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Structural Change and Industrial Classification

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Structural Change and Industrial Classification

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Abstract

Understanding of structural change is compromised because scholars do not clearly articulate the limits of the classification infrastructure (NAICS or GICS) that shapes empirical analysis. These limits are particularly salient in the study of innovation, an activity that by its nature challenges existing categories. Because innovative industries are often not part of the classification infrastructure, they are invisible in empirical analyses and in government statistics. This paper examines the classification of a population of highly innovative, often small, firms working in gaming devices, packaging, filtration, photonics, imaging, biomedical research and fabless semiconductor design. I find examples of knowledge integration, vertical disintegration and emerging industries that challenge both NAICS and GICS exposing their strengths and weaknesses.

Keywords: NAICS; photonics; industrial classification; knowledge integration; vertical disintegration; GICS

JEL code: C81

In a Chinese encyclopedia imagined by Jorge Luis Borges[1], animals were divided into*:*

> *belonging to the emperor, embalmed, tame, sucking pigs, sirens, fabulous, stray dogs, included in the present classification, frenzied, innumerable, drawn with a very fine camelhair brush, et cetera, having just broken the water pitcher, that from a long way off look like flies*

1 Introduction

Exotic classifications and invisible information infrastructures underpin analytical understanding of our economy - an economy continually transforming itself through innovation. The tension between the fixed and somewhat arbitrary character of infrastructure and the dynamic, self-organizing nature of the economy will be explored in this paper. Analyses of industries or sectors whether produced by governments, scholars or investment banks employ industrial classification schemes. The US government uses the North America Industrial Classification System (NAICS), the successor to the Standard Industrial Classification (SIC), and some Wall Street analysts use the proprietary Global Industry Classification Standard (GICS®). These two schemes will be examined in this paper from the perspective of small, innovative firms. The approach used here was pioneered by Bowker and Star whose exploration of the relationship between classification schemes and the reality the schemes purport to represent established the power of foregrounding the normally unacknowledged background to analysis.

Delving into someone else's infrastructure has about the entertainment value of reading the yellow pages of the phone book (Bowker and Star, 2000, p. 321). Nevertheless, those concerned about structural change in the economy should be concerned about classification schemes. The two schemes are based on different conceptual foundations, one traditional (NAICS), the other more forward looking (GICS). At a technical level, if an incompatible conceptual framework underpins a scheme, it may be impossible to see phenomena of interest in the data compiled using that classification. At a more fundamental level, the existence of NAICS and GICS allows a rare opportunity to take two perspectives on classifying the same things. Although both perspectives are logically coherent in themselves, when one is viewed in light of the other, their industry definitions sometimes appear as exotic and arbitrary as the imagined Chinese classification of animals.

2 Background

The conceptual foundations of firm classification schemes have two dimensions: supply/demand orientation and structural assumption. The supply/demand orientation manifests as a production or market basis. In a production oriented scheme, an industry is a group of firms that use similar production processes, that is have similar capabilities. In a market oriented scheme, an industry is a group of firms producing close substitutes. So for example, in a production oriented scheme there might be two industries, one producing wood framed windows and the other producing metal framed windows whereas in a market oriented scheme there might be one industry producing windows. At a higher level, a production oriented scheme will separately classify the production of goods and services while a market oriented scheme will separately classify consumer and industry serving sectors. This distinction originates in economic theory and is widely recognized. When explaining their conceptual framework,

[1] quoted widely by (amongst others): Foucault, 1970, The order of things: an archaeology of the human science, Preface. Bowker & Star, 1999, Sorting Things Out, p. 131.

classifiers articulate their production or market orientation. NAICS is "erected on a production oriented conceptual framework" (OMB, 2009 p. 765). The agriculture-manufacturing-service sector distinction is fundamental to its structure. In opposition, because the goods and services distinction is no longer viable, GICS "has shifted towards a market-oriented perspective" (Standard & Poor's and MSCI Barra, 2006, p. 6)

In contrast to these well-articulated production/market positions, views of industry structure remain implicit. Traditionally industry structure is defined as the number and size of firms in an industry, which relates to concentration and barriers to entry. More recently, management and evolutionary economics scholars have begun to focus on groups or networks of firms that undertake complementary activities. From this perspective, industry structure is defined as the architecture of these relationships (Jacobides et al., 2006). After Dalziel, we can label the two views of industry structure "atomistic" and "relational".

Although the two dimensions of supply/demand orientation and structural assumption are conceptually separable, in practice they are related. Dalziel considers the implications of relational views of industry structure for industrial classification schemes. She points out that in the relational view, the salient group of firms is by definition heterogeneous in its capabilities, and therefore relational analysis entails a market orientation. Dalziel proposes that:

> *An industry classification system that adheres to this empirically-grounded [relational] understanding of industry structure will similarly use demand as the primary organizing principle. As a variety of complementary firms work together to collectively address similar fundamental demands, the classification system's primary unit of analysis must accommodate firms that are different from one another, both in terms of the nature of the specific demand to which they individually respond, and in terms of the activities they undertake.* (Dalziel, 2007, p. 1561)

Here Dalziel proposes not only that a relational classification must be demand-oriented but also that a relational classification scheme cannot be very precise because complementary firms work together to address different "specific demand" within "similar fundamental demand." Neither NAICS nor GICS articulates their structural assumption, so I must do it for them. NAICS, being grounded in economic theory, is the prototypical atomistic scheme and is extremely detailed, running to 1175 categories. GICS implicitly implements a relational approach and is focused on broad categories of demand with limited detail – 123 categories at the lowest level.

Dalziel fully implemented her market-relational classification only in the communications area and criticized NAICS based on its performance in that area. Information and communications technologies seem to be a particular focus of the industry architecture literature and a source of problems with production-atomistic industry definitions (see also Munir and Phillips, 2002; Sampler, 1998). Comparing the production-atomistic and market-relational classification philosophies more broadly will serve to assess the generality of the relational insight. NAICS and GICS may have complementary strengths and weaknesses visible only outside the information & communications sectors. This paper explores that possibility.

3 The classification schemes – NAICS and GICS

Both NAICS and GICS are well-established hierarchical industrial classifications that are regularly revised. The resources invested in maintaining and updating the schemes provide incalculable

benefits to scholars by supplying infrastructures for analysis free at the point of use and by creating a de facto standard through which analyses become comparable and a consensus is reached about the meaning of "industry." The high level categories in each scheme are displayed in Tables 1 and 2.

NAICS is a hierarchical classification scheme with 20 categories at its highest (2 digit) level and 1175 at its lowest (6 digit) level. NAICS was developed under the auspices of the Office of Management and Budget (OMB) and is described by the Census Bureau as "an industry classification system used by statistical agencies to facilitate the collection, tabulation, presentation, and analysis of data relating to establishments" (US Census Bureau, 2002). NAICS' orientation to agricultural, manufacturing and service industries is visible in Table 1. The information sector (51) is relatively new and marks a significant departure from the earlier SIC system.

NAICS can trace its origins to the 1930s and its predecessor, the Standard Industrial Classification (SIC), system which it replaced in 1997. NAICS is revised every five years, most recently in 2007. The 2007 revision focused on new and emerging industries, service industries and advanced technology. The 2012 revision process is underway and will focus on:

- Reducing the level of detail, i.e. the number of 6 digit categories.
- Identifying new and emerging industries
- Accounting for errors and omissions in NAICS 2007 (none have been identified so far)
- Clarifying classification of distribution centers, logistics service providers and sales offices of publishers
- Dealing with manufacturing outsourcing (OMB, 2009)

GICS is a hierarchical classification scheme with 10 categories at its highest level and 123 at the lowest level. GICS was developed by Standard & Poor's and MSCI/Barra "to establish a global standard for categorizing companies into sectors and industries" (Standard & Poor's, 2006). GICS is a decade old, launched in 1999, and is updated annually with the current version published in June 2010. The orientation to broad categories of demand is visible in Table 2 as is a certain inconsistency in the application of the demand framework.

Note that NAICS and GICS differ in several respects in addition to their conceptual orientation. NAICS is older and is committed to continuity; GICS' design represents a break with the past in order to accommodate the emerging structure of the economy. NAICS is more detailed; GICS broader. NAICS is public; GICS is private. Both schemes are international in scope, though in different ways. NAICS is negotiated with Canada and Mexico; GICS, being global, is meant to apply to firms in any country. NAICS is designed for a very heterogeneous set of users: government policy analysts, academics and researchers, the business community, and the public (OMB, 2009, p. 765); GICS was developed by and for Wall Street analysts. Updating NAICS is more cumbersome, given requirements for public consultation and its more heterogeneous set of stakeholders.

In addition, the unit classified differs: NAICS classifies establishments, or firm locations, while GICS classifies firms. Classifying establishments into over one thousand categories offers high precision while classifying firms into 120 categories entails some ambiguity. S&P and MSCI/Barra jointly determine a company's single GICS sub-industry according to its primary business based on its financial performance assessed using revenues, earnings and market perception (Standard & Poor's, 2006, p. 3). Scholars are primarily interested in firms, not establishments and usually use NAICS at a fairly high level of aggregation. Nevertheless, an intractable problem will obtain. Companies such as General Electric, 3M and Tyco International are simply impossible to correctly classify using NAICS

because no narrowly focused category accurately describes them. GICS contains a category for industrial conglomerates thus solving the problem.

GICS methodology notes that the scheme provides "a more uniform distribution of weights among the 10 GICS sectors" – never identifying the more unbalanced competitor. Assume it is NAICS. Graham (2007) details the problems with national economic statistics that do not adequately track activity in the service sector because NAICS service sector categories lack granularity when compared with manufacturing categories. Manufacturing (31-33) accounts for 49% of NAICS codes at the 6-digit level. Yet manufacturing accounts for only 5% of establishments and 18% of sales in the U.S. In contrast, retail (44-45) accounts for 8% of NAICS codes, 16% of establishments and 14% of sales. Service sectors are denied the detail in NAICS that they would seem to warrant based on their weight in the economy while manufacturing is afforded detail unjustified by its economic weight.

[Figure 1 about here]

The more even distribution of weights across categories is illustrated in Figure 1 which juxtaposes NAICS and GICS and the category distribution of: patenting firms, patents, lowest level categories in each classification system, firms,[2] and size of firms.[3] The figure confirms that GICS is more balanced. First, category detail is more evenly distributed across GICS sectors, contrasting with the very high percentage of detail in NAICS manufacturing categories. The NAICS emphasis on manufacturing is warranted neither by the number of manufacturing firms nor by their economic importance. Across GICS categories, the level of detail is more even and corresponds to the number of firms and their economic importance. In NAICS, patenting is almost entirely contained within manufacturing. Within GICS, patenting is more evenly spread across the economy, though the higher patenting propensity in information technology and pharmaceuticals is visible.

Somewhat neglected in firm classification is the identity of the classifier. The government does not publish the classification of establishments used in its economic surveys, in which presumably the firms classify their own operations. NAICS classifications obtained from databases are assigned by employees somewhere in the database companies (Compustat, Moody's etc.) using principles not divulged. The quality of this work will depend on training and time allocated, which in turn depend on the importance of the field to the database. The amount of inconsistency and error I found in these classifications suggests that assigning NAICS codes is not a high priority task in database companies. In contrast GICS classifications are a high priority for S&P and MSCI/Barra because the quality of GICS related products depends on the quality of the classification. S&P and MSCI/Barra hold themselves accountable for this and explain their classification principles in the GICS methodology document. Thus, there is one official GICS category for each classified firm which is available to analysts in Compustat (an S&P product).[4]

A final difference between the two schemes is that GICS has been found to deliver superior results in research applications. Bhojraj et al. (2003) analysed firm financial performance for S&P 1500 firms by sector using several classification schemes including NAICS and GICS and examined movements in stock prices, valuation multiples, firm growth rates and R&D expenditure. Although the literature tends to conclude that sector does not explain much about firm performance, Bhojraj et al.

[2] Numbers of firms obtained from S&P 1500 for GICS and economic census data on establishments for NAICS.

[3] Size of firms is market capitalization for GICS and sales for NAICS.

[4] Only publicly traded firms will be classified however.

found that GICS is significantly better at explaining cross-sectional variation than NAICS. Bhojraj et al attribute the superior performance of GICS to the financially-oriented nature of the categories and to the consistency of the firm assignment process (Bhojraj et al., p. 770).

Table 1 – NAICS at the 2-digit level

2-digit	Sector	
11	Agriculture, Forestry, Fishing and Hunting	
21	Mining	Primary
22	Utilities	
23	Construction	Secondary - manufacturing
31-33	Manufacturing	
42	Wholesale Trade	
44-45	Retail Trade	
48-49	Transportation and Warehousing	
51	Information	
52	Finance and Insurance	
53	Real Estate and Rental and Leasing	
54	Professional, Scientific, and Technical Services	
55	Management of Companies and Enterprises	Tertiary - services
56	Administrative and Support and Waste Management and Remediation Services	
61	Educational Services	
62	Health Care and Social Assistance	
71	Arts, Entertainment, and Recreation	
72	Accommodation and Food Services	
81	Other Services (except Public Administration)	
92	Public Administration	

Table 2 - GICS®

	Sector		Industry Groups	
10	Energy	1010	Energy	
15	Materials	1510	Materials	
20	Industrials	2010	Capital Goods	Industry serving
		2020	Commercial & Professional Services	
		2030	Transportation	
25	Consumer Discretionary	2510	Automobiles & Components	
		2520	Consumer Durables & Apparel	
		2530	Consumer Services	
		2540	Media	
		2550	Retailing	Consumer serving
30	Consumer Staples	3010	Food & Staples Retailing	
		3020	Food, Beverage & Tobacco	
		3030	Household & Personal Products	
35	Health Care	3510	Health Care Equipment & Services	
		3520	Pharmaceuticals, Biotechnology & Life Sciences	
40	Financials	4010	Banks	
		4020	Diversified Financials	
		4030	Insurance	
		4040	Real Estate	
45	Information Technology	4510	Software & Services	
		4520	Technology Hardware & Equipment	
		4530	Semiconductors & Semiconductor Equipment	
50	Telecommunication Services	5010	Telecommunication Services	
55	Utilities	5510	Utilities	

Source: Standard & Poors & MSCI/Barra, 2006

4 Method

NAICS and GICS categories will be examined from the perspective of firms with strong patent portfolios. The patenting firms were identified by Anthony Breitzman of 1790 Analytics as part of a larger project entitled: *An Analysis of Small Business Patents by Industry and Firm Size*, produced in 2008 for the Small Business Administration, Office of Advocacy under SBA contract SBAHQ-07-Q-0010. In this project, all 1,293 US firms with 15 or more patents granted between 2002 and 2006 were identified.[5]

A custom classification scheme was generated by using a qualitative method to classify the firms into industries. In qualitative research, codes are attached to phrases, sentences or paragraphs in text

[5] This project leveraged the 1790 Analytics patent database which identifies organizations with 40 or more patents issued in the last five years. Because the patent office records assignees and not companies, it is not trivial to find all patents owned by a large company. Patents owned by large companies appear under a mixture of firm, establishment and subsidiary names and variants of those names. Mergers and acquisitions constantly change the correct affiliation of firm units. Large firms like General Motors and Procter & Gamble patent under more than 100 names. In the extreme, firms with a history of mergers such as Glaxo-SmithKline patent under more than 300 names. The core 1790 Analytics database tracks 4,000 US firms, foreign firms, non-profits, universities, and government agencies in three patent systems and tracks more than 50,000 individual subsidiary and variant names. It is licensed to information companies such as Thomson Scientific. This database is maintained by a data manager with more than 20 years experience tracking and standardizing assignee names.

(usually interview transcripts) to represent the concept being discussed in the text segment. In this project, the line of business of each firm was coded from text describing each firm. The corpus of text was obtained from Google Finance where available.[6] For firms not covered in Google Finance, text was obtained from firm websites or as a last resort from other websites. No text was found for 3% of firms, see Table 3.

Table 3 – Source of text used in corpus

Text Source	Firms	%	
Google Finance	997	77	94% of the large firms and 55% of the small firms 98% of the public firms and 46% of the private firms.
Website	219	17	
Other	42	3	
NA	35	3	
Total	1,293	100	

In addition, NAICS classifications were obtained for the firms. 1790 Analytics obtained NAICS classifications from Mergent/Moody's International (public firms) and LexisNexis (smaller firms)[7] and SICs from Dun & Bradstreet for the remainder. Codes were obtained for all but 39 firms, or 97% of the 1,293 firms. SIC codes were converted to NAICS where possible. The SIC to NAICS mapping is not always unique, and was converted only in cases were it was unique. The number of firms with a NAICS code was increased by also converting SIC to NAICS at the 3 digit level in cases where this relationship was unique. The final result was database-assigned NAICS classifications for 1150 firms, or 89% of the firms.[8] GICS codes were obtained from Compustat for 735 or 58% of the firms.

5 Traditional innovators - chemicals, pharmaceuticals & semiconductors

I begin with innovative industries that are unproblematic in both schemes: chemicals, pharmaceuticals, semiconductors and contract R&D. In NAICS Chemical Manufacturing is a 3-digit subsector of the Manufacturing sector; in GICS the 6-digit Chemicals industry is found in the Materials sector. In NAICS Pharmaceuticals is within the Chemicals subsector; in GICS Pharmaceuticals is a 6-digit industry under the 4-digit Life Sciences industry group in the 2-digit Health Care sector. Although the placement of pharmaceuticals is very different, it is unambiguous and clear in both cases. Semiconductor manufacturing is similar. In NAICS, Semiconductor Manufacturing is a 4-digit industry group found in the 3-digit subsector Computer and Electronic Product Manufacturing; in GICS, Semiconductors are under the 2-digit Information Technology sector. The two schemes perform equally well here. Contract Research & Engineering is treated differently in each scheme. In NAICS it is found in the 2-digit Professional, Scientific, and Technical Services sector, and there are 6-digit "national industries" for R&D in biotechnology and R&D in Physical, Engineering and Life sciences. In GICS there is a 6-digit Life Science Tools & Services industry in the 2-digit Health Care sector as well as an 8-digit Research & Consulting services sub-industry in the 6-digit Professional Services industry in the 2-digit Industrials sector. Although GICS splits an industry that is united in NAICS, this is unproblematic because the split reflects a clear specialization among companies. Chemicals,

[6] Google Finance seems to get its information from Hoovers.

[7] The codes appear to be NAICS 2002, not the latest NAICS 2007.

[8] There are codes for 98% of the public firms and 75% of the private firms; as well as 95% of the large firms and 84% of the small firms.

pharmaceuticals, semiconductors and contract R&D are innovative industries, but somehow traditional in their innovation and so easily accommodated within existing frameworks.

6 Small industries - gaming machines

I now turn to a more unusual case. Is the manufacture of gaming machines for casinos an industry? Is it innovative? Reflection suggests that there must be such an industry, given the size of the casino industry. The dynamic Las Vegas environment must encourage innovation, and sophisticated electronics and networking should provide technical opportunity to would-be innovators. An analyst might conclude that a high rate of innovation is quite likely. Examining U.S. firms obtaining more than 15 U.S. patents in the five years ending 2006 confirms this supposition, identifying seven highly innovative small and medium size firms creating sophisticated electronics and software for gaming. To further the investigation, one might consult government statistics to determine industry size. Industry statistics are reported using NAICS. A search of NAICS for gaming finds no exact match. Coin operated games/gambling devices/amusement machines manufacturing are included in "339999 – All other miscellaneous manufacturing." The category also includes manufacturing of beach umbrellas, candles, cigarette lighters, feather dusters, fly swatters, marionettes and hat blocks. The images of the 1940's evoked clash with the firms' self-descriptions as providers of:

- innovative new games, dazzling visual environments, and advanced concepts in seating and slot bases
- automatic card shufflers, intelligent table systems components [including] roulette chip sorters; table games, . . . electronic table (e-Table) systems, including electronic and wireless table gaming platforms, and . . . electronic gaming machines.
- integrated casino and jackpot management solutions. . . regulated wagering solutions in wired, wireless and mobile formats . . . . a suite of products that when combined consolidates the management of slot machines, table games, server-based gaming, account wagering, marketing and cage into one fully integrated system.
- a modular and fully integrated suite of software products that enables casinos to track player activity, monitor games through chip tracking and bet recognition, and provide real-time accounting for table games.

Consulting business databases one would find that five of the seven firms are classified, and they fall into three categories: 339999, 713290, and 713210. The inconsistency is troubling for any analyst who sees these firms as fundamentally similar. At the two digit level, 71 is a service category for arts and leisure; it should not contain manufacturing firms. 713210, casinos, is applied to Bally which does also own a casino. Firms in 713290 operate gambling facilities (except casinos) or providing gambling services, i.e. bingo halls, bookies, arcades, etc. This classification states that these firms have more in common with bingo halls than with manufacturing or software firms, an image difficult to reconcile with the firms' development, design and manufacturing activities. This anomaly would be easy to resolve. The best solution would be to remove "coin operating games etc." from the definition of 339999 and include "gaming machine" manufacturing in the definition of the category Other Commercial and Service Industry Machinery Manufacturing - 333319[9].

GICS may be in a slightly better position. Under Consumer Services we find Casinos & Gaming. The definition of this category is: "Owners and operators of casinos and gaming facilities. Includes companies providing lottery and betting services." At present, this definition includes only

[9] To become 333318 in the proposed 2012 revisions.

service providers, not manufacturers of specialized equipment. However, since GICS' conceptual framework would not be violated, the wording could be altered to encompass these companies.

Gaming machine manufacture escapes the attention of NAICS and GICS in part because it is too small. Finding the right level of granularity challenges designers of classification schemes. Exhaustive schemes would be unworkable; coarse schemes would provide no information (few would be satisfied with statistics on the national economy that only reported activity in agriculture, construction, manufacturing and services). Bowker and Star point out that the maximum level of granularity is engineered into a scheme using residual categories, those with "other" or "miscellaneous" in their names. NAICS 333319 is a residual category, and 339999 is the ultimate residual: All Other Miscellaneous Manufacturing.

GICS seems to evade this rule. No GICS category includes "other" or "miscellaneous" in the name, though some categories include the word "other" in the definition. The absence of residual categories in GICS, an apparent strength, may be related to a certain vagueness in its categories, a likely weakness. For example, manufacturers of GPS devices fit into the NAICS 6-digit Search, Detection, Navigation, Guidance, Aeronautical, and Nautical System and Instrument Manufacturing industry. In GICS, GPS manufacture can be placed in Consumer Electronics in the Consumer Discretionary sector (assuming GPS manufacturers don't also sell to firms and the military). Here NAICS excels in precision compared with a certain frustrating vagueness in GICS. The price paid for the high precision in NAICS are the residual categories, which often seem to contain what is most fresh and interesting. The price we pay for eliminating the residual categories is the vague and somewhat meaningless categories in GICS.

7 GICS splits - batteries and analytical instruments

NAICS provides better classification for battery and analytical instrument manufacturers. Efforts to improve the performance and environmental footprint of batteries are producing many patents at the moment. Seven highly innovative small firms were found, and all fit nicely into a 5-digit NAICS industry – Battery Manufacturing. Instrument manufacturers have always been innovative and in NAICS are classified into the 6-digit Analytical Laboratory Instrument Manufacturing industry within the 5-digit industry Navigational, Measuring, Electromedical, and Control Instruments Manufacturing.

GICS is more difficult. Battery manufacturers could be placed either in Electrical Equipment in the Industrials sector or in Consumer Electronics in the Household Durables sector because a firm can produce both industrial and consumer batteries. A firm will be classified based on which market generates most of their revenue. In GICS analytical instruments companies are split between Electronic Equipment & Instruments in the Information Technology sector and Life Science Tools & Services in the Health Care sector. This makes sense in some cases. For example if a firm's products are integrated systems for the analysis of genetic variation and biological function, the Life Science Tools industry is a good choice. Similarly, a supplier of weighing instruments for use in laboratory, industrial and food retailing fits well in Electronic Equipment & Instruments. But there are instruments that find use in a broad array of industries including but not limited to pharmaceuticals – liquid chromatography is used in industries including: environmental, food & beverage, chemical, semiconductor, power, pulp & paper, and petroleum refining. Suppliers will be classified into the Health Care sector because pharmaceutical companies account for the largest slice of firm revenue. This seems somewhat arbitrary and misleading.

GICS can make distinctions that seem non-intuitive when dealing with generic technologies that find application in industries including but not limited to pharmaceuticals or application to both consumer and capital goods. Such industries are unified in NAICS, which seems the better choice.

8 NAICS splits - packaging & filtration

Among U.S. firms with more than 15 patents in the five years ending 2006 were twenty firms that produce packaging. Packaging represents a well established manufacturing industry, so it should be easy to find in NAICS. Unfortunately not, NAICS contains seven related 6-digit industries:

- 322214 - Fiber Can, Tube, Drum, and Similar
- 322221 - Coated and Laminated Packaging Paper
- 322225 - Laminated Aluminum Foil Manufacturing for Flexible Packaging Uses
- 326112 - Plastics Packaging Film and Sheet (including Laminated)
- 332431 - Metal Cans
- 333993 - Packaging Machinery
- 339991 - Gasket, Packing, and Sealing Device

These are scattered across five 3-digit industries: Converted Paper Products; Plastics Products; Boiler, Tank, and Shipping Containers; Other General Purpose Machinery and Other Miscellaneous. Aggregation will not bring together a packaging industry because only at the level of all manufacturing would these categories come together. The sector level splits in packaging arise because manufacture of paper, metal, plastic and glass items are fundamentally different in a production oriented scheme. Some of the packaging firms in this study make packaging machinery or glass bottles and so fit into NAICS categories. However, the more innovative companies engage in more complex production not accurately represented by the micro-fine, material processing concepts NAICS embodies. For example:

- innovative protective packaging products and systems including packaging-made-on-site, bubble, air cushions, Kraft paper cushioning and ready-to-use products, polyethylene foam, loosefill made of recycled polystyrene or cornstarch and Kraft/bubble mailers.
- standard, specialty and custom packaging for high definition discs, DVD, CD, VHS, software, PC and video console game formats, complete custom solutions including 3D modeling, prototyping, design engineering and production
- value-added dispensing systems (pumps, closures and aerosol valves) for the personal care, fragrance/cosmetic, pharmaceutical, household and food/beverage markets.
- packaging and performance-based materials and equipment systems that serve an array of food, industrial, medical and consumer applications.

NAICS materials-based process codes clash with these business philosophies. In the past, firms may have specialized in working wood or plastic or metal and no doubt a number still do. However, innovative packaging firms now integrate knowledge to solve the customer's problems. For example, plastic manufacturing is nicely dissected in NAICS. A well behaved firm might manufacture noodles used as packing material and be rightly classified as a plastic foam producer. An innovative packaging firm might have begun as a noodle maker but evolved into a "packaging solutions" provider. The firm would now produce noodles, other types of plastic including sheet plastic and also Kraft paper based packaging. This has the advantage for customers that they do not have to put together the noodles with the bubble wrap with the Kraft paper. The packaging firm can advise on the best use of different types of packing material and set up a system.

Category scatter tracing to synthesis of previously separate industrial disciplines is also visible in filtration. Four of the patenting firms identified themselves with filtration. These firms were scattered among three NAICS categories by the databases. Table 4 lists the NAICS category numbers and names and describes the firms' businesses. The three NAICS categories represent three conceptual bases: the materials-based view seen in packaging, "other" or miscellaneous categories, and a machinery-for-a-

purpose category. The firms on the other hand seem united not by the materials they use, nor even by the specific products they sell, but by the problem they are trying to solve. Higher precision manufacturing requires cleaner conditions making more extreme demands on filtration. In response, the technology of filtration seems to have evolved in a way that breaks down previous boundaries such as air/fluid filtration. These companies seem to view "filtration" as a challenge broadly present throughout industry, and several clearly do not view NAICS' air/fluid distinction as fundamental. Filtration is not a new problem; that's why NAICS contains categories for air filters and places water purification in the residual category 333319 (along with flight simulators, ferris wheels, corn poppers and ovens). However, innovation seems to have redefined the landscape of filtration in a way that escapes NAICS. Therefore, this new view of filtration will be invisible to NAICS-aided analysts.

Table 4 – Filtration companies

NAICS	NAICS name	Business
325211	Plastics Material and Resin	high technology filtration using microporous membranes in separation and filtration processes for separating the cathode and anode in a variety of battery markets as well as in medical and industrial applications.
333319	Other Commercial and Service Industry Machinery	highly effective, portable, point-of-use and fixed water filtration and purification technologies for consumer, municipal, industrial and medical applications.
333411	Air Purification Equipment	filtration systems including air and liquid filters, and exhaust and emission control products for mobile equipment; in-plant air cleaning systems; compressed air purification systems; air intake systems for industrial gas turbines, and specialized filters for diverse applications, such as computer disk drives and semiconductor processing.
333411		filtration, separation and purification technologies, using filter media, and other fluid clarification and separations equipment for the removal of solid, liquid and gaseous contaminants from a range of liquids and gases.

The packaging and filtration examples illustrate how NAICS' production basis has become anachronistic due to innovative business models involving customer-focused solutions, exemplifying the move from product to customer focus that GICS addresses. In GICS under Materials we find Containers & Packaging with subdivisions for Metal & Glass and Paper. Plastic is not included, but otherwise the category gets closer to accommodating these firms. As for filtration, under Industrials/Capital Goods/Machinery we find Industrial Machinery which includes in its description "pollution control equipment." From the perspective of innovation theory, packaging and filtration companies are united by an innovation model in which they custom engineer increasingly complex products to meet the needs of their large firm customers. Therefore, we would prefer to see the firms classified into one category. GICS does this.

The issue of granularity and residual categories appears again here. One of the NAICS categories in Table 4 is a residual category and two of the packaging categories are residual.

9 Factoryless manufacturers - pipeline & fabless

Packaging and filtration represented integrating knowledge to adapt to more complex products. The second example of business model innovation arises from vertical disintegration or the changing division of labor in innovation. Close examination of heavily patenting small firms established that a great many non-manufacturing firms are being misclassified as manufacturers both in the popular imagination and in the databases. About 200 firms were identified, 70% of them small, that do not produce goods yet are classified as manufacturers.

These misunderstood firms were found largely in biotechnology and semiconductor technology. The largest category of such firms are biotechnology firms, most of whom are pre-commercialization, meaning that they undertake research, including clinical trials, maybe license technology but they do not make anything (laboratory scale facilities to make prototypes would not count as manufacturing here). Such firms might be better labeled "biomedical pipeline" firms. There are also a few similar firms aiming for non-medical technologies such as biofuels, perhaps we could label those "biotechnology pipeline" firms. In semiconductors we find "fabless" firms. Although classified as manufacturing firms by the databases, they do not manufacture anything. They design integrated circuits and license their designs or contract for their manufacture and market the chips. Even more care was needed to identify these firms than the pipeline firms as this industry is particularly coy about admitting to a lack of manufacturing facilities. A few pioneering firms in this area proudly announce on their websites that they are fabless, but for the rest of the firms it was necessary to search the firm's SEC filings for admissions of the truth – all manufacturing is contracted out. Another such industry is Electronic Design Automation (EDA), a specialized type of software for the design of integrated circuits whose purveyors are most often classified as semiconductor manufacturers by databases. One smaller group might be called "communications technology design and market." These firms design and license technology in communication equipment - wireless phones and such. Finally, we identified a clutch of pure play patent licensing companies. The non-manufacturing business model may apply to other firms classified into manufacturing categories but in this study extreme care in identifying non-manufacturers was applied only to the biomedical pipeline and fabless semiconductor firms.

In NAICS, such firms properly belong in 51, the information sector. Manufacturing versus not manufacturing is a fundamental (2 digit) distinction in NAICS because a firm that manufactures has different capital and skill requirements than one that does not. In delineating 51, NAICS defines information goods as not necessarily having tangible qualities, unlike traditional manufactured goods. Unlike services, the delivery of the product does not require direct contact between supplier and consumer. The value of the good lies in its informational content, not in its format. Having rights to these goods is crucial.[10] Pipeline and fabless firms trade in intangibles and so are information firms, not manufacturing firms. Though innovation theorists would quibble that it is impossible to effectively transfer a licensed technology without personal contact, nevertheless, there is a difference in the salience of personal contact between licensing and giving haircuts. Furthermore, establishing rights over their goods is crucial for the designers wishing to trade them as information, which is why they are heavily patented. These firms fit the NAICS definition of the information sector.

Would these firms better fit in 54 - Professional, Scientific, and Technical Services (which encompasses engineering, and specialized design consulting and research)? The contract R&D industry was discussed earlier, and it differs because firms are paid for time spent on projects commissioned by clients. Contract R&D cannot be confused with manufacturing. Information firms devise their own agenda and are paid for the rights to make the goods they design or develop. Designing, licensing and marketing are the hallmarks of innovative sectors of the information industry we identify here. Manufacturing firms also engage in these activities, which may be the source of the confusion.

Perhaps the confusion also arises from an unconscious assumption that these firms are proto-manufacturers destined to transition into manufacturing firms. This seems a rash assumption not supported by evidence. The self descriptions of these firms suggest rather a permanent category of information firms whose existence is possible because of the emerging phenomenon of "task trading."

[10] http://www.census.gov/econ/census02/naics/sector51/51.htm, accessed June 16, 2009.

Task trading was analyzed by Grossman and Rossi-Hansberg in the context of international trade (Grossman and Rossi-Hansberg, 2008). In the new economic order, rather than exchanging goods:

> bits of value [are] being added in many different locations, or what might be called trade in tasks. Revolutionary advances in transportation and communications technology have weakened the link between labor specialization and geographic concentration, making it increasingly viable to separate tasks in time and space. When instructions can be delivered instantaneously, components and unfinished goods can be moved quickly and cheaply, and the output of many tasks can be conveyed electronically, firms can take advantage of factor cost disparities in different countries without sacrificing the gains from specialization.

It is task trading that enables a small firm to engineer an innovative product, contract for manufacture, and control marketing and distribution. A firm using this business model can remain independent and small because they do not need to raise the vast amounts of capital required to enter manufacturing. Dealing with this phenomenon is one of the most difficult issues in the current NAICS revisions. OMB recognizes that three types of firms now exist: traditional or integrated manufacturers, manufacturing service providers (contract manufacturing), and factoryless goods producers. Of these, the factoryless are the most conceptually difficult. OMB proposes either classifying these firms into the manufacturing sectors or into wholesale trade. They dismissed 54 – Professional and Technical Services because not all such firms innovate, presumably OMB would make the same objection to the suggestion here – 51 (OMB, 2009, 767-768). NAICS, innovation theory, indeed our very conception of fundamental economic categories needs to be reworked to accommodate this phenomenon. I argue that our concept of information firms needs to be expanded. However, since the category of all factoryless firms includes many non-innovative firms, another solution is more likely.

As the product/service distinction is a key point of difference between the NAICS and GICS conceptual frameworks, it is no surprise that GICS handles this problem somewhat better. Biotechnology pipeline can be correctly classified into the biotechnology sector because its definition uses "or" not "and" when listing firm activities – as in: "design, development, research, manufacturing or marketing". The same is not true of semiconductor firms however, who are described simply as manufacturers. Presumably, this definition could be changed to mirror the biotechnology definition because doing so would not violate the GICS conceptual framework.

10 Large, growing and ignored - photonics, imaging & display

Small entities are clearly problematic in a classification of something so vast as the US economy; big entities should not be. Yet they are. To Bowker and Star, a classification is "a still life in motion" of necessity a temporarily fixed representation of an ever shifting world (p. 171). The still life portrait of the economy represented by NAICS struggles to incorporate new industries created through technological innovation, even after those industries grow large. The optoelectronics, photonics and imaging & display industries exemplify this problem. These are not small industries. The Optical Industry Development Association (OIDA) reported that the global market was worth $316 billion in 2006 and grew 13% from the previous year (OIDA, 2007, p. 5). There were 35 patenting photonics and optical components companies and 25 patenting imaging & display companies. OIDA divides the optical component category into seven segments. Table 5 lists the hiding place for each segment within NAICS.

Table 5 – Optical component segment and corresponding NAICS category

OIDA optical component category	**Found within NAICS category**
Optical I/O devices	334119 Other computer peripheral equipment
optical components	334413 Semiconductor and Related Device
solid state lighting	334413 Semiconductor and Related Device
optical lens and lasers	334413 AND others
optical fiber communications	334417 Electronic connector
flat panel displays	334419 Other electronic component
optical storage	334613 Magnetic & optical recording media

Table 5 shows that NAICS lumps three segments of photonic and optical components into 334413 - Semiconductor and Related Device Manufacturing - which also includes integrated circuits, memory chips, microprocessors, diodes, transistors, solar cells and other optoelectronic devices. Although all of these production processes can use CMOS and gallium arsenide, the photonics firms in this dataset are distinct from electronic integrated circuit firms. The production processes of photonics firms often involve mirrors, fiber optical cable, OLED or liquid crystal on silicon; semiconductor processes do not. The manufacture of semiconductors also involves wire, but that is not used to justify having only a wire industry that contains all semiconductor firms. Similarly, NAICS seems to violate its conceptual framework by not recognizing the existence of photonics.

What is so strange about this classification is the breakdown of the 5-digit category, 33441 - Semiconductor and Other Electronic Component Manufacturing that contains 334413. Within 33441 there are nine six digit categories available, providing one would think ample scope for classifying photovoltaics, optical circuits, flat panel displays, LED lighting and microprocessor chip manufacturers into separate 6-digit categories so that economic statistics could be produced informing us of trends in these important industries. Table 6 reports the disposition of the nine categories based on the 2002 economic census. 56% of shipments within 33441 are lumped into semiconductor and related, hiding all information on photovoltaics, optoelectronic & photonic circuits and LED lighting. Note however, the electronic resistor industry and the electronic capacitor industry, each of which accounts for less than 2% of shipments in 33441. Somehow NAICS has managed to highlight "industries" few care about and hide industries upon which the future of our economy depends.

Table 6 – Breakdown of NAICS 33441 - Semiconductor and Other Electronic Component Manufacturing

6-digit	% establishments	% shipments	NAICS category name
334411			Electron tube mfg
334412		56%	Bare printed circuit board mfg
334413			Semiconductor & related device mfg
334414			Electronic capacitor mfg
334415			Electronic resistor mfg
334416			Electronic coil, transformer, & other inductor mfg
334417			Electronic connector mfg
334418	30%		Printed circuit assembly (electronic assembly) mfg
334419			Other electronic component mfg

Bowker and Star note than in taxonomy there are two fundamental dispositions - lumpers and splitters, i.e. those who want few large categories and those who prefer exhaustive detail. Either is defensible. NAICS perversely exhibits both at the same time, in the wrong places, lumping key

divisions and splitting on trivial ones. The origin of this problem may be that 33441 was devised when semiconductor technology was new, at a time when resistors and capacitors seemed important because they had been important in electronics before the integrated circuit. Adaptation to the evolution of semiconductor related industries was then limited, perhaps because "we already took care of that with the introduction of 33441." One aspect of this will be solved in the 2012 revision which will eliminate the capacitor and resistor industries (along with slipper manufacturing).

The temptation to spurious historical continuity is well illustrated by imaging and display devices. OIDA lists eight application segments including communications, consumer display, transportation, defense, computers, energy conversion, sensing and medical. Table 7 summarizes the products of nine imaging firms, the OIDA segment, and the NAICS classification of the firm obtained from databases.

Table 7 – Imaging firms and NAICS classification

Firm business	**OIDA segment**	**NAICS**	**NAICS description**
high resolution medical skin imaging systems	Medical	333314	Optical Instrument and Lens
systems using multispectral and polarized light for higher resolution in imaging and in detecting items such as malignant cells in tissue	Medical	333314	Optical Instrument and Lens
ultra-high performance light engine technologies for front projectors and rear projection televisions	Consumer display	333314	Optical Instrument and Lens
digital projection	Consumer display	334119	Other Computer Peripheral Equipment
miniature display and imaging engines	Sensing	334419	Other Electronic Component
machine vision for automated manufacturing	Sensing	334519	Other Measuring and Controlling Device
electronic ink technology for the Kindle	Consumer display	518210	Data Processing, Hosting, and Related Services
imaging technology for security cameras	Defense	541512	Computer Systems Design Services
barcode scanning and high-speed automated data capture using laser, holographic and vision-based technologies	Computers and processing	NA	

Not for the first time, there is a great deal of scatter in the classification no doubt attributable to the absence of a good category for these firms. 333314- Optical Instruments and Lens - is not too bad, as its definition includes laboratory analytical optical instruments, optical alignment and display instruments and optical test and inspection equipment manufacturing. However, these firms do not identify themselves as optical firms, but rather as imaging firms. Why is that? According to *The New Oxford American Dictionary* "optical" means of or relating to sight, especially in relation to the physical action of light. Image as a verb means to make a representation of the external form of something. NAICS 333314 obviously traces back to the days of manipulating light, incorporating binoculars, lenses, prisms, microscopes and diffraction gratings. For these firms, the electromagnetic spectrum is still involved, but the challenge is found less in focusing and diffracting light, than in creating the right light and sophisticated representation of the target. Should NAICS try to stretch 333314, keeping a spurious continuity with the past (prisms and binoculars have nothing to do with imaging engines), or should

NAICS recognize the existence of a new category of activity? As archaeology is less interesting to analysts than accuracy, I would advocate the latter.

GICS performs no better. The definition of Semiconductors under Information Technology has recently been changed to include mention of solar cell manufacturing, implying GICS would treat photonics the same way, were it to mention photonics.

11 Discussion

In the evolving structure of industrial sectors that comprise the economy, change is not restricted to relations between or within parts of the complex whole, but extends to the transformation of the parts themselves. As others have noted, understanding social phenomena requires that we hold some unit of observation constant. In economics and management that unit has been the industry. This is becoming problematic because:

> *much of the action in terms of strategy, technology, and knowledge development does not happen either among firms within a stable industry, or through the growth or decline of certain sectors compared to others. Instead, the action happens in terms of the definition, redefinition, drawing, and redrawing of the very nature of these sectors. Technology does not progress and develop within a sector; rather it shapes (and is shaped by) the encompassing architecture of multiple sectors.* (Brusoni et al., 2009, p. 209)

Most explorations of industry transformation have described a single sector. This paper complements that approach with a cross sector exploration of industry transformation. The analysis leverages mismatches between our canonical, historical understanding of industrial sectors and the emergent understandings of agents of structural change to highlight both transforming industries and fundamental limits of categories that operationalize the concept of "industry" in a fluid environment.

Representing the canonical institutional view of sectors is the NAICS industrial classification system. The product of on-going Federal investment, the system cannot be regarded as naïve or unresponsive to economic change. To respond to structural shifts, the system was radically revised in 1997 and has been updated every five years since. Thus, it has incorporated the emergence of biotechnology, information technology and services. And yet, constrained by constituencies placing a high value on continuity, its response to change also falls short. Representing a more radical response to structural shifts is GICS, a scheme launched in 1999 and based upon an entirely different foundation in order to better represent the current structure of the economy.

Representing agents of structural change are highly innovative US firms. Because the firms examined emphasize patenting, structural change originating in technological innovation is the focus here. Firms whose innovations were purely technological– chemicals, pharmaceuticals and semiconductors - posed no challenge to either scheme. There were also innovators in industries whose definition remained stable and were easily and precisely classified in NAICS but were split somewhat arbitrarily and buried in very broad and meaningless categories in GICS – batteries and analytical instruments. The technologically innovative firms ill served by NAICS tended to have shifted business models, exhibiting knowledge integration or vertical disintegration. This exploration found two examples of knowledge integration - packaging and filtration. NAICS handled those badly while GICS incorporated them easily. There were two examples of vertical disintegration, or changing division of labor in innovation, - biomedical pipeline and fabless semiconductor - firms that specialize in discovery and design without manufacture. NAICS misclassified and hid this phenomenon and in so doing violated its own principles. GICS incorporated these easily without violating its principles, but in so

doing also hid the phenomena within a very broad and heterogeneous category. There were also examples of vital, innovative industries exploiting relatively newly emerging technological opportunity that were completely invisible in both schemes – gaming machines, photonics, and imaging and display.

Invisibility has consequences. Ruef and Patterson found that firms that do not fit well into classification - hybrids, ambiguous entities etc. - suffer lower credit ratings (Ruef and Patterson, 2009). Without an official industry category, there will be no government data on the size of an industry or its employment trends, regional concentration, export trends, R&D etc. This is a problem for policy makers and analysts who seek to understand our economy and economic change. Vast literatures in innovation studies address the visible: biotechnology, semiconductor and pharmaceuticals while the invisible industries discussed here are neglected. The resulting bias is not recognized. No doubt policy favours the visible over the invisible, which becomes a problem if these industries are visible in Asian or European industrial classifications and so cultivated abroad.

This analysis is not meant as a dismissal of industry classification. Aficionados of the case study do not require classification schemes, and emphasizing their arbitrary and subjective elements could dismiss classification altogether. But we need to be able to develop types of understanding of our economies that are not accessible through case studies. Classification schemes enable us to see the whole economy. They are an infrastructural foundation upon which we build understanding of our economies in their entirety.

Both NAICS and GICS believe they are capable of representing the US economy accurately. NAICS would argue that consistent application of a sound principle – classification based on production process – will result in a sound classification scheme. GICS has relegated the production basis to the dustbin of history, and would argue for the superiority of its forward looking principles combined with the clarity and objectivity of classifying firms based on revenue. This paper argues that neither produces an entirely satisfying result. NAICS seeks to maintain continuity with the past, which leads both to a reluctance to add new categories and a plethora of out-dated categories. Business model innovation is reshaping our economy at an even more fundamental level than technological innovation as goods and services are sold together, tasks become tradable in addition to products and the focus shifts to markets and consumers rather than producers. The conceptual basis of NAICS has reified the older structure. GICS on the other hand seeks to incorporate these changes and so is strong precisely where NAICS is weak. Yet GICS' customer-based classification will create unfortunate splits, of battery makers or analytical instrument manufacturers for example. Even worse, GICS inconsistently uses the customer-basis, therefore banks and telecommunications services providers would be unified, aligned with our intuitions. Classification will seem arbitrary when some types of firms are unified and others are divided among customer-based categories. The arbitrariness is compounded when small differences in the source of revenue for a multi-industry serving company define its sectoral identity. Arbitrary splits of intuitively homogenous sets of firms will hide industries and build "industries" that are extremely heterogenous in their composition becoming overly-broad and so meaningless.

Those that curate the industrial classification infrastructure are aware of economic change and seek to adapt, however imperfect is the result. Scholars of innovation studies appear to be less responsive to change. As has been well known for at least 15 years since Griliches' presidential address to the American Economic Association, the evolution of the economy creates measurement difficulties because existing data become inadequate (Griliches, 1994). Griliches observed that this is compounded because economists do not pay a great deal of attention to how data are produced. This paper attended to one of the most neglected aspects of data production: classification. While scholars of finance seem to be aware of classification issues and the deleterious effect of bad classification on results (see Bhojraj

et al. 2003 as well as its cited and citing papers), literature on technological innovation shows little to no awareness (exception Dalziel, 2007). The final SIC revision was issued in 1987. Almost a quarter-century after its last update, 92% of 312 innovation studies papers using a classification scheme used SIC.[11] Even worse, innovation scholars seem unaware of GICS. Scholars of innovation have a choice of industry classifications. Rather than defaulting to the out-dated SIC, analysts should spend a moment considering whether the NAICS' or GICS' conceptual framework will best fit their approach and whether high precision is required.

Whichever scheme is chosen, one must remain mindful of Bowker and Star's insight that expecting classification infrastructures simply to reflect reality is unrealistic. Use of classification infrastructures requires scholars to remain sensitive to the presence of dark spots, or parts of the economy that are hidden by the categories. In addition, there is much work to be done laying the foundations for a third generation of industrial classification that avoids the worst pitfalls of the current schemes.

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[11] Results of a full text search of seven core journals in Google Scholar for "SIC" and "NAICS" in articles published since 2005. Journals were those identified in Fagerberg & Verspagen, 2009, namely: *Research Policy, Industrial and Corporate Change, Journal of Evolutionary Economics, Economics of Innovation and New Technology, Structural Change and Economic Dynamics*. Two journals were added to this list: *Management Science and Technology Analysis & Strategic Management.* Search conducted in December 2009.

References

Bhojraj, S., Lee, C.M.C. and Oler, D., 2003. What's my line? A comparison of industry classification schemes for capital market research. Journal of Accounting Research 41 (5), 745-774.

Bowker, G. and Star, S.L., 2000. Sorting Things Out, MIT Press, Cambridge MA.

Brusoni, S., Jacobides, M.G., and A. Prencipe, 2009. Strategic dynamics in industry architectures and the challenges of knowledge integration. European Management Review 6, 209-216.

Dalziel, M., 2007. A systems-based approach to industry classification. Research Policy 36, 1559-1574.

Fagerberg, J., Verspagen, B, 2009. Innovation studies-the emerging structure of a new scientific field. Research Policy 38, 218-233.

Graham, J.M., 2007. The Measure of a Nation: Quantifying Innovative Strength through Improved Service Sector Metrics, NBR Special Report No. 11, February.

Griliches, Z., 1994. Productivity, R&D and the data constraint. American Economic Review 84 (1), 1-23.

Grossman, G.M. and Rossi-Hansberg, E.A., 2008. Trading tasks: a simple theory of offshoring. American Economic Review 98 (5), 1978-1997.

Jacobides, M.G., T. Knudsen and M. Augier, 2006. Benefiting from innovation: value creation, value appropriation and the role of industry architectures. Research Policy 35, 1200-1221.

Office of Management and Budget (OMB), 2009. 2007 North American Industry Classification System (NAICS)—Updates for 2012. Notice, Federal Register, Wednesday January 7, 764-768.

Optoelectronics Industry Development Association (OIDA), 2007. Optoelectronics Industry Market Report and Forecast. Optoelectronics Industry Development Association, Washington DC.

Munir, K. A, and N. Phillips, 2002. The concept of industry and the case of radical technological change. The Journal of High Technology Management Research 13 (2), 279–297.

Ruef, M., and K. Patterson, 2009. Credit and classification: the impact of industry boundaries in nineteenth-century America. Administrative Science Quarterly 54, 486–520.

Sampler, J. L., 1998. Redefining industry structure for the information age. Strategic Management Journal 19 (4), 343–355.

Standard & Poor's, 2006. Global Industry Classification Standard (GICS^{R}) Methodology. http://www2.standardandpoors.com/spf/pdf/index/GICS_methodology.pdf, accessed August 2009.

Standard & Poor's and MSCI Barra, 2006. GICS^{R} Global Industry Classification Standard. http://www2.standardandpoors.com/spf/pdf/products/GICS_DIRM2006.pdf, accessed August 2009.

U.S Census Bureau, 2002. Economic Census, Glossary of Terms for the Economic Census, http://bhs.econ.census.gov/econhelp/glossary/, accessed July 22, 2008.

Figure 1 – Distributions of firms, patents and categories in the GICS and NAICS classification system