



Globalization of Production: Insights from the Hard Disk Drive Industry

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Summary. — Rapid change in the geographical location of production raises important questions regarding the welfare, development potential, and competitive position of different countries and regions. This paper explores in detail the geography of economic activity in a specific industry, the hard disk drive (HDD) component of the computer industry. Firms in the HDD industry are breaking the production system into ever smaller distinct steps, and spreading the physical location of these steps around the world. Firms from the United States dominate the industry. Our findings suggest that globalization has enabled US firms to sustain their dominant position in the industry, preserve employment in the United States (and possibly expand it), and increase employment worldwide, most notably in Southeast Asia. © 2000 Elsevier Science Ltd. All rights reserved.

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1. INTRODUCTION

The globalization of production has properly become among the most controversial phenomena of this decade. On the one hand, globalization is credited with creating more efficient firms and thus more efficient allocation of economic resources and higher gross national products. On the other hand, globalization is blamed for growing income inequality, deteriorating neighborhoods and regions, and eroding social safety nets. For supporters of the first position, globalization promotes employment by expanding the economy through greater efficiency, and shifting resources to higher value-added activities. For supporters of the second position, globalization hurts the low-wage employees in the advanced countries and disrupts societies around the world. In short, “globalization” has become a hot button phrase, the object of both optimism and pessimism.¹ Moreover, the reduction of barriers to trade and investment as well as recent trade agreements appear to have encouraged a powerful internationalization of production which has grown considerably faster than international trade since the mid-1980s (UNCTAD, 1996).

Rapid change in the geographical location of production raises important questions concerning the welfare, the development

potential, and the competitive position of different countries and regions. Where do firms locate particular activities and why do they choose one site over another? What impact does the globalization of production have on the economies of the home and host countries of multinationals adopting global production strategies? How does globalization affect national welfare and the distribution of wealth within countries? Can, and should, public policy play a greater or lesser role in shaping both the process of globalization and the response to its effects? Answers to all of these questions have become controversial, and properly so, for they touch on deep issues of social welfare, international relations and firm management.

In this paper we explore the pattern of globalization as connected to employment and wages in a specific industry, the hard disk drive (HDD) component of the computer industry, and the forces which shape location decisions. One way to begin to think about these issues is to consider two extreme and stylized depictions of industry globalization. In a fully borderless world, with managers having perfect informa-

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tion, workers willing to move, capital free to flow anywhere, and no regulations, culture, or other impediments to the free flow of factors of production, firms could locate anywhere. We might thus expect disk drive firms to distribute their assembly and production sites rather widely around the globe. Alternatively, in a world with extensive regulation, costly flows of information, divergent cultures, and political and cultural barriers to the free flow of workers, capital and material, we might observe an intense concentration of HDD production and economic activity in regions and districts.

The real world, of course, is more complicated than either of these characterizations. Most industries, including HDDs, exhibit features of both of these contrasting models of behavior—global dispersion and regional concentration. These twin processes are central features of the industry that we document here. Globalization thus arises from the *interaction* of firm strategies and public policies. Firms are influenced by each other and by public policies; public policy toward an industry is influenced by firms' needs and market forces. Decisions by firms shape the distribution of benefits through their effect on employment, spending, investment, research, and taxes. Decisions by governments shape the distribution of benefits through the impact of regulatory, tax and fiscal policy on the incentives of firms and workers.

Despite the importance of these issues, it is not easy to find empirical work that carefully describes the production system in ways that can link patterns of globalization to the controversial issues of welfare effects on states, regions and social categories. This paper seeks to fill some of our gaps of knowledge by exploring in detail the geography of economic activity in the HDD industry. Most analysis of globalization is conducted using economic or census data that aggregate measures of production, employment and wages and thereby lump together the behaviors of many unrelated organizations. By doing so, they downplay the interdependence among firms and present a highly limited view of economy and society. One virtue of our paper is that it studies the location of related firms in a value chain. Our approach rests on the general observation that firm decisions usually involve problems of collective rationality—situations that involve more than one organization where decisions are made with reference to other organizations. In making a foreign investment, for example, it matters to a business firm

whether a competitor or customer has already invested abroad. This makes the industry level of analysis very useful for clarifying some of the dynamics behind globalization.

The disk drive industry is an especially relevant case for exploring these issues because we believe it is a leading indicator of pressures and trends other industries will face as the barriers to globalization continue to drop. With worldwide revenues of more than \$30 billion, hard disk drives is a very dynamic industry with product life cycles of less than 18 months and prices falling at 40% a year for more than a decade. Hard disk drives are "high-tech commodities," with intense technological development yet low product differentiation and fierce price competition. The industry has striking variances in the geographical location of activity, depending on what indicators are used. In 1995, over 80% of the world's hard disks were made by US firms. Yet in the same year, less than 5% of drives were actually assembled in the United States, while 15 years ago over 80% of the world's total drive production and almost all drives made by US firms were assembled here. In 1995, only 20% of the world's employees in the HDD industry worked in the United States, yet over 60% of the wage bill paid by US firms were earned in the United States.

The evidence we have gathered suggests that while US employment in some job categories has suffered from globalization, it is most likely that without globalization the job loss would have been greater. Moreover, globalization has possibly increased US employment because it has resulted in more competitive US firms, which, in contrast with many parts of the consumer electronics industry, dominate the HDD industry. Thus, competitive success and globalization seem closely related. In their struggle to survive, firms in the HDD industry have pursued every source of advantage they can extract from location strategies. Firms are breaking the production system into ever smaller distinct steps, and spreading the physical location of these steps around the world, both through wholly-owned subsidiaries and through a global supply chain. Thus by globalizing, US firms have lowered costs while continuing to innovate. In so doing they have sustained their dominant position in the industry, preserved employment in the United States (and possibly expanded it), and increased employment worldwide, most notably in Southeast Asia.

We start with a brief portrait of how the industry is organized. Then we locate geographically each step in the value chain, providing alternate measurements of globalization. We stress the significance of wages spent in each country, rather than headcount of jobs, as an indicator of the geographical distribution of activity. Next, we explore the dynamics that influence these location choices, emphasizing the “wage–skill” relationship. We explore some ways public policy interacts with managerial incentives and strategy. Finally, we seek to link the HDD example to broader issues in the globalization debate.

of activities that go into making a final product: research, development, parts fabrication and subassembly, tooling, repair, service, marketing, management, etc. The value chain includes the supply chain of physical components, as well as the ancillary activities supporting production, such as equipment, sales, etc. Contemporary producers have broken the steps of the value chain into many discrete pieces. They have then analyzed the economics of each piece and located them around the world to achieve a number of objectives. Final assembly, the “made in country X” label, tells us only one aspect of this complex chain, and often by no means the most important one.

**2. THE VALUE CHAIN:
DISAGGREGATING THE PRODUCTION
PROCESS**

To measure globalization in an industry, we must begin with a portrait of the value chain, which consists of the full sequence and range

(a) Major steps in the value chain

Hard disk drives are built in four main subchains: electronics, head subassemblies, media, and motors, as shown in Figure 1. During final assembly the subassemblies are

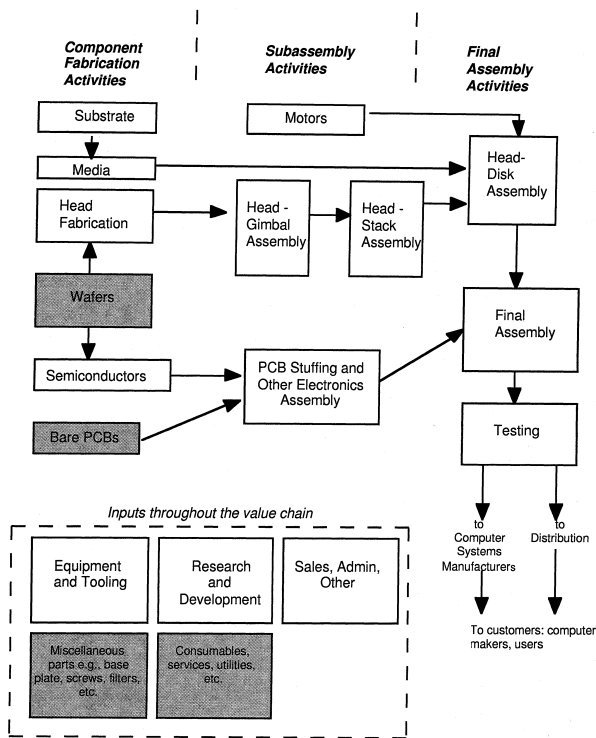


Figure 1. The hard disk drive value chain (Sources: Various. Shaded items are conceptually part of the value chain but not included in our numbers at present).

combined, mainly in clean rooms. The finished HDD is tested, and reworked if necessary.²

—*Electronics* includes semiconductors, printed circuit boards (PCBs) and their assembly, flex circuits that connect the PCB to the rest of the HDD, and discrete components.

—*Heads* are devices that read and write the data. They are manufactured in stages, beginning with very highly automated and technically complex wafer fabrication, followed by the labor-intensive activities of head-gimbal assembly (HGA) and head-stack assembly (HSA).

—*Media* constitute the material on which the information is stored, the “platter”, and can be made of aluminum or glass. Typically, aluminum blank substrates are nickel-plated and polished before the platters are sputtered and finished. As with heads, media are a very high-technology aspect of HDD production.

—*Motors* spin the media with extreme precision. One Japanese company, Nippon Densan, has about a 75% worldwide market share.

These four parts constitute the major subassemblies of disk drives. In addition to these activities, the value chain includes steps that are outside the core flow of materials but are extremely important:

—*Tools and equipment*. These make components, assist in assembly, or test outputs at various stages of assembly. Firms vary in their use of automation and purchase versus in-house manufacturing of tooling. Almost all test instruments are made by specialist suppliers.

—*Research and Development (R&D)*. In an industry with breathtakingly short product life cycles, R&D is of great importance. It continues to be overwhelmingly located in the United States and Japan.⁵

—*Sales, service and management*. These are critical functions for an industry with intense competition and rapid technological change. After-sales service is becoming a particularly important competitive tool, involving such value-added activities as repair, operator training, and engineering support.

Some companies making HDDs, notably IBM, have historically been heavily vertically integrated, and have done most of these steps themselves. The degree of vertical integration is quite variable across companies and over time, however. Thus only by looking at the value

chain, without limiting ourselves to the firms which “make (assemble) HDDs,” can we assess the industry’s globalization. The best measures of employment and value in the HDD industry would be the sum of all the steps noted above.⁴ Our analysis emphasizes companies that make disk drives, media, and heads, with limited coverage of semiconductors and HDD equipment.

(b) *The globalized production chain: produce or buy?*

Globalizing production poses some important strategic choices for firms concerning control of key functions and the balance between in-house activities and contracting to other firms. Take, for example, firms from the United States. In many other segments of the electronics industry, US firms have gone overseas by subcontracting final assembly to low-cost Asian suppliers. In the HDD industry, in contrast, US component suppliers and final assemblers have established overseas production networks within their own firms. They show an ability to manage manufacturing which challenges some commonly held assumptions of US manufacturing inferiority compared to the Japanese and other Asian producers (McKendrick & Hicken, 1997).⁵ We illustrate these choices by looking at Seagate, the world’s largest manufacturer of HDDs.

Seagate assembles all of its disk drives in-house. Furthermore, it is almost self-sufficient in recording heads, printed circuit board assemblies, and makes many of its own disks and spindle motors. Despite the risks associated with vertical integration during economic downturns, Seagate is convinced that it needs to maintain the technology and manufacturing capability in-house. Market pressures are brought to bear on “internal suppliers” by sourcing some percentage of its components externally. Being vertically integrated gives Seagate the capability to make or buy—to adjust its internal and external purchases—but in any event it retains control over the technology and the processes.

Although Seagate has kept control of almost all production, it has globally dispersed its operations to an extraordinary degree. A single component may be worked on in five countries and cross two oceans while Seagate is building it up through its value chain. Seagate develops new products (and processes) at seven locations in the United States and in Singapore. It

assembles disk drives in Singapore, Malaysia, Thailand, and China. In heads, the company fabricates its wafers in the United States and Northern Ireland, and cuts them into bars and assembles them into HGAs in Thailand, Malaysia, and the Philippines. It makes media in Singapore and motors in Thailand. It manufactures printed circuit cables in Thailand and assembles the electronics onto printed circuit boards in Indonesia, Malaysia and Singapore. It is the largest nongovernment employer in Thailand and Singapore.

Component firms have also gone overseas without subcontracting. Komag, for example, designs and manufactures thin-film disks. Established in 1983, Komag now has facilities in the United States, Japan, and Malaysia, is the world's largest independent thin-film media manufacturer, and competes primarily with Showa Denko, Mitsubishi Chemical, and Fuji Electric, all of Japan. About 1,100 of its 2,900 employees (in mid-1995) worked overseas, or almost 40% of all employees. Likewise, Read-Rite develops and manufactures recording heads for hard disk drives and (like Komag) is the world's leading independent supplier in its market segment. Founded in 1983, more than 90% of its employees were located overseas by mid-1995. Read-Rite manufactures wafers at its headquarters in California and in Japan through a joint venture, cuts the wafers and assembles them into HGAs at its Thailand subsidiary, and ships the HGAs to Malaysia and the Philippines for assembly into head-stacks.

The experiences of these companies show the need to distinguish the geography of location from the geography of control. Location means where production is physically situated, in the United States or overseas. Control means who directs the production, a US firm or a foreign contractor. Going overseas is not the same thing as losing control.

3. MEASURING THE VALUE CHAIN: JOBS AND WAGES

Debates about globalization often revolve around the nationality of activity: where is this or that product or component produced? This turns out to be only one definition of nationality, and perhaps not the best one. Depending on which measure is used, it is possible to get just about any number for the US share of the industry. In a business sense, the United States

is still the dominant country in the industry, and US residents are earning most of the money paid by US HDD firms. But by other measures, however, the United States is less than half the industry, and by some measures is below 5%. We provide below seven different measures of location/globalization within three broad categories of location: nameplate, employment, and wages.

We have documented the locations and headcount of most plants in the value chain, and from this construct the various measures.

(a) *Location by nameplate*

What is the nationality of the producer and where is the final product actually assembled? These are usually the most visible of the globalization indicators.

(i) *Nationality of the firm that does the final assembly of HDDs*

The nationality of firms can be defined as the country of incorporation of the controlling parent. By this measure, US firms dominate global production with 85% of world output by dollar value (88% by units), followed by Japan with 15%.⁶ This tells us something important: US firms overwhelmingly dominate this global industry to a degree not matched by much else in the modern economy, from consumer electronics to automobiles. Among segments of the computer industry, for example, only micro-processors rival HDDs in domination by US firms.

(ii) *The geographic location of final assembly*

In what country is the HDD finally put together (thus getting the "made in Singapore" or similar sticker)? By this measure, the US share in 1995 was 5% (and nearly zero in 1998). Thus, while the largest producers of HDDs are US-owned and managed, a substantial amount of the work done in the industry lies outside the United States. This measure suggests that there is very little US presence in the HDD industry (Table 1). Southeast Asia, especially Singapore, is the primary location of final assembly with 64% of world output. Two-thirds as much final assembly takes place in Europe (principally Ireland, Germany, and Hungary), as in Japan. US firms shut down most remaining final assembly activities in the United States in late 1995 and early 1996.⁷

Table 1. *Location of HDD final assembly^a*

US	Southeast Asia	Japan	Other Asia	Europe	Total
4.6%	64.2%	15.5%	5.7%	10.0%	100%

^a Source: Gourevitch, Bohn and McKendrick (1997).

(b) *Location by employment*

The nationality of employment is another major indicator examined by all sides of the globalization debate. Disaggregation within the value chain helps clarify the reality. Although virtually no drives are “assembled in the United States,” a substantial amount of the industry’s employment is “American,” more than any other single country.

(i) *The location of employment by headcount*

We estimated 1995 employment by location and activity for each firm in the HDD industry value chain.⁸ Of a total world employment of 287,000, the United States has the highest headcount of any single country, with almost 20%. Southeast Asia is the dominant region: Singapore and Malaysia have about 12% each, while Thailand has some 13%. Japan, whose firms are important based on nameplate, has less employment by headcount even than China.

The geographic distribution of employment is highly differentiated by stage of the value chain. While only 9% of employment in heads and 7% of HDD final assembly are in the United States, more than 50% of media employees and about 32% of those in semi-conductors work in the United States. A large portion of global employment in production and test equipment is located in the United States. Head subassembly is the most labor intensive stage of production, with over 40% of headcount, followed by final assembly with 22%, while the rest of employment is widely distributed in other steps of the value chain. We will show in section 3 that the labor-intensive stages are predominantly offshore. This skews overall headcount.

(ii) *Fraction of employment controlled by US firms*

Two-thirds of all workers in the industry are employed directly by US firms. In some other branches of electronics, US firms globalized their production by subcontracting manufacturing to overseas firms, but HDD firms glob-

alized by setting up fully owned and controlled subsidiaries overseas.

(iii) *The domestic-overseas split of employment by US firms*

Looking only at people who work for US firms in the industry, about 29% of them are in the United States. The vast majority of the remainder are in Southeast Asia. Employment is clearly influenced by the nationality of the producer. US firms hire more Americans than do foreign firms. Measured by numbers of people, HDD is an industry dominated by US firms most of whose employees are located outside the United States.

(c) *Location by wages*

We have just measured employment by headcount and by position in the value chain. This tells us a lot about globalization, but it does not answer a very important question: What is the actual wage bill paid in each country? Looking only at the number of jobs does not measure the value of the jobs, and these figures are thus deeply misleading about the geographic distribution of the return to employment. Some stages of this industry, such as R&D, require highly skilled workers, with extensive training and education who are paid at a high wage. Other stages of production, notably head subassembly, use large numbers of low-wage, low-skill workers.

To determine the geographic distribution of the value of employment, we estimated the size of the wage bill, taking into account the varying level of wages according to skill level.⁹ We divided workers into two skill levels: high-skilled, for whom we used engineering salaries, and average-skilled, for whom we used national average factory worker wages. We used gross estimates of the ratios between skilled and unskilled workers in each country’s portion of the HDD industry.

(i) *The location of wages paid in each country*

This reflects the actual amount of wages paid, reflecting the difference in wages that go to different skill levels in different countries.

Measuring employment by headcount reveals nothing about the flow of wages in industries that have globalized. Not surprisingly shares of US and Japanese employment are larger on a wage basis than on a headcount basis, with the United States first at just under 40% of worldwide wages and Japan second at almost 30%. No other country has a share larger than 10%, and the entire Southeast Asian region has only about 13% of the world's wages despite employing 44% of the workers.

Thus, using wages as a proxy for economic activity, we estimate that approximately 40% of the industry's worldwide economic activity took place in the United States. Figure 2 summarizes the information and compares headcount with wage-based measures. The disproportionate role of Southeast Asia in headcount, and of the United States in wages, is clearly visible.

(ii) *Location of wages paid by US firms*

Looking at the economic activity of US firms in isolation is also interesting. Much of the controversy in the United States about globalization has to do with the impact of that process on wages and employment. Much is made of the flow of jobs to Southeast Asia, but our data show that although only about 30% of jobs in US-owned firms are still in the United States, over 60% of the wages they pay are paid in the United States. Both of these numbers are higher for United States than for foreign-owned firms. Nor have the US firms sent wages offshore by outsourcing to non-US firms. Healthy US high-technology firms, no matter

how global, pay a large chunk of their wage bill in the United States.

Table 2 compares the different indicators of industry nationality discussed above. Looking at firm ownership, the industry is dominated by the United States. Looking at location of final assembly, the United States is negligible and Southeast Asia dominates. Location of employment and of wages are more useful than either of these. They show a more varied picture: Southeast Asia plays host to more employees than any other region, but more wages go to employees in the United States; among US firms, more than one-quarter of their employees work in the United States and almost two-thirds of the wages are paid there.

With only one year of data, this is a static portrait. Fifteen years ago nearly all the employment and wages generated by US companies were physically in the United States. Thus the majority of employment has gone overseas, and much of what has gone overseas has been in the less technically difficult stages of the value chain. As other countries, like Singapore, move up in skill levels, will the entire system go offshore as happened with televisions, perhaps to return to the United States as subsidiaries of foreign owned firms? We cannot fully answer this question, but we can explore some of the causes of location decisions which illuminate it.

4. DRIVERS OF LOCATION DECISIONS

In the previous sections, we described the value chain of the HDD industry and showed

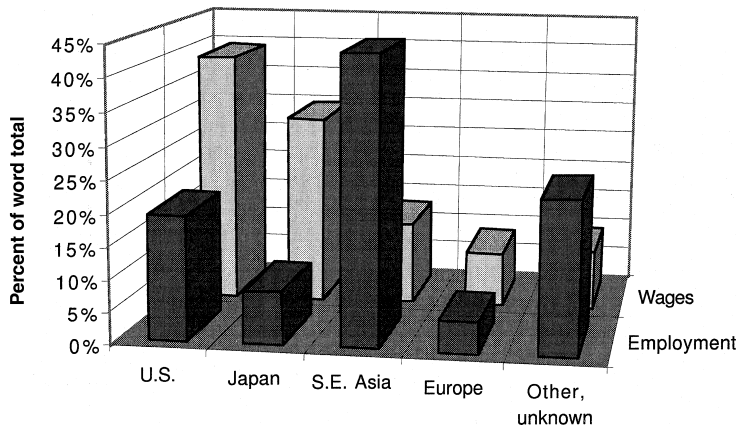


Figure 2. Location of employment and wages in the HDD value chain (Source: As for Table 1).

Table 2. *Summary of alternative indicators of nationality of production, 1995 (All numbers expressed as percentage of world total)^a*

	US	Japan	S.E. Asia	Other Asia	Europe	Other country	Total
<i>All firms</i>							
Nationality of HDD firm (% of unit output)	88.4	9.4	0	2.2	0	0	100
Location of final assembly (% of unit output)	4.6	15.5	64.2	5.7	10.0	0	100
Employment in value chain	19.3	8.3	44.0	17.1	4.7	6.5	100
Wages paid in value chain	39.5	29.7	12.9	3.3	8.5	6.1	100
<i>US firms</i>							
Location of final assembly (% of unit output)	5.1	13	66.8	3.9	11.2	0	100
Employment in value chain	28.5	0.9	55.3	5.9	2.9	6.5	100
Wages paid in value chain	62.4	3.5	19	3	4.6	7.5	100

^a Source: As for Table 1.

the location of employment and wages paid by country and place in the value chain. This section seeks to analyze this data by exploring some causes of location decisions by HDD firms. What accounts for the patterns we observe? There are clearly a multitude of factors, but for this industry at least, three classes of explanations stand out: labor cost/skill issues, agglomeration effects, and government policy.

(a) *Factor costs: the role of technical difficulty, skill levels and labor costs in location*

One explanation for the location of different parts of the HDD value chain is surely the cost of labor and its supply at various skill levels. Low skilled labor is cheap in some places, and relatively expensive in others. Expertise, especially of engineers with skills needed for particular stages of production, is available in some locations but extremely scarce in others. A fundamental relationship in world labor markets is that cost of unskilled labor and the availability of skilled labor are correlated across countries. So, we would imagine that companies seek to place their technically most straightforward but labor-using activities in those locations that have the greatest abundance of inexpensive low skilled labor, and their most “high-tech” engineering-intensive activities where highly skilled labor is the most

plentiful. Intermediate activities, those requiring a mix of labor skills, should be placed in countries with intermediate levels of wages, expertise and skilled labor.

This relationship helps explain shifts in the location of activities over time. Tasks that went to Singapore when that country had low wages—assembly of low-end drives—have moved elsewhere in Asia as Singapore’s wages have risen. New activities requiring higher levels of skill—media fabrication, assembly of high-end drives, semiconductor wafer fab—have moved in, often from the same companies. Thus Singapore has “moved up the value chain”. It is important to emphasize that “moving up the value chain” is a linguistic simplification. Movement is not up a simple sequence that mimics the flow of material, from components to subassembly to final assembly. Rather it is from less to more skilled activities, whatever their sequence in the physical production process.

The relationships among wages, skill requirements, and location can be represented graphically by plotting the actual locations of employment in different stages (Figure 3). Each “bubble” in Figure 3 shows the workers in that stage in that country. The area of the bubble shows the number of employees, its vertical location shows the average factory wage in that country, and the horizontal location shows the approximate skill level. Ordinal rankings were

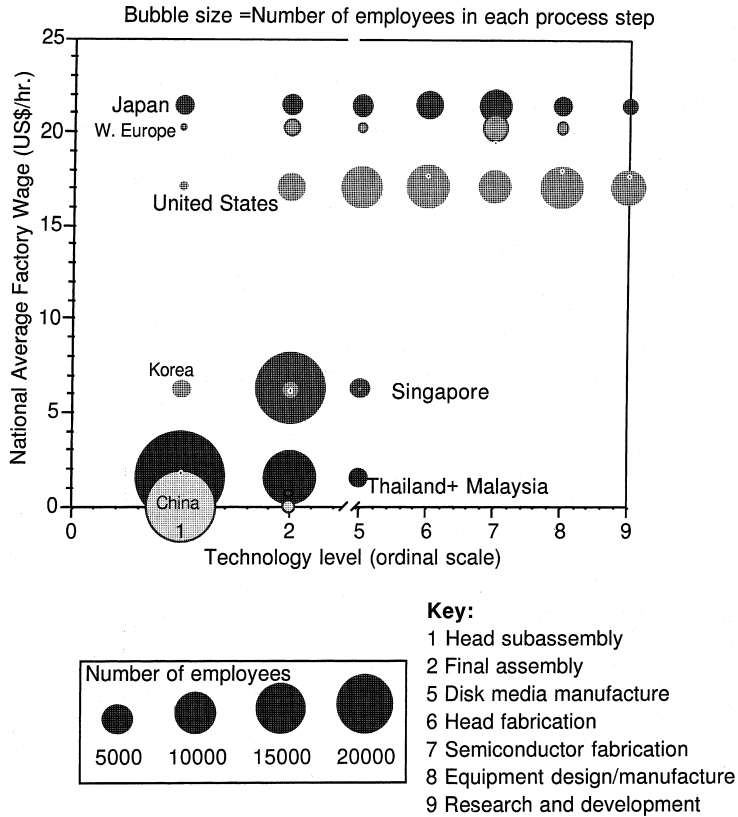


Figure 3. Wage level versus technology level: empirical data (Source: Gourevitch, Bohn and McKendrick (1997)).

used for skill levels, with no attempt to subdivide the workers in a given process step into different skill levels.

Figure 3 shows some support for the hypothesized relationship between skills needed and national wage levels in countries involved in the industry. From the lowest wage countries (China) to higher wage ones, the mix of activities shifts toward higher technology processes. China, with the lowest wages at \$.39 per hour, is used almost entirely for head subassembly, the lowest skilled and most labor-intensive activity in HDD production. Thailand and Malaysia, with average wages \$1.61 and \$1.53, respectively, do some disk drive assembly as well. Singapore (average wage \$6.29) has employment predominantly in disk drive assembly.

Moving to the high-wage countries, the key role of the United States is clearly visible, with sizable employment levels in all activities except head subassembly and disk drive assembly. The

highest technology steps of the value chain—head fabrication, semiconductor fabrication, equipment, and R&D—are done almost exclusively in the high-wage countries, mainly in the United States but also in Japan.¹⁰

Despite the importance of wages and skill levels in influencing location decisions, there are a number of anomalies in the pattern of Figure 3—decisions that cannot be explained by the wage/skill hypothesis. Korea has about the same wage levels as Singapore, yet activity there is shifted toward lower skills than Singapore. There is almost as much media manufacturing employment in Thailand as in Singapore, despite the 4:1 ratio of wages. Meanwhile, most low-wage countries have no HDD-related production at all.

In short, the geography of employment in HDD does not fit cleanly with a prediction based on wages and skills alone. There are also theoretical difficulties with this explanation.

First, as wages are a small percentage of total cost (around 5% of final assembly costs), can they really explain location decisions? Intense competition makes even small savings relevant, so as long as wages are not zero, companies will seek to reduce labor costs. But if wages fall as a component of production, other factors become more relevant and a single minded emphasis on labor cost becomes harder to justify as an explanation of behavior.

Second, the mix of workers and other elements of production are a matter of strategic judgment by management, not a given determined exogenously by technology. Quantum's manufacturing partner MKE uses highly automated factories with only a handful of employees per shift, while Seagate uses labor-intensive methods with thousands of employees to do the same task. Not surprisingly, MKE has only recently shifted some of its operations outside Japan and Singapore.

A third problem with the labor cost explanation lies in the way firms estimate wage costs. It has been common, for example, for manufacturers to allocate fixed overhead expenses proportional to wages. Doing so makes workers seem very costly, so that savings on labor seem to provide an immense benefit. This practice has been criticized by analysts, and the best accounting practices have shifted to better measure the role of wages, but the practice, and its liabilities, appear to continue.

A fourth difficulty with the wage/skill explanation is the link between wage rates and manufacturing performance when production is shifted geographically. The costs of many stages of the HDD value chain are yield-driven, which means that efficiency is diminished and cost increased by scrap and rework. Since material costs are higher than other variable costs, especially in the later stages of the value chain, low yields can dramatically raise costs. As wage costs are a small percentage of total cost, it takes only a few percentage points reduction in yields to outweigh any lower wage rate.

Because yield is so important, managing technology transfer across great distances is a key component of effective managerial practice in globalization. Moving from prototype to volume, and from a "first stage" manufacturing site (where volume production is standardized and yield perfected) to a "second stage" manufacturing site (where yield is stable and low factor costs the only relevant variable) poses challenges to coordination, and may

affect the ability to reach extremely high yield rates. Long distances, unskilled workers, inadequate infrastructure, poor services and other coordination factors may swamp the savings from direct labor costs.¹¹ All of these may affect the ability to achieve the high yield rates required. The systems devised to manage technology over long distances have become for the HDD firms key ingredients of their comparative advantage, about which they are quite proprietary.

Wage-skill relationships are certainly a key element of location decisions, but not the only ones. Among the other influences, agglomeration effects and public policies play important roles.¹²

(b) *Agglomeration effects*

Agglomeration effects have been heavily documented in location-oriented studies. An interesting characteristic of the HDD industry is that it is both globally dispersed and regionally concentrated. In effect, the industry participates in and benefits from two kinds of strong agglomerations, each of which plays a functionally distinct role. In the United States, Silicon Valley continues to hold a substantial share of research, design, development, marketing and management. Prototype manufacturing continues to take place there: there are plenty of clean rooms, robots, testing facilities, and component manufacturing that takes place in the region, even if there is virtually no final assembly. Minnesota and Colorado also serve as important clusters. The major counterpart to this kind of agglomeration outside North America is Japan. While Japan does not dominate final HDD assembly the way it does other elements of the electronics industry, it is the other major location of the high-end research, design, and development in the HDD industry, and it manufactures some critical components in the system.

Southeast Asia, and Singapore in particular, represents the second kind of agglomeration. This region dominates final assembly, most of the labor-intensive subassemblies, and low-tech components such as baseplates.

Clearly, some kind of concentration occurs in key regions. The United States and Japan play host to the principal research, design and development work related to disk drives. Southeast Asia, and to a lesser extent Europe, assemble and manufacture components. These two types of agglomeration are thus inter-

twined and complementary. Decisions, knowledge, and management flow among Silicon Valley and Tokyo, Singapore, rural Thailand and China. The concentration of key activities in certain cities and regions thus suggests some important ways agglomerations benefit industry and, in turn, how firms are able to integrate activities that are physically separated by long distances. Firms must tie together research and product development, which is located in one agglomeration, and assembly and component manufacture, which are located in another.

(i) *The global management of high-tech R&D, face to face contact, and long-distance communication*

Certain R&D activities remain strongly rooted in concentrated areas, while low-wage labor is obviously widely dispersed. Modern technology shrinks distances. Information flows electronically and conveys valuable content about design, markets, and technique. At the same time, face to face relations matter a lot. Managers fly long distances to monitor operations. Is this duality likely to persist and in what areas?

The United States has the highest concentration of skilled people. That concentration acts as a magnet to hold related activities nearby and attract new ones. Singapore would like to move up the value chain into R&D; can it do so, and for what activities? What is likely to remain in Silicon Valley or elsewhere in the United States? How do firms manage the coordination of design with manufacturing over great distances? Some firms regard their skills in this regard as among the most valuable of their assets, proprietary knowledge not to be shared. As technological development pushes the knowledge boundaries, manufacturing tolerances grow ever tighter. These may increase the importance of manufacturing skills, and their relationship to design. Just how will this influence location?

(ii) *Proximity to markets*

Some observers think that being near the purchasers of final product is important, be it because of specialized information, or the service demands of consumers. By this logic, firms upstream in a chain of production move toward those who are downstream. By this logic also, the HDD businesses globalized to be near their customers. The same point has been made about Ireland: HDD manufacturers went there because big players in computers are

located in Ireland, Scotland, and parts of England. Other observers doubt that proximity to markets matters very much in location; computer assembly is located in Japan, the United States and Taiwan, but there is very little final assembly of disk drives in these locations.

(iii) *Proximity to suppliers and service activities*

As the value chain spreads out (R&D in one region, final assembly in another, component supply in yet a third), the coordination among these elements becomes increasingly important. The capacity to supply components and services (repair, installation) gains in importance. It may be important for steps down the value chain to be near items above it.

(c) *Public policy: the role of targeted incentives*

Companies' globalization strategies take place in the context of markets and national economies whose rules are determined by governments. Public policies are therefore important in how firms develop international production strategies and in their location decisions. One simple example drives the point home: there are many low-cost wage areas in the world, yet the hard disk drive industry has concentrated in a few countries. Why do HDD firms locate particular production process in some countries, and ignore some countries altogether?

Many aspects of government policy are relevant. One is the deliberate, self-conscious effort by government to court the HDD industry or firms connected to it. Singapore is the most spectacular example. In the early 1980s, the Economic Development Board (EDB) of Singapore decided to target the electronics industries, including HDDs—in sharp contrast to Hong Kong which pursued a *laissez faire* policy of not targeting any sectors or firms (Berger & Lester, 1997). Singapore's policy rationale lay in the concept of "agglomeration" effects: concentration of the HDD industry would launch spillover effects. Other countries in Southeast Asia have followed suit, though none have targeted hard disk drives in so singular a fashion as Singapore. In Europe, Ireland has become Europe's pole of concentration for HDDs (along with other elements of the electronics industry). As a matter of policy, the Irish Development Agency (IDA) focuses on firms rather than a specific sector, but the effect has been to attract clusters of firms in

related areas, among them HDDs. Thus, one cause of HDD concentration has been the deliberate decision by some governments to focus their attention on it.

Based on our interviews with government officials and corporate executives, the most powerful policy instrument available to governments appears to be taxes and subsidies which go straight to the “bottom line.” Singapore, Thailand, Malaysia, and Ireland all provide substantial tax holidays to firms locating their activities there, and these are noted by executives as important influences on their location choices. Indeed, many interviewees rate it above labor costs in importance on location decisions. Other subsidies also aid the bottom line, including subsidies for land and buildings, labor force training, and research activities. Generally, these policy actions are targeted to specific companies, and are created by direct negotiation between governments and firms. In both Singapore and Ireland, for example, the government Development Agencies negotiate directly with firms, packaging a cluster of tax write-offs and other incentives encouraging firms to come to the respective countries.

While these policy measures are firm-specific, other policy moves are more general. These include trade barriers, local content rules, the speed and ease of regulatory processes, infrastructure and communications systems, and the legal infrastructure in development areas. One attraction of Ireland, for example, is that its membership in the European Union allows firms to meet local content and other regulatory requirements for the very large European market. Similarly, firms pick China in part to get inside its complex regulatory apparatus and to be in place to receive regulatory favors.

Regulation can provide an element of comparative advantage among governments. Singapore is often praised for the speed of its regulatory process—“one-stop shopping” at the EDB—and the efficiency of its harbor, airport, and telecommunications systems. By contrast, some other countries that executives have considered for factories get low marks for infrastructure, regulatory slowness or interference, and other barriers. Indeed, the United States is frequently criticized in the industry not only for wage levels but for regulations and inattention. In Silicon Valley, for example, HDD firms note that both regional regulatory obstacles and the strict statewide regulations are important reasons not to locate new activ-

ities there. At the same time, firms do not appear to pay much attention to low cost or less regulated regions of the United States. US regional development agencies are criticized for the lack of information, awareness, initiative, and capacity. The EDB of Singapore is often held up as a contrast: it knows a great deal about both the entire industry and the needs of specific HDD firms, and is thus able to focus on individual firms and make deals with them. HDD executives complain that no US agencies, state or federal, come to them with the same degree of knowledge or authority.

Globalization puts relentless pressure on policy makers. Singapore’s success drove up wages, causing companies to move low-skill activities to cheaper locations, and thus created new pressure for Singaporean officials to attract new jobs. The EDB then shifted policy to move Singapore toward higher skills in the value added chain: it linked its tax breaks to technology transfer, it moved training subsidies toward engineers, and it increased the R&D budget. All of this takes money which has to be found somewhere, raising costs for the economy as the whole. In turn, this ongoing process in Singapore puts pressure on the United States (and Japan) to provide reasons for firms to keep jobs at home. Public policies thus influence firm decisions in the industry, and at the same time governments are influenced in their public choices by international economic forces of competition with other countries and among firms themselves.

5. IMPLICATIONS AND CONCLUSION

Using the evidence from hard disk drives, we return to the controversies about globalization noted at the beginning of the paper.

(a) *The welfare effects of globalization*

Does globalization hurt the economy? In the HDD industry, it is certainly the case that the *percentage* of industry jobs in the United States has fallen dramatically since the inception of the industry. Does the fall in the share of disk drive industry headcount located in the United States prove that globalization hurts US employment? It is impossible to tell by looking at only one industry. The impact of change in one case requires a comprehensive cross-sectoral dynamic analysis for the whole economy. The overall effect turns on the absorptive

capacity of the economy: as jobs leave one firm or industry they may be growing in another through the logic of specialization which lies at the core of the global market economy. Moreover, as foreign countries gain jobs from the United States, their purchasing power rises, allowing them to buy other US products. Trade produces greater wealth through specialization; the decline of one line of work in a particular country does not prove the disappearance of all work, but the shift from one activity to a more productive one. It may even be the case that there are more jobs in the HDD industry in the United States than there would be without globalization, as international specialization lowers overall costs and expands demand for the product enough to raise total employment. US firms globalized many years before their Japanese competitors; if they had not done so, the Japanese might have captured higher market shares, pushing US firms and employment well below current levels.

Does globalization hurt wages of the low-skilled? The overall welfare effect of globalization for the United States could be positive, yet the distributional effects are severe on certain parts of the population. Certainly low-skilled jobs in the HDD industry are the ones that have left the United States, and the growth of HDD jobs in the United States is largely at the higher value-added end. Again, a single industry study cannot settle this argument one way or another. It can say that low-skilled worker in the United States are the most immediately affected by moving some production processes overseas. Moreover, it is they who pay the search and transition costs of finding a new job (moving, upgrading skills, more education). Despite these drawbacks, the role of globalization in generating economic growth has a beneficial impact: an expanding economy can absorb displaced workers while a contracting economy cannot. US dominance in the HDD industry may well derive substantially from its skills in globalizing (McKendrick & Hicken, 1997). The appropriate comparison would then be the impact on US low-skilled employment of a less globalized but weaker, or even nonexistent, industry.

(b) *Understanding the patterns of globalization*

In addition to the strategic leadership shown by US multinationals, the geographic pattern observed today is due to the evolving interaction of three locational determinants: factor

costs, public policy and agglomeration economies (McKendrick, 1998). The industry has come to be organized into two kinds of clusters: one is technological, the other operational. In the beginning of the industry, disk drive product development and assembly were concentrated together in one location. But over time, functional differentiation became a striking feature of disk drive location, with assembly located almost entirely outside the country of origin while product development continues to be carried out almost entirely at the firms' founding locations. Component fabrication (heads and media) shifted later than assembly and as of 1997 was still done in both regions. Although much of the literature discusses the proximity of clustering of competitors without distinguishing between function, research can benefit from disaggregating functional activities when considering industrial clustering. There are low-wage, low-skill components in the even the most high-tech industry, and there are high-wage, high-skill elements in all but the most basic sectors.

In examining where firms have chosen to site different activities, the concept of wage-skill ratios proves quite useful in suggesting which parts of the value chain move over time. As wages rise in Singapore, low-skill jobs are leaving for other parts of Asia. Other jobs, though, are entering Singapore as they leave high wage/skill areas like Japan and the United States. The items that move are not "up" or "down" in the sequence of the value chain, but rather the lower skilled activities within each step of it. Thus lower skill activities in heads, media, and final assembly may all emigrate when wages rise, while the more skilled activities of each segment remain in place.

The geographical disaggregation of the value chain has important implications for arguments about proximity and clustering in explaining location. These two kinds of clusters resulted from the interactive inducements of lower factor costs, supportive public policy and agglomeration economies. That is, location decisions emerged from this three-way interaction to generate the industry's geographic structure. The interaction of these three factors offers strong explanations for the centrifugal forces dispersing assembly away from the United States, and the centripetal forces retaining product development at home. R&D for heads, media, and drives may benefit from proximity, while some lower skilled manufacturing activities can be thousands of miles

away. At the same time, some kinds of manufacturing activities need to be proximate to one another. Measurements of proximity effects may blur this phenomenon by insufficiently distinguishing between each category of production. Most empirical research on industry location does not capture this interactive and functional character of location.

(c) *The interaction of public policy and corporate strategy*

Public policy has a strong impact on location decisions. Firms seeking low wages in a particular wage/skill combination have many countries from which to choose. Just where they go is strongly influenced by conditions over which public policy has considerable control: tax and other subsidies, infrastructure, regulatory policy, education and training, and research systems. Singapore captured the first steps of globalization in the HDD industry because it went aggressively after these firms. The EDB is widely admired as a major player in the system of this industry. The concentration of previous sitings in a particular region such as Singapore and Southeast Asia generates agglomeration and network effects that influence subsequent location choices. Thus having attracted pieces of the industry, Singapore then benefits from those choices.

Firms move to locations where policy makers are attentive to their requirements. The Singaporean government has shown that policies targeted at specific industries, such as HDD, can succeed in attracting investment, and reinvestment. This is especially true in the absence of countervailing efforts by the firms' home governments. In the case of the United States, which has been the home to the disk drive industry's most successful firms, designing policies to retain the industry may be especially challenging to implement. As a large country, the United States may have too many industries for policy-makers to monitor, as well as too many levels of jurisdiction: federal, state and local governments. This makes it difficult for firms to receive sufficient attention from policy makers regarding their particular competitive circumstances; it also makes them vulnerable to foreign inducements.

International competition thus puts pressure on governments and citizens to provide the services and conditions that attract firms: a well-educated work force, infrastructure, tax breaks, regulatory effectiveness. Some of these

measures require money, especially labor training, research and infrastructure. Raising that money can be left to individuals and markets—risking the classic underinvestment associated with the provision of public goods. Or it can be funded by taxes—risking the flight of capital in search of lower taxes from other governments, in which case governments face competition from other governments. Governments thus face contradictory pressures. They may lower taxes to attract investment, but they thereby jeopardize the income stream needed for education, research and infrastructure, items of great importance as countries move up the value chain of world production. Globalization thus puts micro-incentives of cost reduction in tension with macro-issues of optimal social and economic policies in providing public goods required by the economy and the firms in it.

(d) *Conclusion*

Globalization produces contradictory incentives. To firms' managers, globalization provides substantial opportunities for taking advantage of "competition among countries" for investment, which leads to tax subsidies, deregulation, and other inducements to relocate. At the same time, however, they face substantial managerial challenges in tracking just what are the costs and benefits of activities in different locations. Issues of yield, labor and other factor costs, taxes, local content rules, trade barriers, regulation, research, diversification, risk hedging, technology management, intellectual property rules—these cannot be integrated into simple algorithms that dictate decisions. Managers must satisfice, saving on search costs, looking relentlessly for more, better, and cheaper information with which to make decisions.

The globalization of the HDD industry during the past two decades reveals the complexity of these processes at work. Evaluating the flow of benefits from globalization varies considerably according to the indicator used. The United States continues to receive substantial benefits from this industry because US firms retain significant advantages in locating research, product development and certain elements of production here. But the value chain has shifted a range of activities overseas. The ability of US employees to receive benefits, as opposed to the dominant market position of US firms, depends on

whether being located in the United States continues to provide comparative advantage for these activities. Drive assembly and many elements of component production have moved. Will research and design stay here, sustained by a system of research, education, and development speed? Or will other countries succeed in drawing away those elements of the system as well?

While the experience of the disk drive industry offers a number of insights into the globalization process, a single case obviously places limits on generalizability. Other industries may differ in important ways. For one, they may not be as effectively managed from the point of view of the home country. US disk drive companies were extremely quick to grasp the advantages of manufacturing abroad while keeping control over production, but they also kept product development and other higher value-added activities at home. In this sense, the industry has not been “lost” to other countries along some measures that are important to US national welfare. Another limitation is how the industry is organized. The value chain is composed of activities conducive to the geographic dispersion described in this paper: final assembly need not be proximate to HDDs’ major markets, and a range of disk drive components and

tasks can be physically separated from design across large distances. Other industries may face greater constraints on their geographic division of labor.¹³

So complex are the variables in play that we cannot predict the long-run future of individual companies or the industry as a whole. Short of a major collapse of the world trading system, we can only be confident that this will remain a leading industry with which to track and measure globalization processes. Public policy makers, as well as investors, employees and managers, need to reflect carefully on just how these processes work and how they distribute benefits. Disaggregating the industry into ever-smaller pieces of the value chain, as we have done here, is an empirical fact, an analytic necessity, and a key ingredient in managerial and policy decision-making. It confirms both the simple critique of globalization—that jobs leave the US—and the simple defense—jobs are preserved and even created by the application of comparative advantage. Sharing the resulting costs and benefits of globalization is a matter not only for politics and the political process, but also for the firms and managers who face the challenge of formulating and implementing the strategies necessary to survive in extraordinarily competitive environments.

NOTES

1. For an overview of the debate over globalization, see Rodrik (1997). Note that in some quarters, “global” connotes statelessness. In his analysis of the history and theory associated with the term, Hu (1992, p. 108), for example, says global means that “the company has really transcended nations in the sense that it is indifferent as between different countries and has no home nation”. See also Henderson (1989). For the purposes of this paper, “global” is interchangeable with “international” and is a shorthand for economic activities being distributed across more than one country. We do not mean to imply that the organizations spearheading the globalization process are in any way stateless.

2. In principle, value chain analysis should go all the way back to basic components and all the way forward to final sales. Integrated circuits, for example, are made from bare silicon wafers, which are made from silicon ingots, which are made from sand; disk drives are just a component in computers, which in turn are a component

in computer systems. To render the research task more manageable, we have gone downstream only as far as finished HDDs, and upstream only to semiconductor fabrication. We similarly limited our investigation in other subchains.

3. We include technology development, product design, process development, and pilot production in this category.

4. This value chain is not the same as a total input/output analysis, which would include additional elements that generate employment: transporting products, buying electricity and other services, basic research in universities, etc.

5. The main surviving exception is Quantum, which subcontracts its manufacturing to MKE, a subsidiary of Matsushita of Japan. A variation of this theme is IBM, which makes high-end drives, then extends their product

life by licensing them to NEC when they shift toward the low-end.

6. We include Quantum, which subcontracts the manufacture of its drives to MKE of Japan, in the US numbers.

7. Firms do continue to produce in the United States, largely, though not entirely, in pilot lines; Seagate supports modest volumes of production in Oklahoma City. US production thus was about 1% of the world total in 1997.

8. The major gaps include our coverage of Japanese firms, which is less complete than our coverage of US firms, and our coverage of indigenous supplier firms in Malaysia and Singapore. For about 15% of employment, we know employees work in the industry but we do not know what country they are in, what activity they work on, or both.

9. For methodological reasons, in the discussion below we use wages paid (employment times wage rate) rather than value-added. Presently we are using national average wage data, rather than actual wage levels in the HDD industry. For a further discussion of the methodology used to calculate these numbers, see

Appendix 1 of Gourevitch, Bohn and McKendrick (1997).

10. Our data on semiconductors are not detailed. Figure 3 oversimplifies the distinction between semiconductor fabrication, done in the high-wage countries, and semiconductor assembly, usually done in low-wage countries.

11. For example, in one case we analyzed, a 10% change in yield has more impact on cost than a \$20 per hour change in the wage rate. See Terwiesch, Bohn and Hampton (1997).

12. On the agglomeration or “district” effect see Rauch (1993). Economists’ analysis of agglomeration traces back to Alfred Marshall (1960). See Krugman (1991) and Porter (1990). On issues of regulation see Gilpin (1975), Wade (1990), Haggard (1990), Gereffi and Korzeniewicz (1994), Cowhey (1993), and Richards (1997). On the interaction of variables see Rauch (1993) for a discussion of the ways government policy overcomes first mover disadvantages and induces concentration and the agglomeration affect.

13. We are grateful to a referee for suggesting these points.

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