocode file from Google and MaxMind open source files.

3. Methods

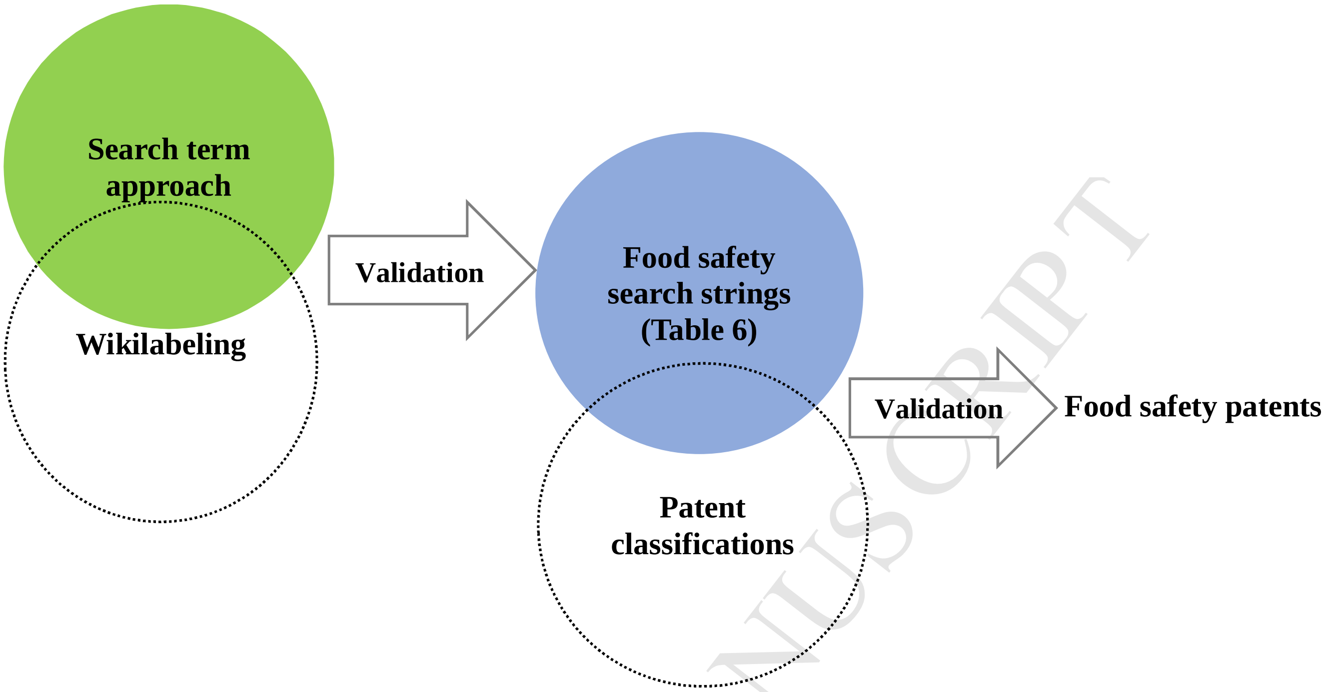
We applied the keywords used in searching food-safety research based on the search string approach referenced in Husbands Fealing et al. [2] (p. 170). A three-stage process was used to extract the final search strings needed to identify food safety patents. Figure 1 summarized this approach graphically.

(1) Combine two advanced techniques—search string approach and Wikilabeling—to identify possible food-safety research.

(2) Validate the initial sets through expert curation. Using this finalized food safety search strings (shown in the appendix) and patent classifications, retrieve the relevant food safety patents.

(3) Validate the results, using query-side and retrieval-side methods.

Figure 1. Framework for Combining Computational Techniques to Identify Food Safety-Related Keywords and Food Safety Patents



Patent documents are more complex than award abstracts owing to the legal language characteristics that do not necessarily show the nature of patent content in lay terms [26]. Therefore, we used a combination of both text analysis and patent technology classifications to identify food safety patents. Additionally, we manually validated food safety patents to reduce Type I (false positive) and Type II (false negative) errors. The initial taxonomy was approximately 700 terms. These terms were vetted by food safety scientists. The final list was almost 300 food-safety terms or concepts. This method can be used by other fields, particularly emerging areas, to determine better the boundaries of the field.

3.1. Identifying food safety search strings

Keyword searches to find relevant patents were commonly used in the literature. For example, Shapira, Gök, Klochikhin, and Sensier [27] used the search-based method to identify green industries such as green goods manufacturing. We created a comprehensive list of keywords related to food-safety research from Wikipedia and other sources: food pathogens, food processing and preservation, biochemistry and toxicology, food-related diseases, food quality and quality control, and food safety in general. The initial challenge was to identify a list of relevant food-safety research keywords. The original list of keywords is generic and nebulous. For example, “nutrition,” “health,” and “pathogen” are too generic. The initial set of search strings were also reviewed by food safety experts in the workshop to remove irrelevant terms.

For example, the term “food security” is rather broad. Food-safety experts in our study recommended excluding “food security” keywords from the topics of hunger, nutrition, and calories: ((food safety) OR (food security*)) NOT ((hung*) OR (nutrit*) OR (calor*)). Furthermore, the term “food quality” is generally irrelevant unless it directly relates to sanitary norms and food pathogen detection. The food-safety experts who vetted our process did not consider research on genetically modified (GM) food to be classified as food-safety research. Therefore, the recommended search string for GM food was: (((ill*) OR (disease) OR (hazard*)) AND ((genetically modified food*) OR (GM food) OR (genetic engine*))). Expert review allowed us to remove numerous false positives to food safety.

We used the Wikilabeling technique that maps the search terms to related Wikipedia pages and compared them for similarities with research documents. The left side of Figure 1 shows the combination of how the Wikilabeling and search terms can be used to identify food safety search strings [28,29], which strengthens the validation process. This approach helps to increase the reliability through Wikipedia’s broad topic coverage and the most up-to-date information repositories, such as Encyclopedia Britannica [30]. For further details on a novel science taxonomy for U.S. government agencies, refer to the following sources [2,31,32].

The method we used in our first stage of the analysis is as follows. Wikipedia-based labeling and classification is an information retrieval and clustering technique that is used to identify topics based on words used in the documents such as Wikipedia. In this case, we compared documents to semantic model vectors of Wikipedia constructed WordNet [22] as follows.

$$SMV_{wiki}\,(s) = \sum_{w \in Synonyms(s)} \frac{tf_{wiki}(w)}{|Synsets(w)|} \tag{1}$$

where w is a token within wiki, s is a synsets, Synonyms(s) the set of word in synsets, $tf_{wiki}(w)$ is the term frequency of the word w in the Wikipedia article wiki and the Synsets(w) the set of synsets for the word w.

The overall probability of a candidate document d, i.e., a publication retrieved from the SAGE database, and a Wikipedia article wiki is

$$wiki_{BEST} = \sum_{w \in d} max_{s \in Synsets(w)}\, SMV_{wiki}(s) \tag{2}$$

where Synsets(w) is the set of synsets for the word w in the target document d and SMV_{wiki} is the Semantic Model Vector of a Wikipedia page.

3.2. Food safety search strings validation

Human validation is necessary for minimizing computation errors. We used two approaches: query-side and retrieval-side validations. Both methods were applied in our validation—specifically, a food safety workshop in Washington, D.C., and a computation technique. A frequently used query-side validation process appears in the scientometric literature. Porter et al. [33] convened a workshop to validate their taxonomy related to the nanotechnology taxonomy. Meanwhile, a retrieval-side validation can mainly be found in the computer science literature. It provides an accurate way in which to minimize errors in terms of precision and recall. Both precision and recall are computed as follows:

$$\text{Precision} = \frac{|\{relevant\ documents\} \cap \{retrieved\ documents\}|}{|\{retrieved\ documents\}|} \tag{3}$$

$$\text{Recall} = \frac{|\{relevant\ documents\} \cap \{retrieved\ documents\}|}{|\{relevant\ documents\}|} \quad (4)$$

To reduce Type I and Type II errors, we used a random sample of both retrieved and unretrieved documents from the NIH, NSF, and USDA: 50 food safety identified documents and 50 unretrieved documents. Then, we contacted food safety experts to review up to 20 documents and determine if they were related to food safety. The results were mixed, which is common in this field, so we conducted a cluster-level validity check--topic modeling. Topic modeling is a computational technique used to generate a list of topics that occur in a given document; it is used to identify scientific disciplines at the NIH [34]. This method is based on the latent Dirichlet allocation [35] method. This process yielded 30 topics generated from the NSF awards and 100 topics from the NIH and USDA awards to validate our results.

Additional validation processes that were used are shown in the appendix to this paper. The final list of concepts includes six main categories with a total of 289 ideas:

1. General terms (2): “food safety”, “food security”
2. Food pathogens (119): “Coxiella burnetii”, “Yersinia pseudotuberculosis”, “Aspergillus parasiticus”, etc.
3. Biochemistry and toxicology (41): “Acid-hydrolyzed vegetable protein”, “Hydrogenated starch hydrosylate”, “Forensic toxicology”, etc.
4. Food processing and preservation (51): “Active packaging”, “Irradiation”, “Frozen food”, etc.
5. Food safety management and food policy (56): “Contaminated food”, “Federal Meat Inspection Act”, “Hazard analysis and critical control points”, etc.

6. Food-related diseases (20): “Foodborne illness”, “Diarrhea”, “High-fructose corn syrup and health”, etc.

3.3. Identifying food safety related patents[4]

So far, the process has generated hundreds of terms that allow us to identify elements of food safety in documents. The steps we used are as follows.

First, we extracted patent titles and abstracts from the PatentsView database, and then the search term strategy was applied. PatentsView is a collaborative initiative between the USPTO, the American Institutes for Research, New York University, the University of California at Berkeley, and two private software companies – Twin Arch Technologies, and Periscopic. PatentsView (www.patentsview.org) makes available more than 40 years of patent data through the API, bulk data downloads, visualization interface, and the Query Builder. The benefit of using PatentsView is that it has inventor, assignee and location disambiguated and ready for analysis of various technology sectors.

The first set of patent data for food safety contained 1,543 documents retrieved using the search term strategy. The clerical review showed that only a portion of these patents genuinely related to food safety. For example, patents US4008383 “Microwave oven door assembly” or US4034890 “Bread box,” which were retrieved because a bread box is an example of a food safe (having the same stem as “safety”). These patents were removed from the set of patents for analysis upon clerical review.

Second, we used patent classifications to refine the search criteria further to retrieve only the most relevant patents. Further review showed that there is a link between Cooperative Patent Classification (CPC) classes of individual patents and their relevance to food safety. So, the retrieved patents further divided into three categories: sure, maybe, and irrelevant. We then

[4] This section is based on Chapter 9, Husbands Fealing et al., which was written by the co-authors.

reviewed the CPC classes to retrieve only the most relevant patents (675 patents in the "sure" CPC classes - A21, A22, A23, B08, B32, and B65).

Third, we retrieved forward and backward citations using the above validated patent dataset. Forward and backward citations amounted to 4,179 and 3,708 patents, respectively. We conducted similar clerical review on the citations dataset and identified the "sure" CPC classes. We retrieved the most relevant food safety patents, containing 2,038 forward and 2,030 backward citations. Some of these patents overlapped. Therefore, we removed the duplicates, and identified the final set of 4,296 food safety patents for the period 1976 and 2016 (patent year granted).

3.4. Food safety related patent data validation

After identifying food safety patents, we applied several additional tests to validate our selection of patents. We proceeded from the following hypotheses:

- It is likely that inventors have a tendency to file applications in a particular set of patent fields over time. Therefore, the technology categories of food safety patents should be similar to technology categories of other patent applications filed by the same inventors across years.
- It is also likely that assignee organizations follow a persistent patenting strategy and the number of food safety patents is likely to be linked to the number of non-food safety patents within similar CPC classes over time.
- Patents filed under the same CPC classes from the "sure" category and under the prevalent World Intellectual Property Organization (WIPO) "Food Chemistry" technology field are likely to correlate with the number of food safety patents in those fields that are filed in similar years.

3.4.1. Inventors: Individuals

Inventors are likely to file patent applications in similar fields. There are 6,595 unique inventors that have food safety patents granted from 1976 to 2016. These inventors have been granted a total of 48,807 U.S. patents, of which 4,296 are food safety patents. Every inventor has an average of 27.1 patents. The correlation between food safety patents and all patents per inventor is 0.32. There is a statistically significant link between the number of food safety and non-food safety patents filed by same inventors within same CPC classes: every food safety patent is associated with 0.6 non-food safety patents by the same inventor in given CPC classes, controlling for year and CPC fixed effects (N=31,572). These measures suggest that inventors indeed tend to have persistent patent portfolios and file patent applications in similar fields, which confirms the validity of food safety patents selection.

3.4.2. Assignees: Organizations

We retrieved data on 1,707 unique assignee organizations associated with selected food safety patents. They vary significantly by size and specialization. The standard deviation is 168.1 with the mean of 22.8 patents per assignee per year. Such variability leads to a small correlation of 0.03 between the number of food safety and non-food safety patents per assignee over time. If keeping only assignees with smaller portfolios below the mean (<23), the correlation goes up to 0.08 showing that specialization matters in smaller organizations with less patenting activity.

Further analysis shows that there is a statistically significant link between food safety patents and non-food safety patents granted to same assignees within the same CPC classes: every 1 food safety patent is associated with 2.32 non-food safety patents, controlling for year and CPC class fixed effects (N=184,608). These results indicate that assignees have persistent patent portfolios, where food safety patents are linked to non-food safety patents.

3.4.3. WIPO Technology Field

The Food Chemistry WIPO technology field is the most frequently observed type of food safety patent. The correlation between the number of food safety patents and all patents in this WIPO field is significant, with the correlation coefficient of 0.85. On average, a given food-safety patent is associated with about 0.09 additional patents in this WIPO field at $p<0.001$. Table 1 shows the number of food safety patents by WIPO technology fields. Patents related to food chemistry are about half of all patents since most of the technological inventions to improve food safety are related to the development of technologies that control and eliminate foodborne pathogens. For example, Bricher and Keener [36] found the significance of the technological development of microbial intervention technologies that control and eliminate foodborne pathogens in food safety processes.

Table 1: Categories of Food Safety Patents

WIPO Field Titles	Freq.	Percent (%)
Food chemistry	2,204	51.3
Handling	709	16.5
Other special machines	325	7.57
Pharmaceuticals	241	5.61
Biotechnology	178	4.14
Basic materials chemistry	102	2.37
Organic fine chemistry	85	1.98
Medical technology	83	1.93
Surface technology, coating	69	1.61
Furniture, games	59	1.37
Others	241	5.62
Total	4,296	100

3.4.4. CPC Classes

The CPC classification is a widely used patent classification at the international level and the USPTO. The “sure” category contains five CPC classes, of which A21, A22, and A23 are the main Foodstuff classes according to the CPC classification scheme. The correlation coefficient between all patents and food safety patents in these CPC classes is 0.96. This can be interpreted as a strong validity measure because patenting activity in similar fields has mainly been following the trends of applications for food safety patents granted since 1976. Unlike the WIPO Food Chemistry technology field, on average, a given food-safety patent is associated with about 9.85 additional patents in these CPC classes, which suggests that A21-A23 cover a much broader field of food-related technologies. CPCs reveal that food preparation or treatment is the top-ranked classification followed by food storage and transport. As a result of this additional validation processes, we can confirm our results.

4. Identification of Food Safety Firms

The number of patents filed by a parent firm and its subsidiaries was mixed. To represent accurately the number of patents by a parent firm, we needed to consider mergers and acquisitions of the firm during the period of analysis. We mainly use the SDC Mergers & Acquisitions database in the LexisNexis Academic database, which covers January 1985 to 2016. Although the SDC database is a comprehensive database, we added missing information from early years and cross checked the information using company websites.

It is challenging to identify all of the firms' family trees because small firms appeared and disappeared frequently in the patent data. We used two criteria to select major parent companies in our sample. First, the threshold of 15 patents is important to identify accurately parent firms [37]. Second, we included major agricultural biotechnology firms that King and Schimmelpfennig [15] identified: BASF, Bayer, Cargill, DOW, DuPont, Kraft, Monsanto, and Syngenta. Based on the first criterion, we have two additional firms: Nestec S.A. and Chr. Hansen A/S. Therefore, our identification of 10 major food safety firms was comprehensive enough to cover most of the areas of agricultural biotechnology. Overall, we considered 10 companies to match each parent company and its subsidiaries.

We needed to extract three key pieces of information from the LexisNexis database: target firms, buyer firms, and announcement date. Since the downloaded files included unnecessary texts for our analysis, we needed to find text information between two substrings. After cleaning the data, we had 1,641 mergers and acquisitions by 10 major food safety companies. Additionally, we also added missing mergers and acquisitions information from company websites.

To match the SDC database and the list of major food safety parent companies, we needed to disambiguate the company names to match apples to apples. Based on name standardization routines,[5] we could standardize the company names in both lists: the list of food safety companies and the EDGAR list. This is how we standardized the assignee names in the PatentsView database.

We followed the NBER patent project name standardization routine. First, we trimmed whitespace from the beginnings and ends of company names. Second, we standardized some symbols. For example, the process recoded all instances of “AND” to “&.” Also, we needed to eliminate punctuation characters such as “%” or “:” and replace them with nulls. Third, we had to standardize the legal entity. For example, we changed “RES & DEV” to “R&D.” Additionally, we also standardized the country/company name endings. For a United Kingdom-based company, we changed “HOLDINGS” to “HLDGS.” After standardizing both sets of company names, we successfully matched the two databases.

5. Findings

5.1. Food Safety Patents

On average, it has taken 2.6 years to grant a U.S. patent after application since 1976. Figure 2 shows the distribution of food safety patents by application year. We used application

[5] https://sites.google.com/site/patentdataproject/Home/posts/namestandardizationroutinesuploaded

date instead of patent grant date owing to significant fluctuations in patent processing time in 1976-2016. The food safety patent applications do not show any clear trend; it is rather uneven. There are possible reasons for these fluctuations. They could be dependent on food safety technology-specific characteristics, market-driven forces, or government policies. Anecdotal evidence suggests that the 1993 *E. coli* outbreak could have been a turning point of food-safety research. A Washington, D.C. Department of Health *E. coli* outbreak investigation found that hamburger patties sold by Jack in the Box were the primary source of the *E. coli* outbreak in 1993. Seven hundred and thirty-two people were infected with the bacterium, which alarmed the public and heightened the public's awareness of food safety concerns. In response to this event, several research organizations such as the National Cattlemen's Beef Association (NCBA) increased funding for research on how to detect pathogens efficiently [38].

The number of patent applications continuously increased until 2000 and then decreased. Johnson [39] stated that the Sanitary Food Transportation Act of 1990, the Nutrition Labeling and Education Act of 1990 (NLEA), the Federal Tea Tasters Repeal Act of 1996, and the Food Quality Protection Act of 1996 could be among the policies that spurred food safety innovation relying on the uptick in patents. Additionally, the influx of food-safety research in the early 2000s coincided with the StarLink corn recall, which occurred in 2000, when numerous food products were found to contain unapproved GM corn. This event raised significant public awareness to the safety of GM food.

In 1998, the European Union banned all imports and planting of GM crops. Public concerns have dissipated over time, with science committees concluding that GM food is safe for human consumption. This could explain the downward trend in the number of food safety patent applications filed after 2000. While this is one of the reasons, there are other possible scenarios.

It is also plausible that the food safety patent trend follows the biopharmaceutical sector, particularly genomic patent applications. [6] This area also shows a noticeable increase related to new human genes owing to the full sequencing of the human genome, but a rapid decrease after 2000. Since 2000, it is less likely to have room for identifying further human genes. Instead, evidence shows that the focus of research shifted to diagnostic uses of genetic information.[7] Another conjecture is that the downward trend in patent applications in food safety might follow the similar pattern with DNA-related patents that the total number of gene patents peaked in 2001 and then declined until 2005, but it rebounded [40]. Again, a rigorous causal analysis is beyond the scope of this paper, but another fruitful future research avenue.

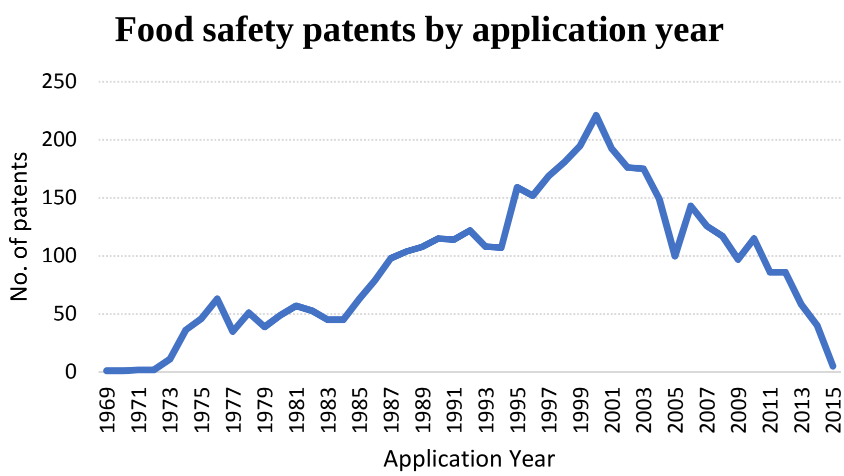


Figure 2. Food safety patent applications per year (1969-2015)

5.2. Food Safety Firms

Table 2 illustrates the distribution of patent assignees by type. The majority of food safety patents filed were by corporations, while governments and individuals were a small

[6] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2935940/
[7] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2935940/

portion of food safety patent. Unidentified patents comprised 17% of the total food safety patents in our data.

Table 2: Food safety patent assignees by type

Assignee Type	Frequency	Percent (%)
U.S. Corporation	2,156	50.19
Foreign corps, incl, state-owned	1,318	30.68
U.S. individual	34	0.79
Foreign individual	14	0.33
U.S. government	25	0.58
Foreign government	5	0.12
U.S. state government	7	0.16
Undefined	736	17.13
Total	4,296	100

Figure 3 shows the geographic distribution of food safety companies and other entities. While a vast amount of patents are from the Eastern and the Midwestern regions of the United States, there are also dispersed around the country. Unsurprisingly, the Midwest has major patent activity in the food safety area in alignment with its strong agricultural sector. For example, the top-five cities for food-safety patents are as follows: Twin Cities, MN (127 patents), Cincinnati, OH (108), New York, NY (73), Northfield, IL (73), Chicago, IL (46). New York, Twin Cities, and Cincinnati are heavily focused on the WIPO Food Chemistry technology field such as Chemistry, Mechanical Engineering, Instruments, and Electrical Engineering. However, patents related to consumer electronics and electrical engineering are found in regions: Greeley, CO (15 patents), Kennesaw, GA (10), Wayzata, MN (4), New Port Richey, FL (4), and Wichita, KS (4).

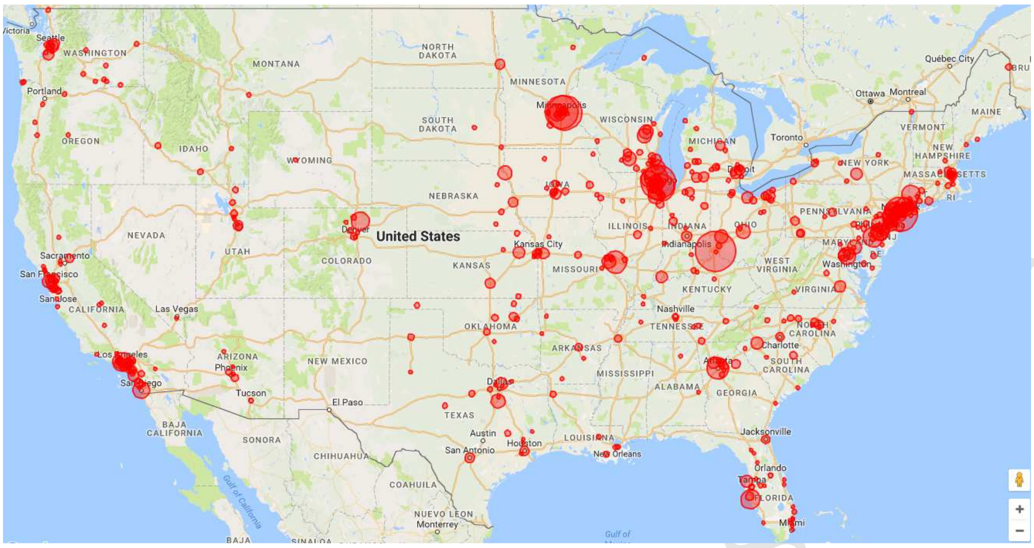


Figure 3. Geographic distribution of food safety companies and other entities with patents Note: the node size is representative of the relative number of patents assigned to firms situated in those locations.

Table 3 shows the list of food safety patents from companies. Large companies with 15 or more food safety patent applications account for more than 80% of all patent applications. There is a mixture of U.S. and foreign companies, which indicates a fierce competition across multinational corporations in this domain. The top food safety patent filing company is Nestec S.A., Switzerland company, while the second and third companies are U.S. companies: The Procter & Gamble Company and Kraft Foods, Inc.

Table 3: Patent applications by companies (1976-2015)

Assignee Organization	**Assignee Country**	**Assignee State**	**Number of patents**	**Share in total (%)**
Nestec S.A.	Switzerland	VD	132	3.8
The Procter & Gamble Company	United States	OH	88	2.53
Kraft Foods, Inc.	United States	IL	61	1.76
Ecolab Inc.	United States	MN	47	1.35
Abbott Laboratories	United States	IL	33	0.95
Nabisco Brands, Inc.	United States	NJ	33	0.95
Microlife Technics, Inc.	United States	FL	32	0.92
Tetra Laval Holdings & Finance S.A.	Switzerland	VD	32	0.92

The Coca-Cola Company	United States	GA	29	0.83
General Foods Corporation	United States	NY	22	0.63
Cargill, Incorporated	United States	MN	21	0.6
General Mills, Inc.	United States	MN	20	0.58
Medical Instill Technologies, Inc.	United States	CT	20	0.58
Chr. Hansen A/S	Denmark	Hovedstaden, Capital Region of De	19	0.55
The Iams Company	United States	OH	19	0.55
Compagnie Gervais Danone	France	Ile-de-France	18	0.52
Kabushiki Kaisha Yakult Honsha	Japan	Tokyo	18	0.52
3form, Inc.	United States	IL	17	0.49
Ajinomoto Co., Inc.	Japan	Tokyo	15	0.43
AptarGroup, Inc.	United States	IL	15	0.43
Paramount Packaging Corporation	United States	PA	15	0.43

5.3. Federal Funding and Patent Activity

We also found that food safety-related federal funding and economic outcomes are closely related to each other in Husbands Fealing et al. (chapter five) [2]. However, this is not the usual case in food safety patenting. As we have seen previously, the majority of food safety patent activity is driven by private companies, not directly by government funding. The role of federal government in food safety patenting is limited: the U.S. Department of Agriculture (21 patents), U.S. Secretary of the Army (2), and the National Aeronautics and Space Administration (1).

Table 4 shows a list of patents, which assigns a full or partial interest in the given patent to the U.S. government. Expectedly, the U.S. Department of Agriculture and affiliated institutions account for most of these patents. Several food safety patents were supported by agencies such as NSF (4 patents) and NIH (9). For example, NSF funded awards are as follows: NSF Alan T. Waterman Award (#9910949) to Chaitan Khosla for developing “an exciting new approach for the production of new antimicrobial agents from engineered organisms,” Food intake and nutrition-related award studying the effect of a peptide in the brain, neuropeptide Y, on feeding (#9007573). We also found that the most of food safety patents in this category are within the WIPO Food Chemistry, Pharmaceuticals, and Biotechnology fields.

Table 4: Government interest statements in food safety patents

Agency	No. of patents
Department of Agriculture	14
National Institutes of Health	9
United States Government (as a whole)	5
National Science Foundation	4
Army	3
Department of Energy	3
Centers for Disease Control and Prevention	1
Total	39

6. Conclusions

We used the method of Wikilabeling with expert validation of search terms on the PatentsView data to identify food safety patents. The resulting database was used to answer the following questions: (1) How are food-safety patents classified? (2) Which firms are actively participating in food safety patenting? (3) What are the geographical and sectoral distributions of food safety patenting? First, we discovered the pace and direction of patenting in the food safety area. We found that more than two-thirds of patents are related to food chemistry and handling, control, and elimination of foodborne pathogens. CPCs reveal that food preparation/treatment is top-ranked, followed by food storage and transport. There are periods of relatively strong patent activity; it is unclear if this is related to outbreaks such as *E. coli* in 1993, the early 2000s StarLink corn recall, and 1990 and 1996 government regulations. Second, we found patenting among large corporations, although some universities are also patenting in this sector. Some firms in the U.S. and abroad have dozens of food safety patents, which could be specific to the product/process or the general patenting strategy of those companies. Third, we observed strong patenting in the usual regions of innovation around the U.S., with substantial activity in the Midwest United States. This paper shows which companies and regions are patent active in the food-safety sector. Drawing conclusions about the most innovative sector or regions in this area cannot be determined solely by observing this patent activity. However, some patterns are apparent in this study.

An important contribution to the analysis was the use of natural language techniques to isolate a taxonomy for food safety. This method can be used to examine multidisciplinary research areas and emerging technology areas. In addition, this method can also be used to examine publications (see Husbands Fealing et al., chapter 10).

There are remaining research questions, such as what are the benefits to federal funding of food-safety research that are not discernable from observing patent activities of firms. We maintain that some of those outcomes are in the production of statutes and laws that improve economic and health benefits to society from the knowledge generated in food-safety research. Understanding the impact of federal funding on food-safety research and consequently laws and practices that govern food safety from farm-to-fork can help us understand the impacts of those expenditures on health outcomes, as discussed at the beginning of this paper. These remain fruitful areas for future research.

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Appendix

Table 5. The Scope of Food-Safety Research

Scope	Description
Agricultural inputs	Feed and feed additives Irrigation water quality Manure and soil amendments Livestock health care Livestock housing
Pre-harvest environmental factors	Climate Soil Wildlife Flooding events
Harvest-related factors	Workers' health and hygiene Machinery Harvest technology
Postharvest and food-manufacturing associated factors	Processing techniques, storage, and transportation conditions (e.g., times and temperatures)
Postharvest treatments	Washes with antimicrobial substances
Food-processing conditions	Cross-contamination, microbial death, survival, and growth
Retail(consumer) handling and storage	Storage conditions (e.g., times and temperatures)
Surveillance systems	Diagnostic capabilities to identify, characterize and trace back illnesses, foodborne outbreaks, and sporadic cases attributable to food (e.g., case-control or cohort studies); foodborne source attribution; and economics of foodborne illness

*Author's modification of the scope of food-safety research [2] page 14

Table 6. Food-Safety Research Search Queries

Categories	Search Strings
General	((food safety) OR (food securit*)) NOT ((hung*) OR (nutrit*) OR (calor*))
Food pathogens	((food*) OR (dairy)) AND ((tetrodotoxin*) OR (myrothecium*) OR (cyclopiazonic acid*) OR (fumitremorgen b*) OR (anisakis*) OR (coxiella burnetii*) OR (neurotoxic shellfish poisoning*) OR (eustrongylides*) OR (parasite*) OR (ergot alkaloids*) OR (yersinia pseudotuberculosis*) OR (zearalenone*) OR (taenia solium*) OR (pseudo-nitzschia pungens*) OR (phomopsins*) OR (shigella*) OR (campylobact*) OR (actinobacteria*) OR (lactic acid bacteria*) OR (grayanotoxin*) OR (acanthamoeba*) OR (nipah virus*) OR (arcobacter butzleri*) OR (t-2 toxin*) OR (moniliformin*) OR (taenia saginata*) OR (verrucosidin*) OR (verruculogen*) OR (cryptosporidium parvum*) OR (aspergillus parasiticus*) OR (rotavirus*) OR (salmonella*) OR (entamoeba histolytica*) OR (escherichia coli o157:h7*) OR (sterigmatocystin*) OR (fusarium*) OR (oosporeine*) OR (clostridium botulinum*) OR (fasciola hepatica*) OR (cryptosporidium*) OR (sporidesmin a*) OR (deoxynivalenol *) OR (listeria monocytogenes*) OR (3-nitropropionic acid*) OR (sarcocystis hominis*) OR (phytohaemagglutinin*) OR (brucella*) OR (protozoa*) OR (aspergillus flavus*) OR (trypanosoma cruzi*) OR (ergotamine*) OR (staphylococcus aureus*) OR (salmonellosis*) OR (fusarium moniliforme*) OR (clostridium perfringens*) OR (trichinella spiralis*) OR (nivalenol*) OR (3-nitropropionic acid*) OR (vibrio vulnificus*) OR (fusarochromanone*) OR (toxoplasma gondii*) OR (fungus*) OR (paxilline*) OR (aflatoxins*) OR (cytochalasins*) OR (kojic acid*) OR (bacillus cereus*) OR (penitrem a*) OR (ciguatera poisoning*) OR (e. coli stec*) OR (fusaric acid*) OR (citreoviridin*) OR (cephalosporium*) OR (pyrrolizidine alkaloids*) OR (ddt*) OR (virulence properties of escherichia coli*) OR (cronobacter sakazakii*) OR (stachybotrys*) OR (trichoderma*) OR (salmonella enteritidis*) OR (nanophyetus*) OR (enterovirus*) OR (lolitrem alkaloids*) OR (diphyllobothrium*) OR (scombrotoxin*) OR (zearalenols*) OR (aflatoxin*) OR (ascaris lumbricoides*) OR (steroids*) OR (ochratoxins *) OR (norovirus*) OR (ht-2 toxin*) OR (listeria*) OR (sarcocystis*) OR (vibrio parahaemolyticus*) OR (yersinia enterocolitica*) OR (nematode*) OR (amnesic shellfish poisoning*) OR (giardia lamblia*) OR (aeromonas hydrophila*) OR (ergopeptine alkaloids*) OR (fumonisins*) OR (staphylococcal enteritis*) OR (sarcocystis suihominis*) OR (patulin*) OR (diacetoxyscirpenol*) OR (corynebacterium ulcerans*) OR (pathogen*) OR (citrinin*) OR (streptococcus*) OR (anaerobic organism*) OR (alternaria*) OR (plesiomonas shigelloides*) OR (diarrhetic shellfish poisoning*) OR

	(caliciviridae*) OR (vibrio cholerae*) OR (cyclospora cayetanensis*) OR (astrovirus*) OR (platyhelminthes*))
Food processing	((hygien*) OR (food safe*)) AND ((active packaging*) OR (animal feed*) OR (curing preserv*) OR (distribution*) OR (extrusion*) OR (industry*) OR (irradiation*) OR (manufacturing*) OR (packaging*) OR (preparation*) OR (preservation*) OR (processing*) OR (storage*) OR (technology*) OR (foodservice*) OR (freeze-drying*) OR (frozen food*) OR (good manufacturing practice*) OR (grocery stores*) OR (liquid packaging board*) OR (mandatory labelling*) OR (nutrasweet*) OR (package testing*) OR (packaging*) OR (packaging and labeling*) OR (pan frying*) OR (pasteurization*) OR (pickling*) OR (poaching cooking*) OR (preservative*) OR (pressure cooking*) OR (pressure frying*) OR (raw meat*) OR (refrigeration*) OR (searing*) OR (security seal*) OR (self-heating packaging*) OR (shallow frying*) OR (shrink wrap*) OR (slow cooker*) OR (smoking cooking*) OR (souring*) OR (steaming*) OR (stretch wrap*) OR (stuffing*) OR (tamper resistance*) OR (tamper-evident*) OR (tin can*) OR (ultra-high temperature processing*) OR (vacuum flask cooking*) OR (vacuum pack*))
Biochemistry	((food*) AND (safe*)) AND (((acid-hydrolyzed vegetable protein*) OR (activated carbon*) OR (aquatic toxic*) OR (environmental microbio*) OR (environmental toxic*) OR (engineering*) OR (bioprocess tech*) OR (chemical toxi*) OR (biotechnology*) OR (chemistry*) OR (coloring*) OR (contaminant*) OR (dehydration*) OR (poisoning*) OR (forensic toxic*) OR (formaldehyde*) OR (lactic acid fermen*) OR (lactose*) OR (monosodium glut*) OR (mushroom poison*) OR (mycotoxin*) OR (paralytic shellfish poison*) OR (pesticide*) OR (pesticide residue*) OR (shellfish poisoning*) OR (sterilization microbio*) OR (succinate*) OR (sucralose*) OR (sugar subst*) OR (toxic capacity*) OR (toxicity class*) OR (toxin*) OR (traceab*) OR (trans fat*) OR (trichothecenes*) OR (trichuris trichiura*)) OR (((foodbo?rne ill*) OR (foodbo?rne dis*)) AND (epidem*)) OR (((ill*) OR (disease) OR (hazard*)) AND ((genetically modified food*) OR (GM food) OR (genetic engin*))) OR (((allerg*) OR (sensitiv*)) AND (gluten*)))
Foodborne illnesses	((food*) OR (foodbo?rn*) OR (food-rela*)) AND ((((ill*) OR (disease*)) AND (anemi*)) OR ((stomach flu*) OR (hepatitis a*) OR (hepatitis e*) OR (hygien*) OR (infection control*) OR (infectious dose*) OR (kidney failure*) OR (listeriosis*) OR (diarrhea*) OR (allergy*) OR (foodborne illness*) OR (gastroenteritis*)) OR (((safe*) OR (illness*) OR (disease*)) AND ((hand wash*) OR (health hazard*) OR (toxic*) OR (health impact))) OR (((ETEC) OR (STEC) OR (coli)) AND ((health*) OR (hygien*) OR (vomit*))))
Toxins	(food*) AND ((safe*) OR (allerg*)) AND (((adulterated food*) OR (contaminated food*) OR (critical control point*) OR (danger zone safety*) OR (dietary suppl*) OR (european safety authority*) OR (fao*)

	OR (hygien*) OR (restaurant*) OR (fat substitute*) OR (federal food, drug, and cosmetic act*) OR (federal meat inspection act*) OR (fixed dose procedure*) OR (food safety act 1990*) OR (food standards agency*) OR (additive*) OR (hygien*) OR (labeling regulations*) OR (safe symbol*) OR (safety*) OR (food safety risk analys*) OR (sampling*) OR (diet* suppl*) OR (generally recognized as safe*) OR (grain quality*) OR (hazard analysis and critical control points*) OR (hazard analysis*) OR (iso 22000*) OR (iso 9000*) OR (infant formula*) OR (inspection*) OR (international association for protection*) OR (international safety network*) OR (nutrification*) OR (organic food*) OR (perishable food*) OR (potentially hazardous food*) OR (poultry products inspection act*) OR (quality assurance internation*) OR (rapid alert system for and feed*) OR (reference daily intake*) OR (starlink corn recall*) OR (title 21 of the code of federal regulations*) OR (total quality management*) OR (us and drug administration*)) OR ((foodbo?rn*) AND (pathogen*)) OR ((hazard*) AND (test* strip*)) OR ((hygien*) AND (regulat*)) OR (((fish) OR (seafood*)) AND (mercur*)) OR (((ill*) OR (diseas*)) AND ((pcr test*) OR (oyster*) OR (sanita*))) OR ((pathogen* AND (source reduc*)))

Highlights

- There are inherent challenges to identify a research taxonomy for multidisciplinary areas.
- We developed a data taxonomy for a multidisciplinary sector – food safety in this case – and then we used to discover food-safety patents by using machine learning techniques.
- This method is applicable to obtain an accurate representation of research taxonomy for emerging technology fields.
- This paper provides a discussion on patents as a measure of new knowledge generation, particularly which companies and regions are patent active in the food-safety sector.

Authors' Bios

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Yeong Jae Kim joins the Tyndall Center for Climate Change Research as a senior research associate after completing his Ph.D. in the School of Public Policy at Georgia Institute of Technology. He has an M.S. in Agricultural Economics from Texas A&M University and has a B.A. from Hanyang University in South Korea. He is an applied economist whose research focuses on the economics of innovation. His research interests lie in conducting an econometric ex-post policy evaluation of energy policies. He is investigating how energy and environmental policy instruments affect the development of low-carbon technologies. A key question that he is attempting to answer in his Ph.D. dissertation is the different role of energy-efficiency policies in technological change. Additionally, his research interests include the role of behavioral economics in environmentally friendly technology adoption.

2. Dr. Kaye Husbands Fealing

Kaye Husbands Fealing is Chair of the School of Public Policy at the Georgia Institute of Technology. She specializes in science of science and innovation policy, the public value of research expenditures related to food safety, and the underrepresentation of women and minorities in STEM fields and workforce. Prior to her position at Georgia Tech, Husbands Fealing was a professor in the Center for Science, Technology and Environmental Policy at the Humphrey School of Public Affairs, University of Minnesota, a study director at the National Academy of Sciences from 2011-2014, and the William Brough professor of economics at Williams College, where she began her teaching career in 1989. She developed and was the inaugural program director for the National Science Foundation's (NSF) Science of Science and Innovation Policy (SciSIP) program and co-chaired the Science of Science Policy Interagency Task Group, chartered by the Social, Behavioral and Economic Sciences Subcommittee of the National Science and Technology Policy Council. At NSF she also served as an economics program director. Husbands Fealing was a visiting scholar at Massachusetts Institute of Technology's Center for Technology Policy and Industrial Development, where she conducted research on NAFTA's impact on the Mexican and Canadian automotive industries, and research on strategic alliances between aircraft contractors and their subcontractors. Husbands Fealing holds a B.A. in mathematics and economics from the University of Pennsylvania and a Ph.D. in economics from Harvard University.

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