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Abstract:

This paper presents and analyzes patterns of trade for a broad category of technology-intensive products, including ATP (advanced technology products), for a group of 15 economies in Asia, Europe, and the United States. Using export data from 1997-2006, we examine the rate of diffusion (distribution of exports over a wider group of economies) and downstreaming (shifting of exports to lower-income economies), by means of index numbers. We find that the degree of downstreaming is highly sector-specific and product-specific; e.g. there has been more downstreaming of electronics than chemicals, of consumer electronics than electronic components, and of certain basic chemicals than specialized products such as photographic film and cosmetics. The exports of many products not normally considered to be ATP continue to be concentrated in high-income economies. We discuss the roles of technology, national and sectoral innovation systems, government policies, and other factors in shaping the degree of diffusion and downstreaming.

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I. Introduction

The production and export of certain goods normally considered to be “advanced technology” has shifted from higher-income to lower-income economies in recent years. In particular, China’s pattern of exports has evolved rapidly, to converge toward that of high-income economies (Schott (2008)). China’s trade with the United States in advanced technology products (ATP), as defined by the U.S. Census Bureau, shifted from deficit to surplus in approximately 2001 (Ferrantino, Koopman, Wang and Yinug (2009)). However, many “high-tech” exports are also sourced from other low-income economies, particularly in Asia. Much of the attention has focused on electronics, with the export of personal computers and other consumer electronic goods from China being the most dramatic case.

It has been widely argued that these changes have important consequences for economic development. Some endogenous growth literature, and related empirical work, suggests that the “right” specialization permanently affects long-run growth (Lucas (1988), Young (1991), Grossman and Helpman (1991), Hausman, Hwang, and Rodrik (2007)), thus implying that “leapfrogging” strategies intended to move the geographical location of high-technology products to developing economies. If, as has been argued, the pattern of specialization in modern manufacturing is not closely tied to traditional sources of comparative advantage such as factor abundance, it is indeterminate and thus potentially easy to influence by policy (Rodrik (2006)). Some U.S. observers have argued that China’s policies have in fact led to a general leapfrogging in technology, and worried that this poses a major challenge to U.S. commercial and security interests (Preeg (2004), Choate and Miller (2005)).

This paper argues that the recent experience of the electronics industry, and particularly of personal computers, does not generalize widely to other products that are technology-intensive and feature significant innovation. The more normal case is that it is difficult to move comparative advantage in innovative products, once it is achieved. Today’s pattern of trade, at least in manufacturing, contains the fossilized economic history of yesterday’s technology. It reveals a lot about which goods are hardest to produce, and a fair amount about where the hardest activities were done first, or best. The fossils may be obscured over time, through patterns of erosion or catastrophe, each of which has its own economic logic. But it is the nature of catastrophes that they are unusual. It is, of course, important to ask what may be special about China, or China’s policies. But it may be equally important to ask what is special about electronics in general, or about personal computers in particular.

We explore this idea using two trade-based indices of *revealed advanced technology products* (revealed ATP), one of which captures diffusion (geographic de-concentration) and the other capturing downstreaming (the movement of exports to lower-income countries). These are both fairly simple, but they reveal a good deal of indirect information about the relative technological complexity of internationally traded goods, especially those involved in multi-stage production process. This information can lead to a more focused inquiry about the relationships between technology, innovation, the international organization of production, and international trade.

II. Background

A. The product cycle[2] – concept and evidence

The idea that there is a logical progression under which newer, more innovative goods are produced in and exported from high-income economies, and later produced in and exported from lower-income economies, is of long standing (Vernon (1966); see also Posner (1961)). In its most idealized form, new goods would be innovated and produced in the most advanced large economies (in the 1960s, the United States), because it had the most innovative capacity and because of "demand-push" innovation to satisfy the tastes of high-income consumers. The good would diffuse, eventually being exported from other economies than the original innovator. When the technology of production became sufficiently mature, the good would be produced in low-wage economies (in our terminology, downstreaming). This pattern was dubbed the "product cycle" by Raymond Vernon. These informal theories developed then there was not a lot of formal theory about the dynamics of comparative advantage, and when empirical work in international trade still faced challenges in testing the static implications of the Heckscher-Ohlin model.

Available tests of the product cycle have shown that it is not the typical pattern for all goods. In fact, patterns of long-run comparative advantage have shown a good deal of persistence, with only occasional downstreaming. For example, Gagnon and Rose (1995) examine exports of six economies disaggregated to SITC4 from 1965-1989. They divide products into 3 categories – surplus, deficit, and balanced trade, using dividing lines at one standard deviation from the mean. Over their period, only about 1 percent of products switch between surplus and deficit, implying only a limited role for product cycles. Similarly, Proudman and Redding (2000) consider 22 broad ISIC-defined manufacturing sectors from 1970-74 to 1990-93, and measure revealed comparative advantage (RCA). For France, Germany, the United Kingdom and the United States, only a couple of categories switch from RCA ≥ 1 to RCA < 1 over the period. Japan, which was still experiencing convergence in per capita income during the period in question, Japan is the most dynamic, losing RCA in "rubber and plastic," "textiles and clothing" and "other manufacturing" and gaining RCA in "non-electrical machinery," "electrical machinery," "motor vehicles" and "computers." Even for Japan, the other 15 industries do not change their status with respect to comparative advantage.

It follows that an appropriate theory of the product cycle should account for the prevalence of such stickiness or persistence of comparative advantage in the usual case, and allow for some criterion as to when diffusion and downstreaming in the product cycle are actually observed.

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[2] A word on our use of terminology is in order here. We use "product cycle" in the sense of Vernon (1966) to refer to the geographic relocation of production and exports from one country to another, not in the alternate senses of the time it takes between the development of a new product and its marketing, or the time between generations of new products. Similarly, we use "downstream" ("upstream") to denote a geographical location of production in a low-income (high-income) location, and not in the alternate sense of a stage in a vertical production process closer to the final good (closer to the initial inputs). When we wish to refer to the stages in the production chain, we will do so explicitly.

B. Predictions of trade theory about the product cycle[3]

In the traditional Heckscher-Ohlin model of international trade, the pattern of trade is determined by relative factor abundance. This implies that patterns of comparative advantage can shift over time only if relative factor abundance is evolving over time. An implication of this is that if some economies have faster-growing capital/labor ratios (or human capital/labor ratios) than others, the production and export of some capital-intensive or human-capital intensive goods will shift to these countries. Since there has been relatively rapid accumulation of physical and human capital in Asia, this by itself would account for product cycles in some goods. This prediction is robust to the addition of increasing returns and product differentiation, as in the first generation of Chamberlin-Heckscher-Ohlin models (Helpman (1981), Helpman and Krugman (1985), as long as scale economies are firm-specific and not nation-specific.

"New trade" theories with a focus on technology often predict that initial conditions drive the pattern of trade, leading to persistence in the pattern of comparative advantage over time. This persistence can come from a technological advantage that operates at the national level. For example, in the case of national, sector-specific economies of scale, if sectoral differences in scale economies outweigh sectoral differences in factor proportions, then the pattern of comparative advantage is determined by initial conditions (Kemp (1969), Markusen and Melvin (1981)). If nation-specific learning-by-doing in sectors is important, initial conditions also determine the pattern of trade (Lucas (1988), Grossman and Helpman (1991, ch. 8).

Such nation-specific, sector-specific technology economies can arise from regional agglomerations at the national or sub-national level (Marshall (1920), Krugman (1991). The characteristic features of a Marshallian industrial district or "Silicon Valley" include an abundance of specific skilled labor, which may move from firm to firm within the district; a similar localized abundance of producers of specialized capital goods and other inputs; and a general culture of knowledge exchange in which the secrets of a particular trade are, in Marshall's phrase, "in the air," and innovations are easily developed through a process of imitation, adaptation, and collaboration.

However, it is at least theoretically possible that certain kinds of knowledge may diffuse rapidly on a global level, leading to global scale economies (Ethier (1979), (1982)) or global knowledge spillovers (Grossman and Helpman (1991, ch. 7)). In the case of global technological dynamics, initial conditions do not matter for the pattern of trade, and one should expect relatively rapid product cycles.

In the actual history of technology and comparative advantage, there is not a single initial condition. Rather, there are initial conditions for new innovations at different times. The observed empirical pattern of regular persistence of comparative advantage, and occasional diffusion and

[3] Much of the argument in this section relies on the discussion in Brasili, Epifani, and Helg (1999).

downstreaming through product cycles, suggests that the extent of nation-specific as opposed to global economies related to technology is an empirical question. In this regard, Keller (2004) has demonstrated that trade-related knowledge spillovers are partly localized and fall with distance. Case studies of learning curves show that they are sometimes nation-specific, e.g. U.S. Navy ships in World War II (Searle (1945)) and sometimes more nearly global, e.g. light-water nuclear reactors (Cowan (1990))

C. Synthesis

To summarize, the factors tending to preserve historical patterns of comparative advantage in its initial or fossilized form are three-fold:

- Relative factor abundance that changes slowly over time.
- Nation-specific economies of scale
- Nation-specific learning-by-doing

There are also at least three factors that lead to the observance of product cycles (downstreaming and diffusion):

- Relative factor abundance that changes rapidly over time
- Global economies of scale
- Global learning-by-doing

To these may be added two more:

- Foreign direct investment
- Fragmentation or vertical disintegration of the production process.

These two factors are interrelated. Vernon (1977) observed that the increasing prevalence of foreign direct investment meant that multinational firms were increasingly making strategic decisions about the location of production, thus possibly leading to an acceleration of the product cycle. The process of fragmentation or vertical disintegration by its nature alters the geography of production. A combination of reduction in transport costs and economies of scale in executing individual stages of the production process means that it is possible to separate the various stages of production physically according to the comparative advantage associated with deep stage. In the case of China, measures of the “vertical specialization” or “domestic content” of Chinese exports show that the share of imports in the value of Chinese exports is particularly high for electronics and other "high-technology" products (Dean, Fung, and Wang (2007); Koopman, Wang, and Wei (2008). This suggests that fragmentation is also an important driver of more rapid geographic product cycles.

III. Empirical Strategy and Data Description

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Our main empirical strategy is to derive measures of the product cycle at a high level of disaggregation over a recent period, using a widely used index of concentration or diffusion (the Herfindahl-Hirschman index) and a second index of the level of relative income associated with revealed comparative advantage in the export of a particular good, to capture the concept of downstreaming. Measurement of diffusion and downstreaming correspond to the two phases of the traditional product cycle. Since the measurement of diffusion is also a measure of concentration, it can also be used as an indicator of Marshallian agglomeration economies that may inhibit downstreaming and lead to persistence in comparative advantage.

A. Main features of the dataset

Export data for 15 economies for the period 1997 – 2006 are obtained from the UN COMTRADE system maintained by the United Nations Statistical Division[4]. This ten-year period is shorter than is often used to test hypotheses relating to the product cycle, but sufficiently long so that disaggregated data can be used without product definitions changing too much.[5] Observations were taken on exports to the world, as reported by the exporting economy, of all HS-6 level subheadings, hereinafter "products." The selected products include all those in 21 HS-2 chapters selected from the 96 regular chapters, as listed in Table 1. Broadly speaking, the product landscape consists of chemicals and allied products; machinery, electronics, and instruments; transportation equipment; and armaments. For comparability over time, the products are defined using the HS 1992 nomenclature. Products for which at least one year in the time period had no exports reported by any of the 15 economies are dropped[6]. In total, this yields 2035 products. The economies included in the dataset are listed in Table 2. They include the six largest OECD economies and nine Asian economies. Together, these 15 economies represent approximately 70 percent of world exports of the products in question, though the percentage

[4] This database can be accessed at http://comtrade.un.org/db/, accessed Aug 17, 2009. Data for Chinese Taipei were obtained separately from the version of COMTRADE available through the World Integrated Trade Solution (WITS).

[5] We have experimented with a longer dataset over the period 1962-2006, using the older SITC2 product categorization. At this level, products such as cellular phones and personal computers did not exist, and even mainframe computers are only imperfectly identified in the categorization.

[6] This procedure resulted in the dropping of 22 products from the dataset. Additionally, products 846110, 392041, and 850890 were dropped due to an apparent data anomaly wherein several top exporters stopped reporting after 2001.

varies from product to product.. Where available, re-export data is subtracted off of gross exports to yield net export data for the included economies and years.[7]

The HS-2 chapters are selected so as to include all products defined as Advanced Technology Products (ATPs) by the U.S. Census Bureau, as well as chapters which are related to these chapters by type of product. Table 3 presents the categories of ATP products, while Table 4 provides a tabulation of the number of ATP products falling in each HS Chapter. The ATP products, defined at the HTS-10 level[8], are selected based on expert judgment of Census staff regarding the technology intensity of products. The list of products used to construct China's High and New Technology Product Import and Export Statistics Catalogue corresponds closely to the Census ATP list.[9] Because the ATP list represents an independent judgment about technology intensity, it is a useful reference point to compare with inferences about technology intensity drawn from the trade data.

B. Construction of Indices

Two indices are constructed for each product. In the following definitions, the index i represents a specific product (HS6 subheading), j refers to the economy exporting the product, and t represents the year. Letting x_{ijt} be the value of exports of good I from economy j in year t, the indices are defined as follows.

The first, HHI, is a Herfindahl-Hirschman index measuring the extent to which exports of a given product are concentrated among the economies in our sample. The HHI for each product i and year t pair is given by the following formula:

$$HHI_{it} = \sum_j s_{ijt}^2$$

Where j is the index over economies and

$$s_{ijt} = \frac{x_{ijt}}{\sum_j x_{ijt}}$$

is the export market share of economy j in year t. Thus, an HHI value near 1 indicates that production of the product is concentrated entirely in one of our 15 economies, while low values (0.067 being the lower bound) indicate that exports are diffused throughout these economies.

[7] This results to an adjustment to the data for Hong Kong, the United States, and Thailand. The data for Singapore include re-exports. Thus, Singapore's exports are overstated relative to those of Hong Kong and include some double-counting.
[8] Found at http://www.census.gov/foreign-trade/reference/glossary/a/atp.html, accessed Aug 14, 2009. The concordance based on 2006 US Import HTS10 nomenclature is used. Where products at the HS-6 level corresponded to multiple ATP categories, the ATP category with the most instances of that HS-6 subheading was assigned to the product.
[9] See Ferrantino, Koopman, Wang and Yinug (2009) for details.

The second index we construct, EXPRELY, is a GDP-normalized version of the index PRODY defined by Hausmann, Hwang and Rodrik (2007). EXPRELY is constructed as follows: First, for each economy j in year t, the total exports[10] of economy j in that year are given by:

$$\overline{x}_{jt} = \sum_i x_{ijt}$$

Individual economy GDPs are per capita on a constant year 2000 dollar basis as taken from the World Bank's World Development Indicators.[11] Y_{jt} is then this GDP per capita value normalized by dividing by the GDP per capita of the US in the same year:[12]

$$Y_{jt} = \frac{GDP_{jt}}{GDP_{US,t}}$$

For each product i,

$$EXPRELY_{itT} = \sum_j \frac{x_{ijt}/\overline{x}_{jt}}{\sum_j x_{ijt}/\overline{x}_{jt}} * Y_{jT}$$

Thus, $EXPRELY_{itT}$ is a weighted average of the (normalized) year T GDPs of the economies exporting product i in year t, where the weights are the revealed comparative advantage of the economy. Rather than using GDP_{jt} in this expression, we compute EXPRELY in each year using only the GDP for each economy in a specified year T, in order to allow for cross year comparison of the index. In particular, we fix the level of Y to its 1997 level in all years. Relative incomes change significantly over the period, particularly in the case of China which experiences more rapid growth than average and which has a heavy weight in the calculations. For products whose exports become concentrated in China over time, if Y is allowed to vary by year the calculated values of EXPRELY includes both the movement to China (downstreaming of the product) with the relative position of China in the distribution of per capita income (upstreaming of China itself), making the results difficult to interpret. By fixing the level of per capita income to that of a particular year, we insure that EXPRELY isolates the geographic movement of products "downstream," without conflating this effect with the general dynamics of development.

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[10] Note that this is the total value of all exports for country j in year t, rather than the sum of exports of products included in our dataset.

[11] WDI data available at http://www.worldbank.org/. GDP data for Chinese Taipei is not available as part of the WDI data. Purchasing Power Parity GDP per capita data for Chinese Taipei is taken from the University of Pennsylvania's Penn World Table and converted to an exchange rate basis, using benchmark information.

[12] Initially, this procedure was adopted to create an index that would be bounded above by one, however, as later years were incorporated into the sample, the GDP per capita of the US was exceeded by that of Japan, allowing for EXPRELY to exceed one in some cases. The normalization still allows for a useful comparison of the index for a given product to a product exported exclusively by a country with the GDP of the US, which would have an EXPRELY value of 1. Normalized GDPs in benchmark years are given in Table 14. See figure 4 for GDPs over the entire time span 1962-2006.

IV. Stylized Facts and Anomalies

A. Relationship between diffusion and down-stream in cross-section and time series

Figure 1 presents a scatter plot of the relationship between HHI (diffusion) and EXPRELY (relative income level of economy with revealed comparative advantage) in 2006. For ease of interpretation, the names of the 15 economies are placed on the horizontal axis approximately at the level of their relative per capita income in 1997, as used to construct the index. A fifth-order polynomial is fitted to the data (see Appendix). The overall pattern is U-shaped. On the right, exports are concentrated in the highest-income economies, the United States and Japan. In the middle, exports are relatively diffused among all the economies, and associated on average with economies in the middle of the income distribution, e.g. Italy and Chinese Taipei. On the left, exports are concentrated in the lowest-income economies. While there are several of these, the left tail is accounted for primarily by concentration in China. For each of the 201 products with HHI > .25 and EXPRELY < .4 in 2006, China accounts for the largest market share. Of the outliers, some are clustered in upward-reaching "fingers" from the main U. These correspond to products that are concentrated in particular middle-income economies.

If taken from right to left, this pattern suggests something like the traditional Vernon product cycle (diffusion followed by downstreaming), followed by a final phase in which exporting is concentrated in China. This impression may be misleading, as Figure 1 represents a cross-section and not a time-series. Time-series behavior may not be the same as cross-section behavior.[13] Thus, we approximate the typical dynamic behavior of HHI and EXPRELY between 1997 and 2006 using flexible second-order polynomial regressions with dHHI and dEXPRELY as the dependent variables (see Appendix).

The resulting dynamics are superimposed over the stylized U in Figure 2. The results suggest on average that during the period in question, exports of many products became both more concentrated and more extreme in terms of the level of relative income they were associated with. Products that in 1997 were associated with a level of EXPRELY above .8 became more concentrated and moved upstream toward either the United States or Japan. Products associated with an upper-middle level of income (France, Germany, Hong Kong, Singapore, United Kingdom) remained about where they were. At somewhat lower incomes (Italy, Chinese Taipei) the typical product downstreamed but remained diffuse, while products associated with income levels equal to that of Korea or lower experienced both downstreaming and concentration (in China). While there are many special cases among the products in question, the overall pattern is one of agglomeration of exports in one of the three largest economies – China, Japan, or the United States – for the products in question.

[13] An analogous problem comes up in relation to the two famous "inverted U" relationships of development economics: the Kuznets curve relating per capita income to income inequality, and the environmental Kuznets curve relating per capita income to pollution.

B. Sector-specific patterns

1. For the product landscape as a whole

Values of HHI and EXPRELY were calculated for both 1997 and 2006 for eleven aggregates of products; the ten ATP technology categories, which together account for 177 of the 2035 products, and for non-ATP products in the product landscape as a single group, accounting for the other 1858 products. The results are portrayed in graphic form in Figure 3. The non-ATP products in the product landscape, represented by group 0, correspond approximately to the middle-level income of Italy, and both diffused and downstreamed moderately during the period. Of the ten ATP categories, there is a marked difference between electronics and information and communications, and all the others. While eight of the ATP categories are both more concentrated and more upstream than the typical products in our landscape, two ATP categories, electronics and information and communications, begin in a position downstream from the average in 1997 and moved further downstream, with the decline in EXPRELY for electronics being especially rapid.

These results highlight the fact that electronics, and to a lesser extent information and communication, represent special cases. One would expect that more technology-intensive products would usually be produced in high-income economies, and that the advantages of agglomeration in fostering innovation would be similarly associated with many of these products. The complex knowledge necessary for innovative success in biotechnology, aerospace, weapons, and nuclear technology keeps these products upstream and concentrated. The largest group of ATP products, "flexible manufacturing," is relatively diffuse, but still exported largely from high-income economies, This category includes advanced machine tools, including multi-planar and digitally controlled machine tools, used in many industries, and related instrumentation. The small category of "advanced materials," which has actually moved further upstream between 1997 and 2006, includes doped wafers for manufacture of semiconductors and optical fibers and cables – both components that are essential for many of the products in the two ATP sectors moving rapidly downstream.

2. Machinery, computers, and instruments

We consider a broad subgroup labeled "machinery, computers, and instruments," which includes all products in HS chapters 84, 85, and 90. These amount to 905 products, or nearly half the total in our product landscape. Grouping them together like this enables us to consider computers, classified in HS 84, jointly with electronics in HS 85 and with many electronics-intensive products classified as instruments or measuring devices under HS 90. The grouping also includes a wide variety of capital equipment operating primarily on mechanical rather than electrical or electronic principles.

Table 5 presents a cluster analysis of machinery, computers, and instruments based on the values of HHI and EXPRELY in 2006, reporting the within-cluster means. Consistent with our earlier results, the largest cluster, Cluster 1, contains products that are moderately diffused and relatively upstream. The second largest cluster contains products which are somewhat more diffused and further downstream The third cluster contains 106 products which are both relatively concentrated (HHI = .331) and farthest downstream (EXPRELY = .243). Exports of most of these products are relatively concentrated in China. The smallest cluster contains 53 products which are both highly concentrated (HHI = .544) and, on average, further upstream than the other clusters (EXPRELY = .755).

Also reported is the percentage of products in each cluster categorized as Census ATP. There is a broad correlation between the relative income level associated with a product and the likelihood that it is classified as ATP on technological grounds. 21.3 percent of the products Cluster 4, the furthest "upstream," are ATP products. Moving downstream to Clusters 1, 2, and 3, the percentage declines to 17.1 percent in Cluster 1 (EXPRELY = .669), 12.3 percent in Cluster 2 (EXPRELY = .455), and 6.6 percent in Cluster 3. This suggests that the use of EXPRELY as a proxy for the technological sophistication of a product has some merit, at least for machinery, electronics, and instruments.

This also means that 41 of the 52 products in Cluster 4, or about 79 percent, were *not* classified by Census as ATP. It may be the case that the engineering concepts used by Census for categorizing goods as technology-intensive may not actually capture all of the characteristics of a product that make it difficult to produce, or that prevent its technology from being cheaply or easily diffused. If our indices actually reveal something about the difficulty of technology, or the degree to which technologies experience localized economies of agglomeration, then there ought to be something "advanced" about these 41 products as well. Examples of such "revealed-ATP" products include outboard motors, cylinders for rolling machines, commercial dish washing machines, ski lifts and chair lifts, bulldozer blades, milking machines and parts, brewery machinery, offset printing machinery, dobbies and jacquards for spinning machines and looms, dry-cleaning machines, pneumatic hand tool parts, electron beam machine tools, domestic kitchen waste disposers, and cameras for narrow-gauge film.

While the "upstream" location of some of these products may be explained in part by a trade between rich economies with similar patterns of demand, along the lines of the hypothesis of Linder (1961), there are likely enough to be technology-specific challenges associated with many of them. Moreover, similarity of rich-country demand must be coupled with at least some degree of technological sophistication to prevent easy downstreaming. For example, Christmas lights are exported from China although their pattern of demand is presumably focused on high-income economies. It is likely harder to transfer the technology to produce outboard motors than that for Christmas lights.

It is also interesting to ask whether the ATP products in machinery, electronics and instruments in Cluster 3 (downstreaming and concentration in China) have any particular characteristics. The seven products in question are listed in Table 6. Of these, one is in a basket category that has recently been removed from the ATP list, and another (nuclear reactors) has some data difficulties. Of the remaining five, one has been well-studied. HS 852190, labeled in 1992 as "video recording and reproduction apparatus, nes," is the category which now includes iPods and other MP3 players. The value chain of the iPod has been described by Linden, Kraemer and Dedrick (2007). The iPod is a classic case of coordinated effort organized by a multinational firm (Apple, United States), managing a vertically disintegrated production process. Apple's gross margin makes up about one-quarter of the retail value of the iPod. Components of the iPod are produced in the United States, Japan, Korea, Chinese Taipei and Singapore. Foreign companies also manage the China-based operations of hard drive manufacture (Toshiba, Japan) and insertion, test, and assembly (Inventec, Chinese Taipei). Moreover, although Linden et al. do not say so, the hard drive may have further imported components. Of the others, the category labeled "cash registers" consists mainly of automated point-of-sale equipment such as toll collection devices. The three products in the category of transistors and semiconductors were until recently exported heavily by Japan or Singapore and have moved to the Philippines, suggesting perhaps another FDI story.

Machinery, electronics, and instruments which are both identified as ATP and appear in the upstream/concentrated cluster are identified in Table 7. These include such products as numerically-controlled metal drilling machines (Japan), stereoscopic and diffraction-apparatus microscopes (Germany and Japan), heart pacemakers (United States and France), certain other wood and metal-working machines (Italy and Germany), small turbo-jet engines (United States), and theodolites and tachometers (Japan). It would be useful to be able to identify those features of technology which tend to make them resistant to relocation in search of low-cost labor.

One can also group machinery, electronics and instruments products in terms of the economies that dominate in their export. We identify groups of geographically-focused products by clustering on 2006 market shares and identifying for each economy the cluster for which the market share is maximized. The results of this are presented in Table 8. Of the six clusters, five are associated with a single dominant producer. The largest of these consists of products primarily specialized in by Germany, followed by China (with Thailand), Italy, Japan (with Hong Kong and Korea), and the United States. The role of Italy in exports of so many goods in this category may not be familiar. However, the emergence of Marshallian industrial districts fostering regional specialization in the so-called "Third Italy" during the 1960s and 1970s is well-documented (Lazonick (2005)). The advantage of many of these districts is in a form of decentralized or "putting-out" manufacturing, as opposed to centralized mass production (Brusco (1992)). Italian specialties include machinery for leather-making, printing, food processing and agriculture, specialized wood and metal-making machinery, ski lifts and sunglasses.

3. Organic chemicals and allied products

By contrast, we consider a group of chemical products defined primarily by their relation to organic chemistry (HS 29, 30, 32-35, 37-40). Many of these products are chemical precursors (inputs) into other products in the category. This group of 713 products constitutes about 35 percent of the product landscape. In this section we present stylized facts, reserving a more detailed description of some of the technical features of these products until later. For the present, it is appropriate to note that organic chemistry as a whole is more technically challenging than inorganic chemistry.[14] This fact is reflected in Figure 4, in the position of chapter 28 (inorganic chemicals) relative to the various chapters involving organic chemistry mentioned above.

A cluster analysis involving the organic-chemistry chapters is presented in Table 9. Relative to each other, the four groups derived are similar to those presented in Table 9 for machinery, electronics, and instruments. In an absolute sense, the ranges of both HHI and EXPRELY are noticeably higher for the organic-chemistry clusters than for the clusters in machinery, electronics, and instruments, suggesting that these products are on the whole more difficult to produce as well as more subject to specialization. (This can also be observed in Figure 4). Moreover, none of the 24 products in this group classified as ATP is primarily exported from the cluster furthest "downstream." This reinforces the view that the circumstances permitting the production and export of certain electronic products are special cases, and do not in general apply to advanced chemical products.

The tendency for the exports of organic chemicals and allied products to cluster in a few high-income economies is further reinforced by the cluster analysis by country market share presented in Table 10. For comparison with Table 8, we again use six clusters. The most notable difference is that while for machinery, electronics, and instruments, five of the six clusters were dominated by a single economy, in the case of organic chemicals and allied products five clusters are dominated by only four economies. There is a German cluster, a United States cluster and a German-United States cluster, which between them account for nearly half the products in the category. This is a reflection of long-standing historical developments. Germany's advantage in advanced chemistry dates from the work of Justus von Liebig at the University of Giessen in the 1840s, and the subsequent close links between industrial innovation and university research developed at German firms such as BASF (Mokyr (1990), 119-120). Similarly, it was in the United States that the unifying principles involving scaling up of "unit operations" in experimental or batch production to a level providing workable and economic large-scale production processes were codified in the new discipline of chemical engineering, developed at MIT from 1915-1920 (Rosenberg (1998)).

C. Technological difficulty and the production chain

International trade takes place in both intermediate goods as well as final goods. The combined forces of falling costs for logistics, strategic decision-making by multinational corporations, and international fragmentation of the production process

[14] Students that have taken a single chemistry course in high school or college in effect learn inorganic chemistry, because it involves simple molecules of a few atoms each whose equations can be easily worked out. Organic chemistry, involving more complex molecular structures, is generally only studied by students concentrating in chemistry, chemical engineering, or medicine. The basics of inorganic chemistry were reasonably well understood at the industrial level by the latter part of the 18th century (Mokyr (1990), 107-109), and at the theoretical level by the time of John Dalton's *New System of Chemical Philosophy* in 1808. By comparison, significant industrial successes involving applications of organic chemistry were not achieved until the synthesis of artificial dyes in the 1850s and 1860s, with basic practices such as polymerization following in the 1920s and onward (Walsh (1984); Ruttan (2001), 286-315).

mean that there is an increasing amount of trade in intermediate goods, as well as in the embodied services of product design and managerial coordination which are at the core of innovation. Merchandise trade data allow us to track the trade in goods. Are there systematic principles that relate the technological difficulty of earlier stages of the production process to the later ones?

In electronics, the earlier stages of the production process embody greater difficulty than the later ones. Inspection, testing, and final assembly of personal computers, cell phones, MP3 players and other consumer electronic goods is a mature, labor-intensive process which easily gravitates toward low-wage locations. Production of semiconductors and integrated circuits is more difficult and must take place under carefully regulated conditions. Within the semiconductor industry, the most advanced products are designed by so-called "fabless" firms specializing in innovation and contracting production to "front-end" foundries. Front-end production in turn is more skill-intensive than "back-end" testing, assembly and packaging of semiconductors (Yinug (2009)). The technology involved in equipment and inputs for manufacturing semiconductors is sufficiently advanced that economies with a comparative advantage may seek to regulate exports of such equipment for strategic reasons (GAO (2008)).[15].

In organic chemistry, by contrast, the earlier stages of the production process involve refining relatively simple organic chemicals from mineral sources such as petroleum, natural gas, or coal, or, increasingly, from biological sources (e.g., ethanol). Basic chemical precursors are in turn synthesized into intermediate organic chemicals through a variety of chemical processes (e.g., polymerization for plastics). These in turn are used to make final chemical products. At each stage of the production process, the chemistry becomes more complex. The production of photographic film involves the careful combination of many organic chemicals on an emulsion. Exports of film (HS 37) are significantly upstream from exports of cameras (included in HS 90; see Figure 4 and Appendix 3). Cosmetic and perfume products (HS 33) similarly involve difficult formulations of multiple compounds, and mixtures of compounds. This can be confirmed by examining the list of ingredients in an inexpensive bottle of shampoo. As revealed by the income level associated with comparative advantage, cosmetics and perfumes are significantly more challenging or "upstream" than electrical and electronic goods (Figure 4 and Appendix 3).

Thus, the relationship of the earlier or later stages of a vertical production process with the degree of technical complexity varies significantly depending on the nature of innovation in each product category. Figure 5 summarizes the stylized facts presented above. In electronics, the earlier stages of the production process are "high technology," whereas in chemistry, the later stages of the production process are more technology-intensive. Figure 6 shows in more detail some of the linkages in petrochemical production chains.

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[15] The point here is not to enter into the debate about whether such controls are effective in their objectives, or appropriate on welfare grounds. The existence of the policy is simply put forth as evidence that the goods in question are recognized to represent technological "high ground."

To see whether the trade data reveal technological complexity, particularly by higher values of EXPRELY and (perhaps) by higher values of HHI, we constructed a number of sub-categories of products. These include both categories designed to correspond roughly to the stages of production portrayed in Figure 5, as well as other categories of interest.[16] We then re-calculated the indices for products aggregated by sub-category. The results of this procedure appear in Table 10.

For petrochemicals and products, the first three categories correspond to the stages of production in Figures 6 and 7. In accordance with our hypothesis, we find that secondary petrochemicals are exported from higher-income economies than are basic petrochemicals, while products of petrochemical-consuming industries are exported from still higher-income economies. This progression is stronger in 2006 than in 1997. In 1997, but not in 2006, we find that the more advanced products are also more regionally agglomerated than the less advanced products. A fourth category of "plastic and rubber articles," including tubes, pipes, and other forms, involves the application of mechanical processes such as molding to the results of chemical processes, and, not surprisingly, reverts to lower-income processes on average.

For pharmaceuticals, the detailed product descriptions in the Harmonized system enable a distinction between bulk medicaments (defined by chemical composition) and medicaments by dosage (made up in pill form). There is significant trade in bulk medicaments which are made up closer to the market of final consumption. (USITC (1994)). Both categories of pharmaceuticals are, on the whole, upstream and concentrated relative to the petrochemical categories. Moreover, medicaments by dosage are upstream and concentrated relative to bulk medicals. Like photographic film and cosmetics, medicaments by dosage often involve mixtures of two or more complex therapeutic compounds. Dosage requirements preferred by local medical practice are also reflected in the production of these goods, as well as features of the product such as texture or "mouth feel" important to the final consumer. It may also be the case that regulation for safety and efficacy is applied more stringently at the level close to the consumer.

The production chain for computers is reflected approximately in the first three categories under "electronics and related products." Here, the dramatic change is in the position of computers. In 1997, inputs to semiconductors (doped wafers and manufacturing machinery) are relatively upstream (EXPRELY = .750) as are computers (EXPRELY = .719), while semiconductors are exported from lower-middle-income economies (EXPRELY = .369).[17] By 2006, computers have "downstreamed" more dramatically than any of the other categories we analyze (EXPRELY = .250), while the positions of inputs to semiconductors and semiconductors/integrated circuits have remained relatively unchanged. This produces the pattern suggested in Figure 5, with

[16] The definitions of these categories are available from the authors on request.
[17] The downstreaming of semiconductors to markets such as Korea, Chinese Taipei, and Malaysia, for export in final assembly of computers in the United States, Japan, and Europe, was already well underway by the late 1980s and early 1990s. This history is recounted in Macher, Mowery and Hodges (1998) and Langlois and Steinmueller (1999).

inputs for semiconductors being the most advanced relative to computers. The position of other electronics-intensive products also indicated that EXPRELY is at least in part an indicator of technology intensity; electro-medical devices are relatively upstream (EXPRELY = .692 in 2006, not much different than in 1997), while cameras (photographic and cinematographic apparatus) are even further downstream than computers and have moved their quickly in recent years (EXPRELY = .324 in 1997 and .140 in 2006).

Not only have electronic goods experienced an unusually intense product cycle relative to other goods, but computers have downstreamed very rapidly relative to other electronic goods. This applies both to desktop computers and to notebook computers. After looking at all of the evidence, it appears less appropriate to view the shift of personal computers to China as paradigmatic of broader changes in the global economy at least in the sense of geographic patterns of production[18], and more appropriate to ask what is so special about personal computers.

Some suggestions as to the technological and managerial peculiarities of personal computers are offered by Dedrick and Kraemer (2009). The strong market positions of Intel in microprocessors and Microsoft in operating systems imply that those two firms may absorb as much as 90 percent of profits in the value chain for personal computers. This may have led to more intense searching for reductions in production costs elsewhere in the supply chain. Another feature of the development of the industry is the "middlement" role of original design manufacturers (ODMs) from Chinese Taipei, such as Quanta, Compal, Wistron, and Inventec. Such firms engaged in design and development of personal computers on behalf of U.S. and Japanese multinationals such as Apple, Dell, HP, IBM, Sharp, Sony, and Toshiba, and accounted for 73 percent of the world's production of notebook computers by 2005. Production of such computers was increasingly outsourced to Chinese Taipei in the 1990s, with design activities following. After taking a leading role in design and development, the ODMs organized production activities in China from about 2000 onward, concentrating notebooks in Shanghai/Suzhou and desktops in Shenzhen/Guangdong, with other concentrations of production in Malaysia, Mexico, the Philippines, Singapore, and elsewhere. The geographical and cultural proximity of Chinese Taipei to Shanghai/Suzhou in particular meant that it was feasible for managers to move to the mainland for extensive stays to organize production networks.

The case of personal computers is an interesting example both of path dependency in the history of innovation and in the adaptation of organizational structure to the needs of the marketplace (Pavitt (2005)). Korean manufacturing firms, which are organized in large, interlocking families, are relatively good at achieving economies of mass production, and have played a significant role in the semiconductor industry, for example in following the mass production strategy of DRAMs originally adopted by the Japanese. The supply of smaller, more agile entrepreneurial firms in Chinese Taipei was better

[18] The fact that personal computers are themselves a general-purpose technology, responsible for increases in productivity and innovation in all industries, and that their production in China has made this technology more abundant and affordable worldwide, is of course of great significance.

suited for the elaborate systems coordination tasks required of ODMs. In an alternate history where Korean firms had succeeded in becoming the dominant players in personal computers in the mid-1990s, it may be wondered whether the further move to China would have been as rapid as it in fact was.

Machinery of the mechanical type is more difficult to categorize as being in the same category as either chemicals, where the final product are relatively technology-intensive, or electronics, where the first inputs are relatively technology-intensive. The Harmonized System contains a large number of "parts" categories that are explicitly mapped to the machines they are included in, and can thus be used to test the hypothesis of relative technology intensity of parts versus final product as revealed by trade. A partial and preliminary test of this hypothesis is presented in Table 11, which considers approximately 40 categories of machinery including agricultural, food-processing, print-making, and construction machinery, as well as engines, pumps, packing and weighing machinery. In general no strong conclusions can be drawn about machinery. Parts tend, on average, to be produced in slightly higher-income economies than final machinery, and to be slightly less concentrated geographically, but there are plenty of special cases. This suggests that the relationship between the stage of production and the intensity of technology for machinery is very case-specific, as well as the implications thereof for international trade.

V. Conclusions, and topics for further research

The movement of production and exports of electronics (in general) and personal computers (in particular) to Asia (in general) and China (in particular) is sometimes held to be a sign of broad changes in the global economy and a wholesale reconfiguring of comparative advantage. We have shown that such widespread changes in comparative advantage are in fact less common than is often supposed. Many technology-intensive products, as well as many products not often thought of as embodying advanced technology, are in fact technology-intensive, and continue to be exported from high-income countries. The initial conditions under which innovation and production take place may become "fossilized" through patterns of local industrial agglomeration.

This does not mean that the technologies become stagnant. Rather, the advances in technology take place in a localized fashion. In addition to Silicon Valleys, there are likely to be many pharmaceutical valleys, cosmetics valleys, and valleys of pasta-making machinery. These are of comparable importance to the dynamics of comparative advantage as the processes by which electronics has undergone rapid downstreaming and diffusion. In particular, it appears to be harder in general for technologies related to organic chemistry to undergo rapid product cycles. This in turn has implications for a world in which biotechnology is likely to be the source of a significant share of new innovation.

The roles of foreign direct investment and production fragmentation in the product cycle are likely to be important, but we have not directly examined them. There are a number of cases in our data for which market shares change rapidly in a year or two. We suspect a significant share of these cases can be associated with specific acts of direct investment or contract production. Similarly, it should be possible to test directly the hypothesis that the product cycle is more rapid in industries prone to fragmentation and vertical disintegration.

The theoretical framework underlying predictions about the product cycle can be used to interpret the Chinese experience, and perhaps the experience of other countries. China's rapid growth, beginning with the opening-up of the late 1970s, has featured above-average accumulation of both physical and human capital by global standards,. This type of growth, observed elsewhere in Asia, was a precondition for the attraction of certain kinds of goods and the movement of comparative advantage on Heckscher-Ohlin grounds. However, China's recent exports of ATP products have been associated with three types of policy initiatives – encouragement of foreign direct investment, encouragement of the processing trade (importing intermediate goods to use as inputs into exported goods), and the development of a variety of government policy zones associated with further incentives. Each of these policies is associated with a high share of ATP exports, both in general and relative to non-ATP exports (Ferrantino, Koopman, Wang, and Yinug (2009)).

In advance of the adoption of such policies, it would not have been possible to predict which goods would be subject to rapid product cycles. The industrial organization of the personal computer and iPod, as they have developed, were not known in the early 1980s. However, any goods that did undergo diffusion and downstreaming would be more likely to be attracted to places that encouraged foreign direct investment, since multinationals play a key role in reorganizing the production process, and that encouraged processing trade, since this is attractive to goods with fragmented production processes. Thus, when the personal computer came, it would eventually come to China, and to other countries with similar patterns of factor accumulation that adopted particular policies. China's size, as well as the encouragement of regional agglomerations by policy, may also have led to nation-specific, sector-specific economies of scale and learning-by-doing, making it more likely that the products once having moved to China would be likely to stay there.

In conclusion, though the dynamics described in this paper apply to the current state of technology and international trade, it is unknown whether, and for how long, they will continue to do so in the future. Massive changes in the technology and organization of production, from the old vertical disintegration of the pre-industrial putting-out system to the factory system of the Industrial Revolution to today's vertical disintegration, and from mass production driven by large-scale machinery to the dynamic of miniaturization associated with 20th century electronics, can happen suddenly and without warning at any time. Such changes in the future may lead to new patterns of international specialization very unlike those described here.

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Table 1
List of HS-2 Chapters Included in Short-Term Dataset[19]

HS-2	Chapter Description
28	INORGANIC CHEMICALS; ORGANIC OR INORGANIC COMPOUNDS OF PRECIOUS METALS, OF RARE-EARTH METALS, OF RADIOACTIVE ELEMENTS OR OF ISOTOPES
29	ORGANIC CHEMICALS
30	PHARMACEUTICAL PRODUCTS
31	FERTILIZERS
32	TANNING OR DYEING EXTRACTS; TANNINS AND DERIVATIVES; DYES, PIGMENTS AND OTHER COLORING MATTER; PAINTS AND VARNISHES; PUTTY AND OTHER MASTICS; INKS
33	ESSENTIAL OILS AND RESINOIDS; PERFUMERY, COSMETIC OR TOILET PREPARATIONS
34	SOAP ETC.; LUBRICATING PRODUCTS; WAXES, POLISHING OR SCOURING PRODUCTS; CANDLES ETC., MODELING PASTES; DENTAL WAXES AND DENTAL PLASTER PREPARATIONS
35	ALBUMINOIDAL SUBSTANCES; MODIFIED STARCHES; GLUES; ENZYMES
36	EXPLOSIVES; PYROTECHNIC PRODUCTS; MATCHES; PYROPHORIC ALLOYS; CERTAIN COMBUSTIBLE PREPARATIONS
37	PHOTOGRAPHIC OR CINEMATOGRAPHIC GOODS
38	MISCELLANEOUS CHEMICAL PRODUCTS
39	PLASTICS AND ARTICLES THEREOF
40	RUBBER AND ARTICLES THEREOF
84	NUCLEAR REACTORS, BOILERS, MACHINERY AND MECHANICAL APPLIANCES; PARTS THEREOF
85	ELECTRICAL MACHINERY AND EQUIPMENT AND PARTS THEREOF; SOUND RECORDERS AND REPRODUCERS, TELEVISION RECORDERS AND REPRODUCERS, PARTS AND ACCESSORIES
86	RAILWAY OR TRAMWAY LOCOMOTIVES, ROLLING STOCK, TRACK FIXTURES AND FITTINGS, AND PARTS THEREOF; MECHANICAL ETC. TRAFFIC SIGNAL EQUIPMENT OF ALL KINDS
87	VEHICLES, OTHER THAN RAILWAY OR TRAMWAY ROLLING STOCK, AND PARTS AND ACCESSORIES THEREOF
88	AIRCRAFT, SPACECRAFT, AND PARTS THEREOF
89	SHIPS, BOATS AND FLOATING STRUCTURES
90	OPTICAL, PHOTOGRAPHIC, CINEMATOGRAPHIC, MEASURING, CHECKING, PRECISION, MEDICAL OR SURGICAL INSTRUMENTS AND APPARATUS; PARTS AND ACCESSORIES THEREOF
91	CLOCKS AND WATCHES AND PARTS THEREOF
93	ARMS AND AMMUNITION; PARTS AND ACCESSORIES THEREOF

[19] Chapter Descriptions in this table are complete as taken from the U.S. International Trade Commission website, www.usitc.gov. All following tables include abbreviated chapter descriptions for presentation purposes.

Table 2
Economies included in the dataset

Abbreviation	Name
CHN	China
DEU	Germany
FRA	France
GBR	United Kingdom
HKG	Hong Kong
IDN	Indonesia
ITA	Italy
JPN	Japan
KOR	Korea
MYS	Malaysia
PHL	Philippines
SGP	Singapore[20]
THA	Thailand
TWN	Chinese Taipei
USA	United States

[20] Although Singapore was also one of the five founding members of ASEAN, we have chosen to group it with the "Asian Tiger" countries for data presentation.

Table 3
ATP Categories as defined by the US Census Bureau

ATP Category	Description
01	BIOTECHNOLOGY
02	LIFE SCIENCE
03	OPTO ELECTRONICS
04	INFORMATION & COMMUNICATIONS
05	ELECTRONICS
06	FLEXIBLE MANUFACTURING
07	ADVANCED MATERIALS
08	AEROSPACE
09	WEAPONS
10	NUCLEAR TECHNOLOGY

Table 4

Cross-Tabulation of HS products in each included chapter falling into each ATP Category. HS Chapters containing ATP designated products are highlighted.

ATP / HS2	0 NonATP	1 Biotech	2 LifSci	3 OptoEl	4 InfoComm	5 Elec	6 FlexMan	7 AdvMat	8 Aero	9 Weap	10 NucTech	TOTAL
28	177	0	2	0	0	0	0	0	0	0	2	181
29	271	1	18	0	0	0	0	0	0	0	0	290
30	25	3	1	0	0	0	0	0	0	0	0	29
31	26	0	0	0	0	0	0	0	0	0	0	26
32	45	0	0	0	0	0	0	0	0	0	0	45
33	34	0	0	0	0	0	0	0	0	0	0	34
34	23	0	0	0	0	0	0	0	0	0	0	23
35	13	0	0	0	0	0	0	0	0	0	0	13
36	8	0	0	0	0	0	0	0	0	0	0	8
37	36	0	0	0	0	0	0	0	0	0	0	36
38	54	0	0	0	0	0	0	1	0	0	0	55
39	122	0	0	0	0	0	0	0	0	0	0	122
40	66	0	0	0	0	0	0	0	0	0	0	66
84	438	0	0	1	3	0	39	0	9	0	4	494
85	232	0	0	3	12	10	3	1	0	0	0	261
86	24	0	0	0	0	0	0	0	0	0	0	24
87	76	0	0	0	0	0	0	0	0	0	0	76
88	7	0	0	0	1	0	0	0	7	0	0	15
89	17	0	0	0	0	0	0	0	0	0	0	17
90	98	0	23	9	1	1	8	2	4	3	1	150
91	53	0	0	0	0	0	0	0	0	0	0	53
93	13	0	0	0	0	0	0	0	0	4	0	17
TOTAL	1858	4	44	13	17	11	50	4	20	7	7	2035

Figure 1
Scatter of HHI and EXPRELY, 2006

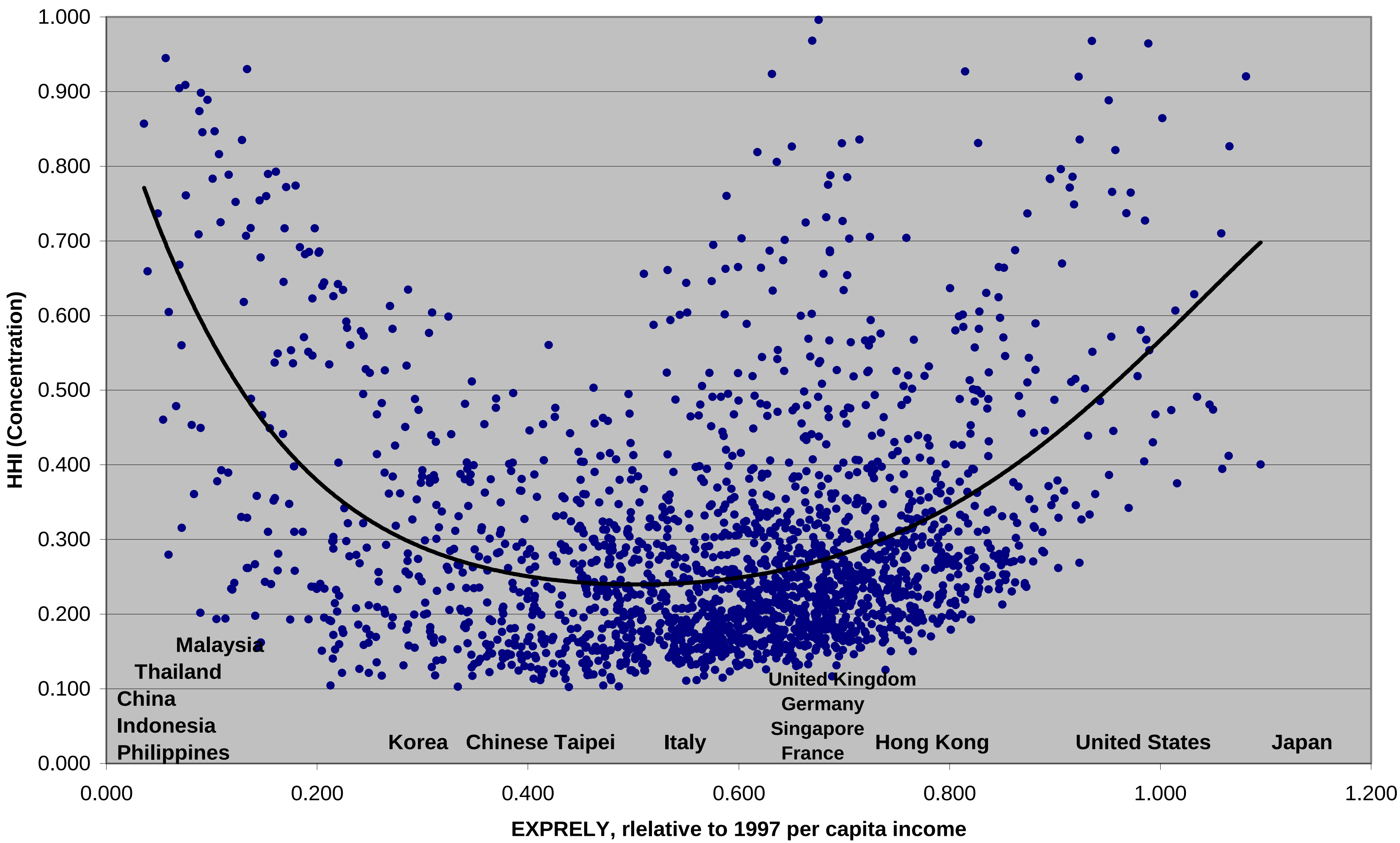


Figure 2
Fitted relationship between HHI and EXPRELY in 2006,showing dynamics from 1997 to 2006

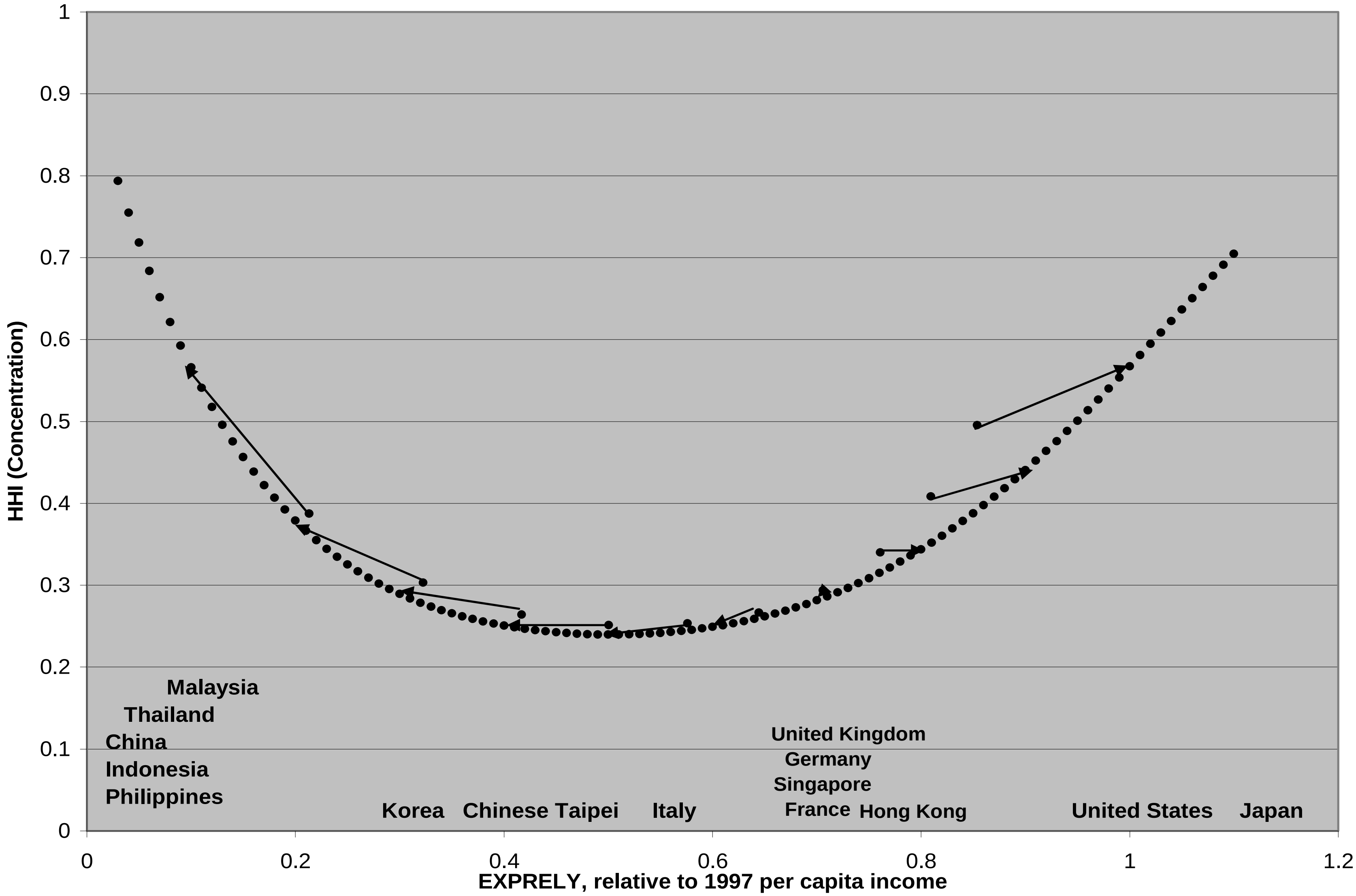


Figure 3

EXPRELY v. HHI by ATP Category, 1997 and 2006
(number of products included in category in parentheses)

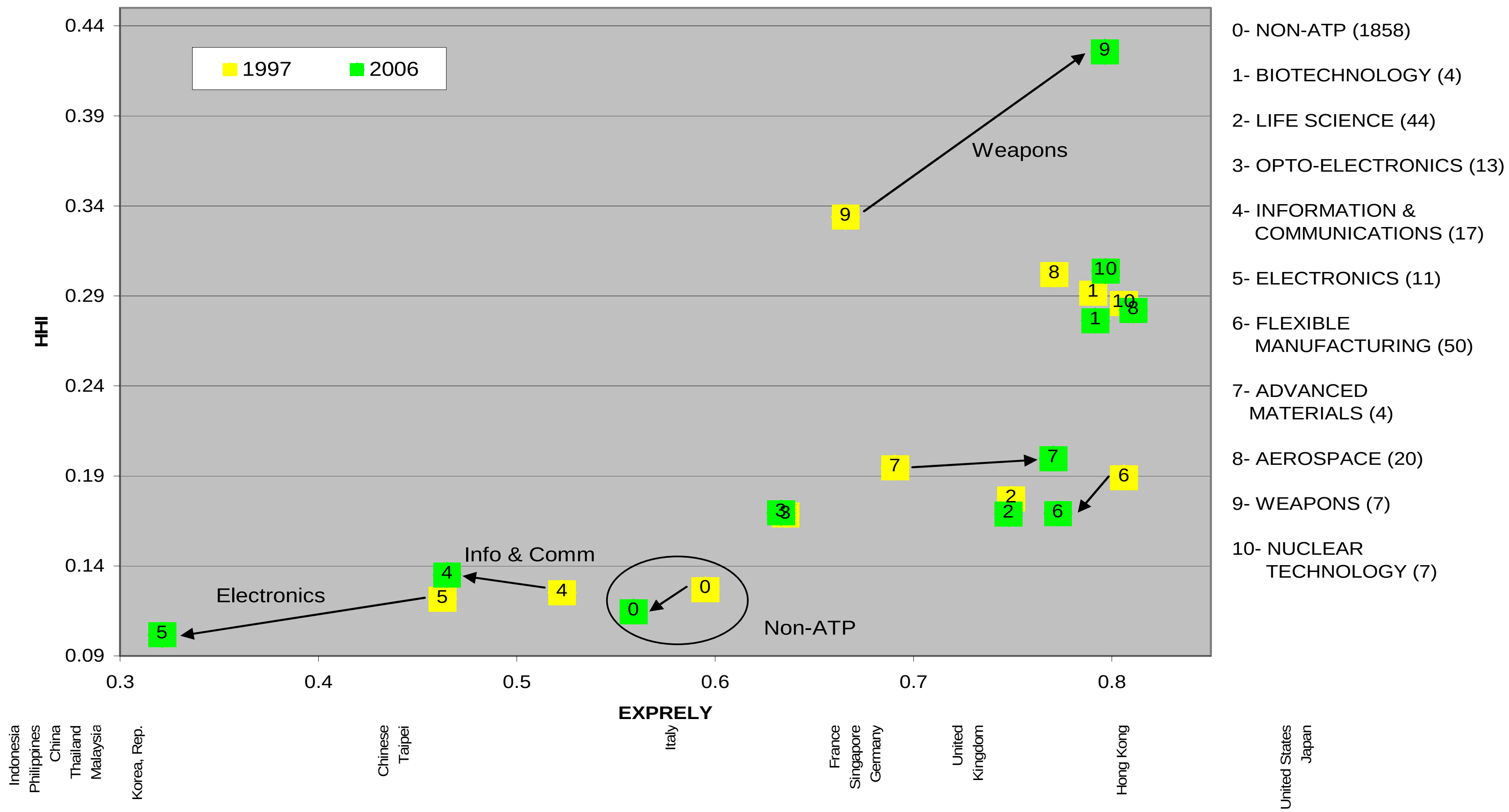


Figure 4

EXPRELY v. HHI by HS2 Chapter, 1997 and 2006
(number of products included in category in parentheses)

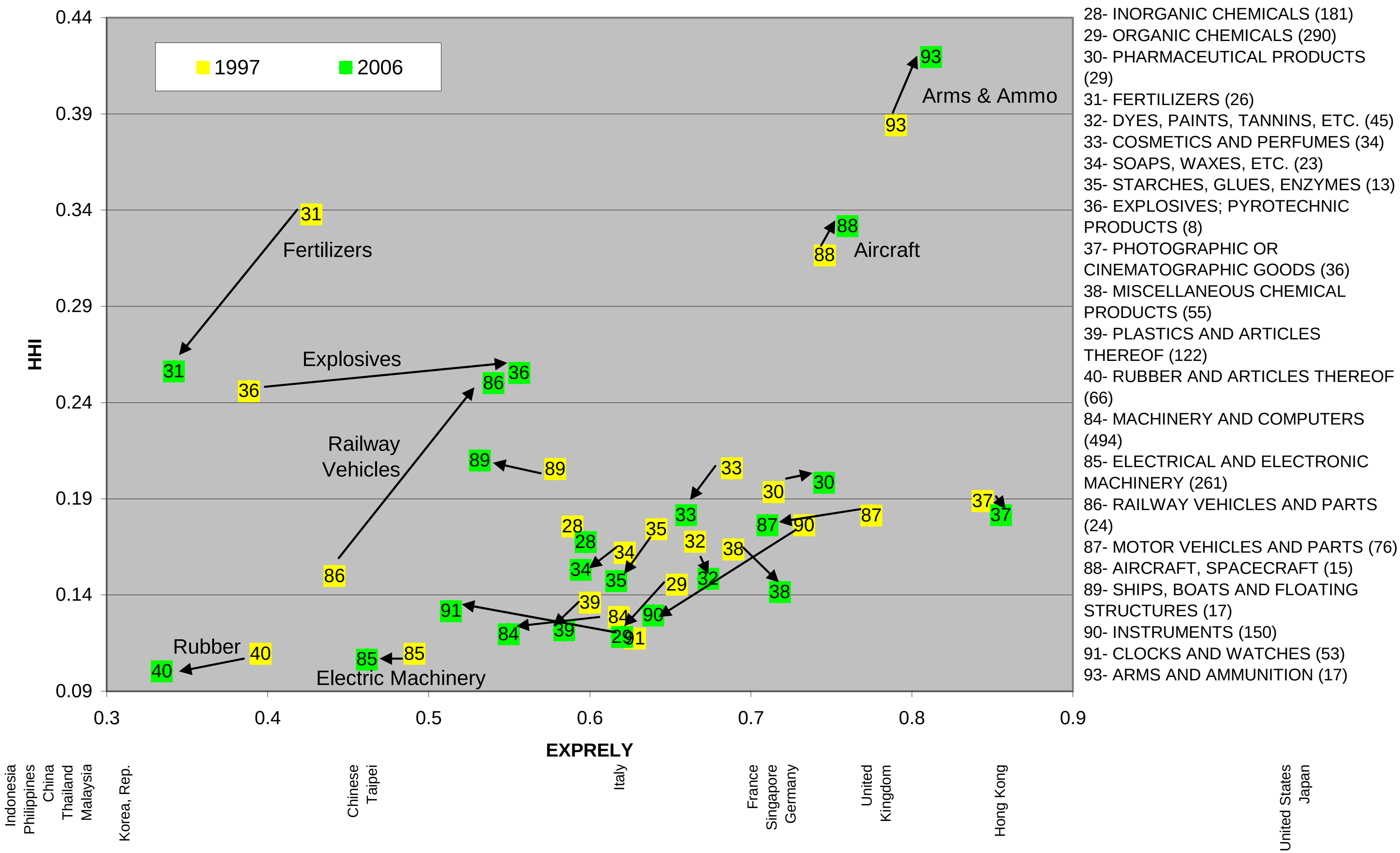


Table 5
Cluster Analysis of Machinery, Electronics and Instruments (HS 84, 85, and 90)

Clustering on Indices in 2006:

Cluster	_FREQ_	HHI_06	EXPRELY_06	Desc	# of ATP Products	% of Products designated ATP
1	560	0.233	0.669	Low HHI; High EXPRELY	96	17.1%
2	187	0.199	0.455	Low HHI - moderate EXPRELY - diffuse	23	12.3%
3	106	0.331	0.243	Moderate HHI; LOW EXPRELY – downstreamed	7	6.6%
4	52	0.544	0.755	High HHI; HIGH EXPRELY – hitech	11	21.2%

Table 6
ATP products in HS 84, HS 85, and HS 90 falling in Cluster 3 ("Downstreamed")

Product	Product_Name	HHI_06	EXPRELY_06	Notes on Market Share
847050	Cash registers	0.181	0.341	Was dominated by Japan, China has taken over
840110	Nuclear reactors	0.352	0.159	lumpy data
851999	Sound reproducing apparatus, non-recording, nes	0.717	0.169	Was dominated by Japan, China has taken over (no longer on ATP list)
852190	Video record/reproduction apparatus not magnetic tape ***(includes iPODs and MP3 players)***	0.537	0.160	Was dominated by Japan, China has taken over
854121	Transistors, except photosensitive, < 1 watt	0.162	0.147	Was dominated by Japan, Philippines has taken over
854129	Transistors, except photosensitive, > 1 watt	0.193	0.105	Was shared by Japan, Malaysia, Singapore, USA, Philippines has taken over (MS spiked in 2005 – FDI?)
854150	Semiconductor devices, not light sensitive or emitting	0.194	0.113	shared largely by Singapore and Philippines, Philippines has taken over

Table 7
ATP products in HS 84, HS 85 and HS 90 falling in Cluster 4 ("Upstream")

Product	Product_Name	HHI_06	EXPRELY_06	HS2	ATP_Code	ATP_Category	Notes on Market Share
845910	Way-type unit head machines, metal working	0.601	0.587	84	6	FLEXIBLE MANUFACTURING	Italy has highest MS over most of period
845921	Numerically controlled metal working drill machines	0.491	1.035	84	6	FLEXIBLE MANUFACTURING	Japan dominates
846510	Multi-purpose machines for wood etc work	0.542	0.637	84	6	FLEXIBLE MANUFACTURING	Germany (followed by ITA, USA)
841111	Turbo-jet engines of a thrust < 25 KN	0.469	0.868	84	8	AEROSPACE	USA (Followed by Germany, GBR)
840120	Machinery & apparatus for isotopic separation & parts	0.685	0.687	84	10	NUCLEAR TECHNOLOGY	Germany (followed by USA, GBR)
900661	Photographic discharge lamp flashlight apparatus	0.439	0.931	90	2	LIFE SCIENCE	Japan (followed by China, Germany)
901210	Microscopes except optical, diffraction apparatus	0.405	0.985	90	2	LIFE SCIENCE	Japan (followed by US, Germany)
902150	Pacemakers for stimulating heart muscles	0.476	0.706	90	2	LIFE SCIENCE	US and France (followed by Germany)
901110	Stereoscopic microscopes	0.576	0.735	90	3	OPTO-ELECTRONICS	Germany (followed by Japan)
901520	Theodolites and tacheometers	0.371	0.894	90	3	OPTO-ELECTRONICS	Japan
901720	Drawing, marking-out, instruments nes, slide rules	0.582	0.828	90	4	INFORMATION & COMMUNICATIONS	USA

Table 8
Products in HS 84, HS 85 and HS 90 clustered by economy market share in 2006

Cluster	1	2	3	4	5	6
Number of products	217	94	113	364	75	42
GER_Market_Share	43.4%	17.8%	13.2%	15.8%	13.4%	8.2%
UK_Market_Share	5.1%	3.8%	4.5%	8.9%	3.9%	6.1%
FRA_Market_Share	5.4%	7.2%	3.9%	8.9%	5.0%	5.3%
ITA_Market_Share	9.2%	36.4%	4.8%	7.1%	6.0%	4.4%
HK_Market_Share	0.0%	0.1%	0.0%	0.1%	0.3%	0.2%
SNG_Market_Share	2.1%	1.5%	2.5%	5.1%	2.0%	4.6%
KOR_Market_Share	1.8%	2.8%	2.9%	4.0%	4.1%	0.5%
IDN_Market_Share	0.2%	0.4%	0.8%	1.5%	0.4%	0.3%
MYS_Market_Share	0.9%	1.2%	3.4%	3.7%	1.5%	0.7%
THA_Market_Share	0.4%	1.0%	2.5%	2.2%	0.9%	0.4%
PHL_Market_Share	0.1%	0.1%	0.3%	1.0%	0.2%	0.3%
USA_Market_Share	13.2%	10.3%	8.2%	18.9%	8.0%	56.2%
CHN_Market_Share	5.3%	8.5%	45.4%	9.0%	10.5%	6.7%
JPN_Market_Share	11.1%	5.0%	4.2%	9.4%	40.1%	5.3%
TWN_Market_Share	1.8%	3.9%	3.3%	4.3%	3.8%	0.8%
# of ATP Prods	38	4	8	62	20	5
% of Prods classified as ATP	17.5%	4.3%	7.1%	17.0%	26.7%	11.9%

Table 9
Cluster Analysis of Organic Chemicals and Allied Products (HS 29, 30, 32-35, 37-40)

Clustering on Indices in 2006:

Cluster	N	HHI_06	EXPRELY_06	Description	# ATP Products	% of Products classified as ATP
1	304	0.283	0.717	Low HHI, High EXPRELY -- diffuse, mainly exported from High income Economies	16	5.3%
2	59	0.609	0.819	High HHI, High EXPRELY - "hitech"	1	1.7%
3	241	0.216	0.543	Low HHI; Moderate EXPRELY - diffuse, exported from all economies	7	2.9%
4	109	0.370	0.254	Low/Moderate HHI; Low EXPRELY - "downstreamed"	0	0.0%

Table 10
Organic Chemicals and Allied Products clustered by economy market share in 2006

Cluster	1	2	3	4	5	6
FREQ	136	85	118	32	197	145
GER_Market_Share	11.4%	11.7%	6.9%	70.9%	33.5%	11.7%
UK_Market_Share	6.6%	4.0%	6.6%	1.8%	6.2%	15.6%
FRA_Market_Share	6.6%	4.6%	5.3%	2.2%	9.3%	12.3%
ITA_Market_Share	3.6%	3.5%	4.2%	3.0%	6.0%	11.0%
HK_Market_Share	0.1%	0.1%	0.2%	0.0%	0.2%	0.0%
SNG_Market_Share	2.4%	3.4%	4.2%	1.0%	2.4%	6.0%
KOR_Market_Share	2.5%	4.2%	2.7%	0.9%	2.8%	4.8%
IDN_Market_Share	1.6%	0.7%	0.6%	0.2%	0.9%	2.7%
MYS_Market_Share	0.7%	1.6%	0.9%	0.6%	1.5%	3.2%
THA_Market_Share	1.5%	1.1%	0.8%	0.3%	1.6%	3.8%
PHL_Market_Share	0.1%	0.1%	0.0%	0.0%	0.1%	0.2%
USA_Market_Share	9.5%	20.9%	50.9%	8.8%	20.0%	13.2%
CHN_Market_Share	45.2%	5.7%	7.9%	4.7%	6.0%	6.9%
JPN_Market_Share	6.1%	34.4%	5.7%	2.3%	6.3%	5.8%
TWN_Market_Share	2.0%	3.9%	3.1%	3.3%	3.1%	2.9%
# of ATP products	5	2	2	0	6	9
% of Products which are ATP	3.7%	2.4%	1.7%	0.0%	3.0%	6.2%

Figure 5
Electronics vs. Chemicals:
Technological Complexity In The Production Chain

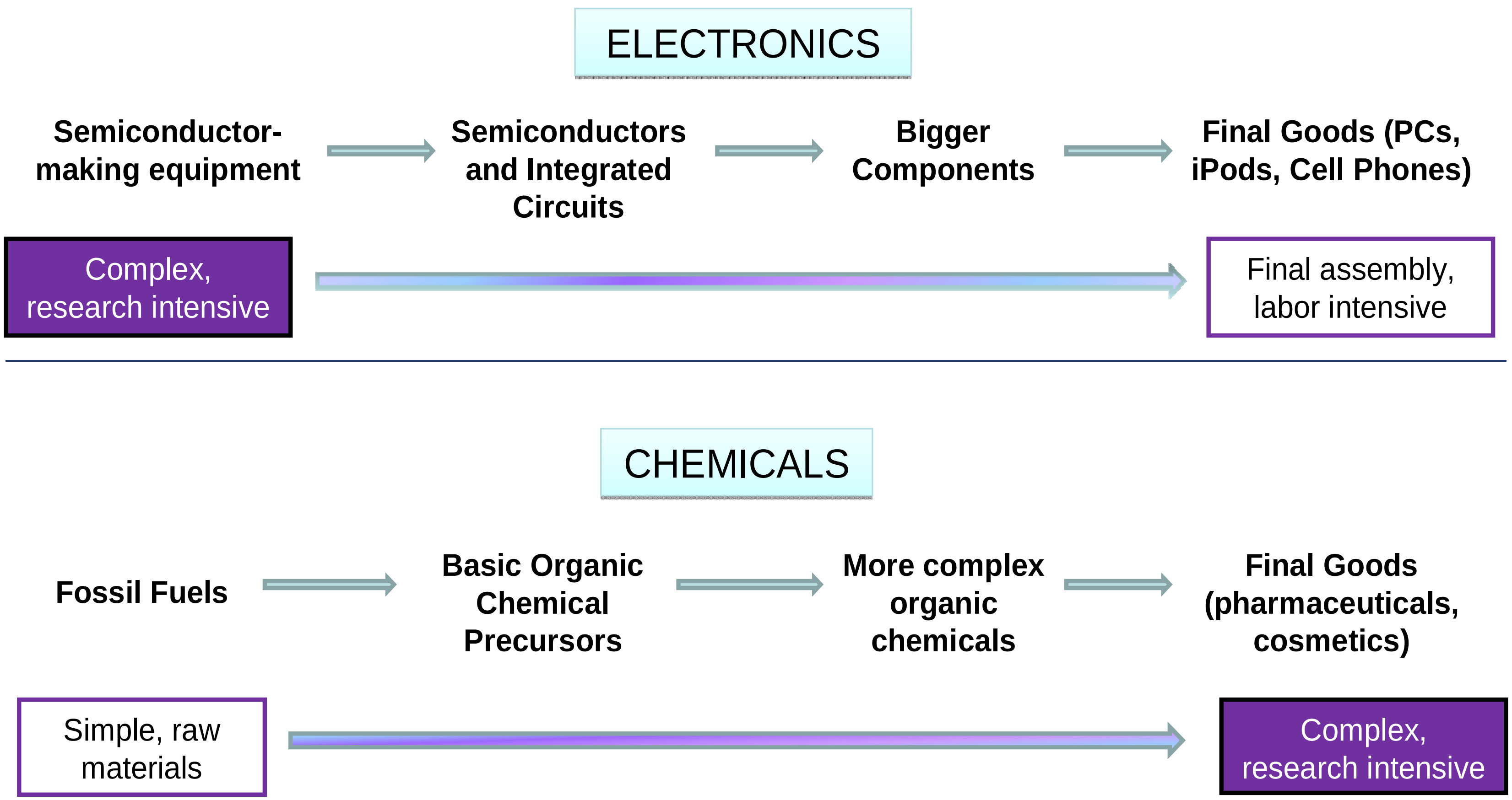
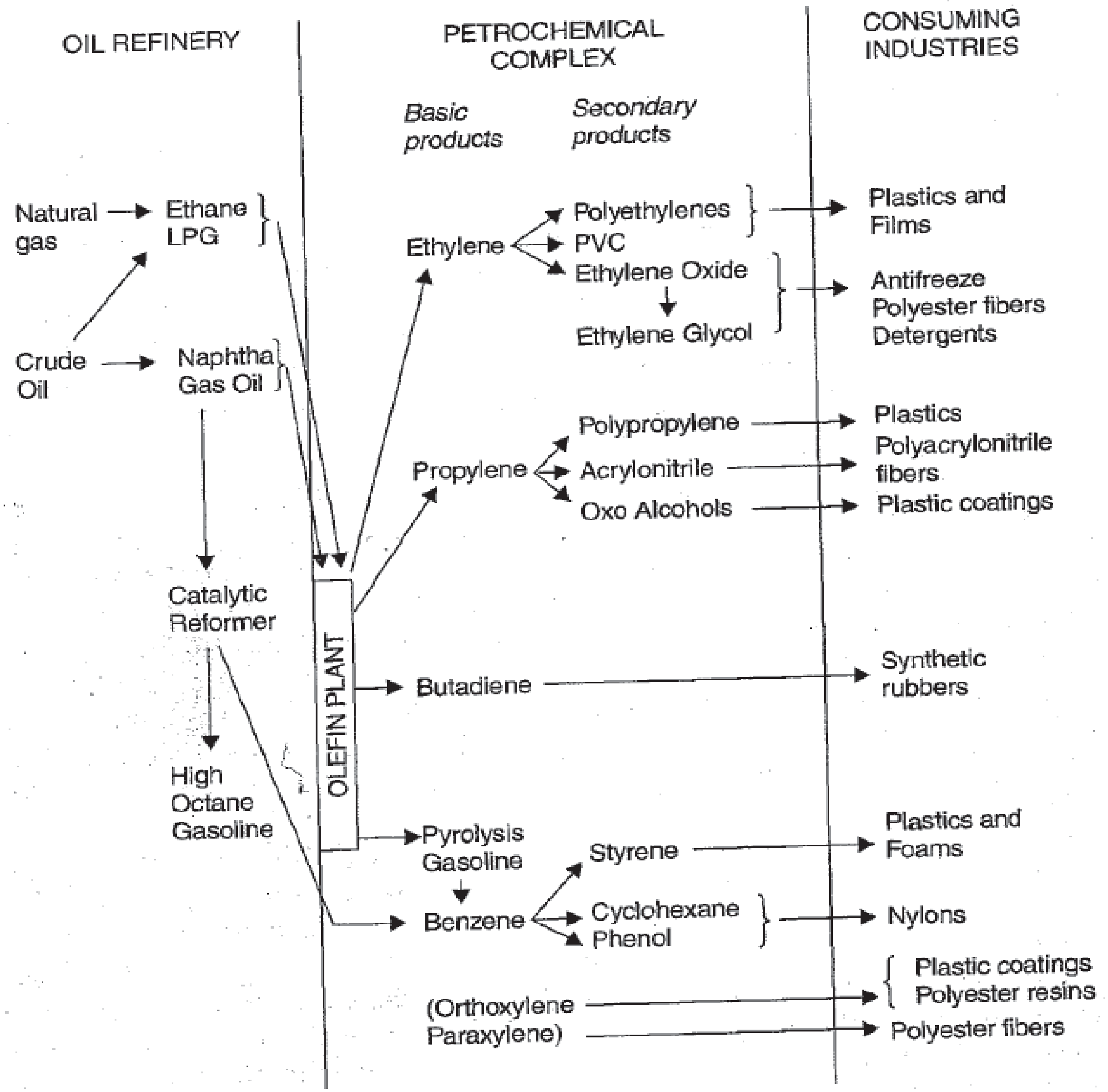


Figure 6
Production Pathways in Chemicals and Products[21]



[21] Source: Margaret Sharp, "Innovations in the Chemicals Industry." In *The Handbook of Industrial Innovation*, Mark Dodgson and Roy Rothwell, eds., Aldershot, England: Edward Elgar, 1994: 171, as reproduced in Vernon W. Ruttan, *Technology, Growth, and Development: An Induced Innovation Perspective*, Oxford, England: Oxford University Press, 2001, 295.

Table 7
Indices by industry subgroups

	Relative Income Level EXPRELY		Concentration HHI	
Petrochemicals and products	1997	2006	1997	2006
Basic petrochemicals	0.556	0.479	0.135	0.128
Secondary petrochemicals	0.557	0.536	0.142	0.124
Petrochemical-consuming industries	0.641	0.601	0.152	0.130
Plastic and rubber articles	0.506	0.471	0.118	0.131
Pharmaceuticals				
Bulk medicaments	0.582	0.661	0.148	0.176
Medicaments by dosage	0.665	0.691	0.207	0.200
Electronics and related products				
Doped wafers and machinery used in manufacturing semiconductors	0.750	0.753	0.221	0.194
Semiconductors and integrated circuits	0.369	0.357	0.118	0.114
Computers	0.719	0.250	0.157	0.322
Computer input, output, and data storage units	0.410	0.225	0.133	0.196
Capacitors, resistors, printed circuits, and parts	0.463	0.432	0.128	0.139
Electrical relays, switches, circuit breakers, etc.	0.642	0.559	0.161	0.139
Radio, TV, and telecommunications equipment	0.347	0.338	0.099	0.208
Parts of radio, TV, and telecommunications equipment	0.523	0.419	0.112	0.168
Transmission equipment for radio, TV, telecom, and TV cameras	0.636	0.489	0.169	0.186
CRTs and other vacuum tubes	0.494	0.302	0.141	0.133
Photographic and cinematographic apparatus	0.324	0.140	0.126	0.127
Electro-medical devices	0.699	0.692	0.235	0.217

Table 11

Relationship between indices for machinery and parts in HS 8401-HS 8443

EXPRELY_06 (Parts) – EXPRELY_06 (Machines):

Range	Number of categories
Greater than 0.1	6
0 to 0.1	23
-0.1 to 0	11
Less than -0.1	5
Median	0.012

HHI_06 (Parts) – HHI_06 (Machines)

Range	Number of categories
Greater than 0.1	2
0 to 0.1	16
-0.1 to 0	20
Less than -0.1	6
Median	-0.004

Appendix 1
Regressions used in Figures 1 and 2

	HHI_2006	d EXPRELY	d HHI
Intercept	0.926 (0.065)	-0.204 (0.028)	-0.047 (0.023)
EXPRELY_06	-4.79 (0.028)	-0.079 (0.898)	-0.135 (0.063)
$EXPRELY\_06^2$	13.98 (4.25)	0.213 (0.065)	0.091 (0.054)
HHI_06		0.185 (0.079)	0.376 (0.065)
HHI_06^2		-0.067 (0.079)	0.107 (0.061)
EXPRELY_06*HHI_06		-0.047 (0.069)	0.150 (0.047)
$EXPRELY\_06^3$	-21.55 (8.96)		
$EXPRELY\_06^4$	17.23 (8.62)		
$EXPRELY\_06^5$	-5.21 (3.08)		
N	2035	2035	2035
R^2	.247	.184	.282

dHHI = HHI_06 – HHI_97
dEXPRELY = EXPRELY_06 – EXPRELY_97
Standard errors in parentheses

Appendix 2
Average HHI Values for HS Chapters, 1997-2006 (annual averages over 10 years)

HS2	Chapter Description	Average HHI
93	ARMS AND AMMUNITION; PARTS AND ACCESSORIES THEREOF	0.399
88	AIRCRAFT, SPACECRAFT, AND PARTS THEREOF	0.330
31	FERTILIZERS	0.291
36	EXPLOSIVES; PYROTECHNIC PRODUCTS; MATCHES; PYROPHORIC ALLOYS; CERTAIN COMBUSTIBLE PREPARATIONS	0.264
86	RAILWAY OR TRAMWAY LOCOMOTIVES, ROLLING STOCK, TRACK FIXTURES AND FITTINGS, AND PARTS THEREOF; MECHANICAL ETC. TRAFFIC SIGNAL EQUIPMENT OF ALL KINDS	0.212
89	SHIPS, BOATS AND FLOATING STRUCTURES	0.208
33	ESSENTIAL OILS AND RESINOIDS; PERFUMERY, COSMETIC OR TOILET PREPARATIONS	0.194
30	PHARMACEUTICAL PRODUCTS	0.194
87	VEHICLES, OTHER THAN RAILWAY OR TRAMWAY ROLLING STOCK, AND PARTS AND ACCESSORIES THEREOF	0.183
37	PHOTOGRAPHIC OR CINEMATOGRAPHIC GOODS	0.180
28	INORGANIC CHEMICALS; ORGANIC OR INORGANIC COMPOUNDS OF PRECIOUS METALS, OF RARE-EARTH METALS, OF RADIOACTIVE ELEMENTS OR OF ISOTOPES	0.167
90	OPTICAL, PHOTOGRAPHIC, CINEMATOGRAPHIC, MEASURING, CHECKING, PRECISION, MEDICAL OR SURGICAL INSTRUMENTS AND APPARATUS; PARTS AND ACCESSORIES THEREOF	0.162
38	MISCELLANEOUS CHEMICAL PRODUCTS	0.156
34	SOAP ETC.; LUBRICATING PRODUCTS; WAXES, POLISHING OR SCOURING PRODUCTS; CANDLES ETC., MODELING PASTES; DENTAL WAXES AND DENTAL PLASTER PREPARATIONS	0.156
35	ALBUMINOIDAL SUBSTANCES; MODIFIED STARCHES; GLUES; ENZYMES	0.156
32	TANNING OR DYEING EXTRACTS; TANNINS AND DERIVATIVES; DYES, PIGMENTS AND OTHER COLORING MATTER; PAINTS AND VARNISHES; PUTTY AND OTHER MASTICS; INKS	0.154
29	ORGANIC CHEMICALS	0.131
39	PLASTICS AND ARTICLES THEREOF	0.130
91	CLOCKS AND WATCHES AND PARTS THEREOF	0.129
84	NUCLEAR REACTORS, BOILERS, MACHINERY AND MECHANICAL APPLIANCES; PARTS THEREOF	0.119
40	RUBBER AND ARTICLES THEREOF	0.110
85	ELECTRICAL MACHINERY AND EQUIPMENT AND PARTS THEREOF; SOUND RECORDERS AND REPRODUCERS, TELEVISION RECORDERS AND REPRODUCERS, PARTS AND ACCESSORIES	0.103

Appendix 3

Average EXPRELY Values for HS Chapters, 1997-2006 (annual averages over 10 years)

HS2	Chapter Description	Average EXPRELY
37	PHOTOGRAPHIC OR CINEMATOGRAPHIC GOODS	0.782
93	ARMS AND AMMUNITION; PARTS AND ACCESSORIES THEREOF	0.750
88	AIRCRAFT, SPACECRAFT, AND PARTS THEREOF	0.723
87	VEHICLES, OTHER THAN RAILWAY OR TRAMWAY ROLLING STOCK, AND PARTS AND ACCESSORIES THEREOF	0.694
30	PHARMACEUTICAL PRODUCTS	0.685
90	OPTICAL, PHOTOGRAPHIC, CINEMATOGRAPHIC, MEASURING, CHECKING, PRECISION, MEDICAL OR SURGICAL INSTRUMENTS AND APPARATUS; PARTS AND ACCESSORIES THEREOF	0.659
38	MISCELLANEOUS CHEMICAL PRODUCTS	0.658
32	TANNING OR DYEING EXTRACTS; TANNINS AND DERIVATIVES; DYES, PIGMENTS AND OTHER COLORING MATTER; PAINTS AND VARNISHES; PUTTY AND OTHER MASTICS; INKS	0.620
33	ESSENTIAL OILS AND RESINOIDS; PERFUMERY, COSMETIC OR TOILET PREPARATIONS	0.617
29	ORGANIC CHEMICALS	0.586
35	ALBUMINOIDAL SUBSTANCES; MODIFIED STARCHES; GLUES; ENZYMES	0.573
28	INORGANIC CHEMICALS; ORGANIC OR INORGANIC COMPOUNDS OF PRECIOUS METALS, OF RARE-EARTH METALS, OF RADIOACTIVE ELEMENTS OR OF ISOTOPES	0.552
34	SOAP ETC.; LUBRICATING PRODUCTS; WAXES, POLISHING OR SCOURING PRODUCTS; CANDLES ETC., MODELING PASTES; DENTAL WAXES AND DENTAL PLASTER PREPARATIONS	0.551
39	PLASTICS AND ARTICLES THEREOF	0.532
84	NUCLEAR REACTORS, BOILERS, MACHINERY AND MECHANICAL APPLIANCES; PARTS THEREOF	0.517
89	SHIPS, BOATS AND FLOATING STRUCTURES	0.515
91	CLOCKS AND WATCHES AND PARTS THEREOF	0.497
86	RAILWAY OR TRAMWAY LOCOMOTIVES, ROLLING STOCK, TRACK FIXTURES AND FITTINGS, AND PARTS THEREOF; MECHANICAL ETC. TRAFFIC SIGNAL EQUIPMENT OF ALL KINDS	0.421
85	ELECTRICAL MACHINERY AND EQUIPMENT AND PARTS THEREOF; SOUND RECORDERS AND REPRODUCERS, TELEVISION RECORDERS AND REPRODUCERS, PARTS AND ACCESSORIES	0.415
36	EXPLOSIVES; PYROTECHNIC PRODUCTS; MATCHES; PYROPHORIC ALLOYS; CERTAIN COMBUSTIBLE PREPARATIONS	0.394
40	RUBBER AND ARTICLES THEREOF	0.347
31	FERTILIZERS	0.338