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ADVANCES IN LOGISTICS AND THE GROWTH OF INTRA-FIRM TRADE: THE CASE OF CANADIAN AFFILIATES OF U.S. MULTINATIONALS, 1984–1995*

MICHAEL P. KEANE†
SUSAN E. FEINBERG‡

Intra-firm trade in intermediates between U.S. multinational parents (MNCs) and their Canadian manufacturing affiliates increased dramatically in the 1984–1995 period (i.e., it roughly doubled). Tariff and transport cost declines were far too small to explain this phenomenon. But we show that the advent of improved logistics management practices, including the 'just-in-time' (JIT) production system, can explain much of the growth of intra-firm trade. JIT lowers the inventory carrying cost component of intra-firm trade, and, by 1984, this was more important than tariff and transport costs in many industries. We combine regression analysis with numerous case studies to draw our conclusions.

I. INTRODUCTION

IN A RECENT PAPER, FEINBERG and Keane [2006] studied intra-firm and arms length trade by U.S. multinational corporations (MNCs) and their Canadian affiliates, using confidential firm-level data from the Bureau of Economics Analysis (BEA). They noted the following rather striking fact about Canadian manufacturing affiliates: In 1984, sales of intermediates back to parents represented 38% of affiliate total sales. But, by 1995, this figure had risen to 63%. Clearly, the role of the Canadian affiliates was radically transformed in the 80s and 90s, as they shifted away from final goods and towards production of intermediate inputs for parents.[1]

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†Authors' affiliations: ARC Federation Fellow, Departments of Economics and Marketing, University of Technology Sydney, NSW 2007, Australia, and Department of Economics, Arizona State University, Tempe, Arizona 85287, USA.
email: michael.keane@uts.edu.au

‡Rutgers Business School, Rutgers University, Newark, New Jerscy 07102, USA.
email: feinberg@rbsmail.rutgers.edu

[1] Originally, many Canadian affiliates were set up on the 'branch plant' model. That is, they produced small quantities of the parent's products for sale in the Canadian market, in order to

According to Statistics Canada, more than half of assets in Canadian manufacturing are controlled by foreign MNCs, the bulk of these being U.S. owned. Thus, not surprisingly, the growing export orientation of the Canadian affiliates of U.S. MNCs has important implications for the Canadian economy as a whole. Indeed, according to data from Statistics Canada and from Martins [1994], the export intensity of Canadian manufacturing (i.e., exports over total shipments) increased from below 30% in 1984 to 52% in 1995.[2]

In this paper we ask what caused the dramatic increase in shipments of intermediates between Canadian affiliates and U.S. parents in the '84–'95 period. Casual empiricism points to tariff reductions, since the U.S.-Canada free trade agreement (FTA) went into effect in 1989. But Feinberg and Keane [2006], henceforth FK, note several problems with a tariff explanation. First, the mean level of U.S. tariffs on Canadian imports was about 3.8% in 1984, falling to about 1.2% in 1995. Thus, tariff reductions only reduced the cost of imports from Canadian affiliates by about 2.5% on average. Yet, as FK note, the increase in intra-firm exports from affiliates to parents was about 95%. Thus, at the aggregate level, the elasticity of demand for intra-firm intermediates would have to be very high (i.e., about 40) to explain the increase based on tariff reductions.[3] FK conclude that tariffs can account for only about a 5% increase in intra-firm exports from Canadian MNCs to U.S. parents, consistent with a plausible demand elasticity of about 2.

The puzzle is far more severe at the industry level. As FK note, there is essentially no correlation between the magnitude of the tariff reduction for an industry and the increase in intra-firm trade. For example, in autos and auto parts industries, tariffs were essentially eliminated by the Auto Pact of 1965, yet the increase in intra-firm trade in '84–'95 was almost as large as the average increase across all industries. In industries like computer equipment and electrical and electronic equipment, increases in intra-firm trade were well above average, yet tariffs were already quite low by 1983. For tariffs to explain observed increases in intra-firm trade in these industries, one needs completely implausible demand elasticities in the 75 to 100 range.

circumvent high tariffs that existed in the '30s and '40s. But, by the early '80s, most MNCs had 'rationalized' their North American operations, with the Canadian affiliates assigned to produce larger volumes of a smaller set of final goods (see Section VIII below).

[2] Export intensity peaked at 57% in 1999 and then drifted down to 50% by 2003. This is because growth in domestic demand exceeded growth in exports in the 2000–2003 period.

[3] U.S. Census data also shows no significant reduction in transport costs (freight and insurance) over this period. And Trefler [2004] calls the FTA a 'relatively clean policy experiment' in the sense that it did not involve other major changes in policy besides tariff reductions (such as reductions in non-tariff barriers or capital constraints). Thus, it seems unlikely that declines in transport costs or non-tariff barriers could explain the phenomenon either.

The situation is quite different with arms'-length trade (i.e., exports from Canadian affiliates to unaffiliated third parties in the U.S. and vice versa). FK note that increases in MNC-based arms'-length trade are highly correlated with tariffs, with the largest increases concentrated in industries where tariff reductions were most substantial (see FK Fig. 5 and 6).

Thus, FK conclude that tariffs can explain most of the increase in arms'-length MNC-based trade, but only a small fraction of the dramatic growth in intra-firm trade. Instead, their model 'explains' increased intra-firm trade via increased share parameters for intermediates in the production function.[4] But it leaves the source of these changes in technology a 'black box.'

In this paper, we seek to understand the underlying cause of the dramatic increase of intra-firm trade that occurred in the '80s and '90s. To this end, we adopt an unusually eclectic research strategy that includes: (i) regression analysis based on confidential BEA data, (ii) case studies of many Canadian affiliates, drawing on interviews with executives of several Canadian affiliates that we conducted in 1995, as well as extensive readings from the business press, trade publications, corporate reports, etc., and (iii) extensive reviews of the operations research, industrial engineering, logistics management and international business literatures.

All these sources of evidence support the hypothesis that advances in logistics management, such as the just-in-time production system (JIT), which many U.S. MNCs began to adopt in the mid-80s and early 90s, were a key factor leading to increased intra-firm trade. First, our regression analysis reveals a strikingly strong correlation (at the industry and firm level) between a measure of adoption of JIT and increased intra-firm trade.

Second, work in the operations and logistics literatures shows that the finding makes sense theoretically. An important part of the cost of transporting goods intra-firm, not captured by physical transport costs or tariff costs, is the inventory carrying cost that arises from time goods are in transport and time goods sit in stock before they are used in the next stage of the production process. These inventory costs are higher to the extent that larger buffer stocks of intermediates must be held to insure against faulty

[4] In recent influential models of intra-firm and intra-industry trade by Yi [2003] and Eaton and Kortum [2002] there are many varieties of intermediates, and tariff reductions increase the number of varieties that are traded. If varieties are close substitutes in production, small tariff reductions can have big effects on intra-firm trade. However, their calibrated models give demand elasticities on the order of -10, which is still far too small to explain a near doubling of intra-firm trade using tariff reductions of a few points. Furthermore, if this variety mechanism is at work, the total volume of intra-firm trade should be very sensitive to tariffs at the industry level. This is inconsistent with the results in FK, who find essentially no relationship. It is clearly difficult to reconcile a story designed to explain how intra-firm trade could be very sensitive to tariffs with data where there is essentially no correlation at the industry level.

shipments shutting down the next stage of production. *Advances in logistics, such as the JIT system, as well as systems for tracking parts in transit, lower these inventory carrying costs, thus lowering the cost of intra-firm trade in intermediates*. At a time (i.e., 1984) when tariff and physical transport costs were already quite low, it seems plausible that inventory carrying costs were the main cost of intra-firm trade in many industries. Indeed, the only two operations research studies of the issue we are aware of, the HP study by Lee, Billington and Carter [1993], and the DEC study by Arntzen *et al.* [1995], both found such inventory-carrying costs to be much more important than tariffs.

Third, our case studies provide numerous examples of JIT adoption leading to increased intra-firm trade, through a variety of mechanisms. For instance, besides reducing inventory carrying costs of intra-firm trade, JIT adoption is closely linked with other management innovations, like concurrent engineering (CE) and the 'product platform' approach to new product development, which also increased intra-firm trade. Moreover, JIT lowers the efficient scale of manufacturing plants. This increased the efficiency of Canadian affiliates, whose plants had previously been inefficiently small vis-à-vis larger U.S. plants. Thus, JIT adoption was crucial to transforming Canadian affiliates into efficient producers of intermediates for parents.

Of course, if advances in logistics reduce inventory costs of transporting goods intra-firm, they should also reduce inventory costs of outsourcing to third party suppliers. Thus, one may wonder why JIT didn't lead to more outsourcing, rather than more intra-firm trade. In this regard, we stress that nothing in our results suggests that advances in logistics did not *also* increase outsourcing. Unfortunately, as the BEA data do not report stage of processing of inputs purchased from third parties, our statistical analysis cannot address this point directly.

However, our case studies suggest the growth of outsourcing and intra-firm trade in the 80s and 90s were actually part of the same phenomenon. Under intense foreign competition, especially from the Japanese, U.S. manufacturers strove to improve supply chain management. They sought to emulate firms like Toyota by outsourcing many activities they had previously performed in-house, instead sourcing from 'best in class' suppliers who could deliver on a JIT basis. Canadian affiliates, acting as semi-autonomous agents, often successfully competed with third party suppliers to achieve this 'best in class' status. They did it by transforming themselves from inefficient final goods producers into efficient JIT producers of key intermediates.

And a key point is that, while JIT may lower inventory costs, it also *increases* other aspects of the costs of transacting with third parties. As we'll see when we discuss principles of JIT in more detail, the system requires a tremendous amount of proprietary information sharing between suppliers and buyers.[5] It also involves a high level of relationship specific assets and the use of very few – often just one – supplier (i.e., bilateral monopoly/oligopoly).

Because adoption of JIT makes transactions more complex and involves relationship-specific investments, it may tend to favor intra-firm transacting.[6] At minimum, it requires creation of close links between manufacturers and their suppliers to foster mutual interest. These may take the form of minority equity holdings, relationship specific assets, shared employees, long term contracts, joint ventures, or even vertical integration.[7] Thus, rather than viewing the outsourcing of the 80s and 90s as merely a shrinking of the boundaries of the firm, it would be more accurate to see it as a blurring of firm boundaries across links in the supply chain.

The organization of the paper is as follows: Sections II–III present a set of hypotheses about what drove the increase in intra-firm trade, and a regression analysis motivated by these hypotheses. Then, sections IV–VIII present our case study evidence, based on affiliates in four major industries (autos, computers, chemicals, electronic equipment). Section IX concludes.

II. WHAT CAUSED THE TRANSFORMATION OF CANADIAN AFFILIATES IN 1984–95? FOUR HYPOTHESES

As FK show, the transformation of Canadian manufacturing affiliates in the 1984–1995 period had several key features: (i) shipments of intra-firm intermediates from affiliates to parents roughly doubled, and the cost share of such intermediates in U.S. parents' production functions more than doubled (from 1.3% in 1984 to 3% in 1995), (ii) these increases in intra-firm trade were essentially uncorrelated with tariff reductions at the industry level, and (iii) increased intra-firm trade occurred almost entirely on the *intensive*, not the extensive, margin (i.e., very few MNCs initiated intra-firm trade during the '84–'95 period). This observation is further explored in

[5] JIT requires tight coordination between manufacturers and suppliers, not only in timing of arrival of components, but also in their design (i.e., JIT requires components be designed to facilitate 'quick changeovers'). Thus, manufacturers must share proprietary information with suppliers about production planning (i.e., demand forecasts) and new product development. JIT also requires a high level of quality assurance, which can only be achieved if suppliers share proprietary cost and process information with manufacturers. See, e.g., *Crain's Detroit Business* ('Suppliers Fear GM Scrutiny', Sept. 28-Oct. 4, 1987, p. 1), 'Suppliers are concerned that intimate business information gathering by GM during on-site inspections of plants will result in price slashing demands, loss of business for those faring badly on assessments, and technology advances being disclosed to competitors.'

[6] See Klein, Crawford and Alchian [1978], Williamson [1979], Grossman and Hart [1986] and Stuckey and White [1993].

[7] Dyer and Ouchi [1993] note that Nissan owned an average 33% equity stake in its suppliers in 1990. See also Lyons *et al.* [1990], Helper [1991], Handfield *et al.* [2000], Liker and Wu [2000] and Useem and Harder [2000] for good discussions of the complexities of purchaser/supplier relations under the JIT system.

Feinberg and Keane [2005], who find that tariffs are statistically insignificant in MNC decision rules for whether to engage in intra-firm trade.[8]

A fourth key fact is that increases in intra-firm trade occurred in many industries. In Table I we list the diverse set of industries with the largest increases in intermediate input shares. Note, in particular, that while autos and transport equipment account for a large share of U.S.-Canada intra-firm trade, the phenomenon of increasing intra-firm trade is not primarily driven by that industry. According to Statistics Canada, autos and transport equipment accounted for 55% of U.S.-Canada intra-firm trade (in both directions) in 1989. But, by 1996, the share of Canada-to-U.S. intra-firm trade accounted for by autos had fallen to 52%, while the share in the U.S.-to-Canada direction had fallen to 51%. This is consistent with FK's finding that the increase in intra-firm trade in the auto and transport equipment industry was slightly less than the 95% average increase across all of manufacturing.

In light of this evidence, we clearly need to base an explanation for increasing intra-firm trade on some phenomenon that was pervasive across many manufacturing industries beginning in the early 1980s, and that is unrelated to tariff reductions. Based on our interviews with affiliate executives from the mid-90s, and a preliminary reading of the business press of the period, we formed four hypotheses about what drove increased intra-firm trade. We then proceeded to test these hypotheses using regression analysis – where we regress measures of intra-firm trade on industry, affiliate and parent characteristics – in combination with case study evidence. We now describe the development of the four hypotheses that guide our work:

Our *first hypothesis* is that advances in information technology (IT) and logistics management facilitated coordination of fragmented production processes across geographically separate locations.[9] For example, beginning in the early 1980s, it became possible to use computer-based materials requirement planning (MRP) systems that coordinate ordering and shipping of components across locations so they arrive on time for the

[8] In our interviews with executives of Canadian affiliates, they frequently noted that substantial reorganization of production and distribution operations is necessary to initiate intra-firm trade or arms-length trade. Firms are unwilling to undertake such changes in response to small tariff reductions. See also Roberts and Tybout [1997].

[9] Strader, Lin and Shaw [1999] refer to a supply chain where intermediate components made in multiple locations are ultimately assembled into a final product at one location as a 'convergent assembly' supply chain. Using multiagent simulation models, they show that improved information sharing across units can dramatically reduce the inventory stocks needed to maintain a given order fulfillment cycle time in such a system. Jones and Kierzkowski [1990] develop a model where reduced communicated costs lower the cost of coordinating fragmented production processes across countries, leading to increased intra-firm trade in intermediates.

next stage of processing.[10] And the use of bar codes to help track intra-firm flows of materials became prevalent during our sample period.[11] The advent of computer assisted design and manufacture (CAD/CAM) in the early 80s meant that one could have a complete description of all components, as well as their stocks and usage rates, on line, thus facilitating resource planning.[12] And computer based logistics systems made it possible to track parts globally.[13] All these innovations reduce the 'hidden' cost of transporting intermediates intra-firm that arises because a production process may be disrupted if a shipment arrives late, or consists of flawed or incorrect parts, or gets sent to the wrong plant, etc. Improved logistics management means smaller buffer stocks are needed to protect against such disruptions, which in turn means inventory-carrying costs are lower.

To proxy for the cost reducing effects of improved logistics, we included in our intra-firm trade regressions the ratio of IT capital to sales (IT/S), measured at the industry level, as well as the inventory-to-sales ratio (I/S), measured at the industry or firm level. IT/S proxies for the presence of one enabling technology (i.e., computers) for improved logistics management, while I/S captures the actual success of the firm (or its industry) in implementing improved logistics.

The plausibility of our first hypothesis hinges on the timing of adoption of advanced logistics management practices by MNCs. To address this, we

[10] For example, *Chemical Week* ('How Companies Are Holding Down Inventories', Feb. 8, 1984, p. 28) contains a detailed discussion of the widespread adoption of computer based inventory management, as well as JIT inventory control methods, in the chemical industry in the early '80s. One informative excerpt is as follows: 'One of the more sophisticated setups is operated by Allied. When sales personnel . . . talk to a customer . . . Allied's computerized inventory-management system tells the salesman where in the Allied network the finished product is available, or *where it is in transit or in production* (emphasis added). Once an order is placed, the system then signals the inventory mangers how much of the material should be replaced in stock, what additional quantities should be produced, and how much feedstock should be purchased.' *Industry Week* ('Integrated Manufacturing II; Team Approach Pays Off,' Sept. 29, 1986, p. IM1) discusses early attempts by U.S. MNCs to adopt computer integrated manufacturing systems (CIM), and emphasizes better inventory management as a central goal of CIM.

[11] See, e.g., 'Industries Line Up to Use Bar Coding,' *The Financial Post*, April 6, 1985, p. 34.

[12] That CAD/CAM assists not just design but also logistics planning was noted by *Business Week* ('The Speedup in Automation,' Aug. 3, 1981, p. 58) which noted that 'After years of false starts, America's manufacturers are finally in position to make a stunning leap into total automation. . . . U. S. dominance in CAD technology . . . is a cornerstone of America's thrust in automation, because the data generated by designers and engineers as they fashion products on a CAD system's video screen provide much of the information that is necessary to computerize the overall production planning effort. This includes manufacturing the tools, *ordering the raw materials*, and *scheduling the production runs*.' [emphasis added].

[13] For example, *Computerworld* ('A Global Standard at Black & Decker', March 19, 1986, p. 39) describes the development of such a system at Black and Decker: 'In January 1984 . . . the Manufacturing Planning Control System (MPCS) project was given high priority. . . . the MPCS . . . will put in place global commodity coding methods . . . such standardization will enable someone sitting at a terminal in North Carolina to inquire about the status of certain parts they are getting from a plant in France.'

TABLE I
INDUSTRIES WITH LARGEST INCREASES IN INTERMEDIATE INPUT SHARES

A. Parent's Cost Share for Intermediates Imported from Canadian Affiliate (ND)

		ND Share		
Industry	Code	84–87	92–95	Increase
Other Transport Equipment	379	0.82%	7.79%	6.97%
Chemical Products*	289	0.45%	5.89%	5.44%
Glass Products	321	0.25%	4.01%	3.77%
Computers*	357	0.83%	4.51%	3.68%
Special Industry Machinery*	355	1.39%	4.04%	2.65%
Motor Vehicles and Equipment*	371	3.54%	5.94%	2.40%
Lumber and Wood Products	240	0.25%	2.19%	1.94%
Soaps and Cleaning Products	284	0.03%	1.83%	1.80%
Industrial Chemicals*	281	0.54%	2.34%	1.80%
Ferrous Metals	331	0.78%	2.27%	1.49%
Food Products (misc).	209	0.44%	1.65%	1.21%
Construction Machinery	353	5.32%	6.41%	1.09%
Electrical Machinery (misc.)*	369	0.18%	1.25%	1.07%
Rubber Products	305	1.59%	2.48%	0.89%
Refrigeration Machinery	358	0.83%	1.71%	0.88%

B. Affiliate's Cost Share for Intermediates Imported from U.S. Parent (NF)

		NF Share		
Industry	Code	84–87	92–95	Increase
Appliances	363	14.37%	40.94%	26.57%
Medical Instruments	384	11.56%	34.24%	22.68%
Apparel and Textile Products	230	2.31%	15.38%	13.07%
Industrial Machinery	356	23.93%	35.81%	11.89%
Chemical Products	289	6.93%	18.14%	11.22%
Ferrous Metals	331	5.35%	15.18%	9.83%
Paper and Allied Products	265	7.60%	16.02%	8.41%
Soaps and Cleaning Products	284	1.95%	9.49%	7.55%
Nonferrous Metals	335	10.13%	17.39%	7.26%
Furniture and Fixtures	250	20.03%	25.89%	5.86%
Other transportation equipment	379	5.92%	11.62%	5.70%
Plastic Products	308	17.76%	22.86%	5.09%
Rubber Products	305	17.59%	21.89%	4.30%
Computers	357	21.61%	25.47%	3.86%
Motor Vehicles and Equipment	371	22.57%	26.10%	3.52%

Note: Industries indicated with an asterisk are discussed in detail in the case studies section. Industries must have four or more observations to be included in this list. There are 50 manufacturing industries in our data set.

conducted a detailed study of the business press from early 80s through the 90s, reading literally thousands of articles on such topics as logistics management, MRP, inventories, etc. Strikingly, the timing is exactly right for explaining our data; that is, it was precisely in the early 80s that large U.S. MNCs began making serious efforts to implement advanced logistics management, including computer based inventory management, MRP and bar coding systems, and the JIT system.[14] And, as we show below, these

[14] We emphasize 'large' and 'beginning.' The adoption of advanced logistics practices throughout manufacturing as a whole was a very gradual process, and the large U.S. MNCs like GE, Westinghouse, Ford, DuPont etc., typically explored these methods first. Good

efforts are reflected dramatically in the inventory data, beginning right around 1984.

It is important to understand *why* U.S. MNCs became so interested in logistics in the early 80s. In the business press, and management/industrial engineering literatures of the time, the following theme is repeated frequently: In the late 70s/early 80s, U.S. manufacturers across many industries suffered severe market share losses to Japanese firms. Many realized that this was not a temporary problem, but rather a long-term structural problem: Japanese manufacturers were simply more efficient, in that they could produce higher quality goods at lower unit costs than U.S. manufacturers. [See Appendix A of the web supplement for documentation.]

This situation led many U.S. MNCs to send study teams to Japan in the early 80s to learn about Japanese manufacturing techniques.[15] One observation was that the 'quality management' movement had taken a strong hold, as a result of W. Edwards Deming's and J.M. Juran's trips to Japan in the 1950s to teach methods of statistical quality control and total quality management (TQM), and the great receptiveness of Japanese manufacturers to these methods.[16]

discussions of the early efforts by U.S. MNCs to adopt advanced logistics methods can be found in 'Integrated Manufacturing,' *Industry Week*, Sept. 29, 1986, p. IM1, and in 'Catching on; Can Kanban Ban Inventory Blues?,' *Industry Week*, July 26, 1982, p. 21.

[15] Amongst the first to send a study team was GE in 1979 (see 'Can Kanban Ban Inventory Blues?,' *Industry Week*, July 26, 1982, p. 21). Westinghouse set up a 'productivity and quality' center with 300 employees in Pittsburgh to study Japanese methods in 1979 (see 'Operation Turnaround,' *Business Week*, December 5, 1983, p. 12), and sent over 200 managers to Japan in 1982 alone (see 'Can Japanese Magic Work Here?,' *Industry Week*, Aug. 8, 1983, p. 46). Other examples of firms that sent study teams in the early 1980s are: Lone Star Manufacturing, the largest car air conditioner manufacturer in the U.S., who sent teams starting in 1981 (see 'How a Bunch of Texans Found the Eastern Holy Grail,' *The Financial Times*, Oct. 10, 1983, Section I, p. 8), Omark Industries, whose president John Warne visited Japan in 1981 (see 'Why Everybody's Talking About 'Just-in-Time,' *Inc.*, March 1984, p. 77), General Motors (see 'Toyota on GM Deal: Giving Aid to an Opponent,' *The New York Times*, March 22, 1983, Section D, p. 1), and U.S. Steel, Bethlehem Steel, as well as just about all other U.S. Steel makers, beginning in 1980, according to *Industry Week* ('Steel Launches an Invisible Revolution,' March 7, 1983, p. 52). The last article concluded that 'the Japanese were superior in nearly every routine aspect of steel-making,' and, 'what U.S. steel-makers decided they really needed to learn . . . was how to better manage the quality function.' Additional firms hired consultants from Japanese manufacturers. For instance, Inland Steel hired consultants from Nippon Steel in 1985 to teach it TQM (see 'The Push for Quality,' *Business Week*, June 8, 1987, p. 130). Other firms were able to study their own Japanese affiliates or joint venture partners. Examples are Ford and Mazda, who formed an alliance in 1979, and Xerox and Fuji Xerox, who formed a joint venture in 1981 (see 'Friction Free New Export Item: Japanese Quality Control Method Increasingly Finds its Way Abroad,' *The Japan Economic Journal*, June 1, 1982, p. 11). In the early 80s, president Kenzo Sasaoka of Yokagawa HP (YHP), a joint venture partner of Hewlett-Packard that produces electric measuring devices and medical equipment, took the initiative to sell HP on TQM by making several trips to Silicon Valley (*op. cit.*).

[16] See 'Quality: Whose Job Is It?' *Industry Week*, October 18, 1982, p. 54 for a discussion.

Another discovery was that many Japanese manufacturers had logistics and supply chain management practices to far superior those of U.S. firms.[17] This is attributable to Taiichi Ohno's development of the 'Toyota production system' in the 1950s (see Ohno [1988], Shingo [1989], Suzaki [1987], Schonberger [1982], Monden [1981]). This system includes, as one of its key components, the 'just-in-time' (JIT) production system, although the system as a whole is sometimes referred to as the 'lean production system' (see Krafcik [1988], Womack *et al*. [1990]), or just the 'Toyota system.' The JIT system was widely disseminated among Japanese manufacturers in the 70s (see Nakamura, Sakakibara and Schroeder [1998]).

A third discovery was that some Japanese manufacturers used a technique of new product development known as 'concurrent engineering' (CE). The basic idea is to design new products using cross-functional teams, rather than having functional areas perform tasks sequentially.[18] Toyoda Kiichiro implemented CE at Toyota in the '50s.[19] A closely related idea is 'design-for-manufacture' (DFM), where ease of manufacture is considered early in the design process,[20] and the 'product platform' approach, where new product varieties are designed to share many parts in common.[21] The use of CE and product platforms facilitates rapid new product development. And part commonality facilitates use of 'flexible manufacturing systems' (FMS), where quick changeovers between varieties allow one to produce low volume/high variety at low unit cost.[22]

At a deeper level, JIT links all these ideas. The goal of JIT is just as much the elimination of defects (i.e., quality control) as the reduction of inventory, since a key part of the JIT philosophy is that work-in-progress inventories hide quality problems. In contrast, JIT enforces high quality, because just-in-time shipments of defective parts would cause assembly to cease. It is precisely this 'fragility' of the JIT production process that leads to quality improvements, because defects have dramatic effects that are discovered immediately.

[17] See Nakamura and Nakamura [1989] for evidence of lower inventories across a range of Japanese industries.

[18] The sequential approach was typical in American firms in the early '80s. E.g., marketing does market research to determine attributes of a new product, then R&D/engineering design a product with those attributes, then manufacturing determines how the product can actually be produced. This process leads to 'iterations' where downstream departments send designs back up the chain for modification because, e.g., a particular feature can't be easily manufactured. CE reduces iteration by having functional areas work together from the start of the process.

[19] See Womack, James P. and Daniel T. Jones [2003], p. 234–5.

[20] See Dewhurst and Boothroyd [1987] and 'The Best Engineered Part is No Part At All,' *Business Week*, May 8, 1989, p. 150.

[21] See Nobeoka and Cusumano [1995] for further discussion.

[22] See Clark and Wheelwright [1993]. See also Stecke and Raman [1995] for a good discussion of the relationship between the platform approach and FMS, including how part commonality facilitates quick changeovers.

Similarly, JIT is also closely linked with CE. JIT supply requires quick changeovers between producing different varieties of differentiated products (since optimal inventory is increasing in the fixed cost of changeovers). CE facilitates JIT, because engineering and manufacturing must cooperate in the design of a new product in order to build in the parts commonality across varieties that makes quick changeovers, and hence JIT, possible. Parts commonality and quick changeovers also facilitate FMS. Indeed, Willenborg and Krabbendam [1987] surveyed several firms that had implemented FMS, and found that 'in most of the projects studied, management saw the FMS as a means to shift . . . to Just-in-Time production.' Q10

These discoveries about Japanese manufacturing methods created intense interest by U.S. MNCs in improved logistics beginning in the early 80s. Many decided to adopt (or adapt) techniques like JIT, TQM and CE to the North American setting.[23] The gradual adoption of JIT by U.S. manufacturers had dramatic effects. For instance, in Figure 1, we see that the inventory-to-sales (I/S) ratio in U.S. manufacturing hovers in the 15 to 16% range from 1958–1982, with upward blips during recessions.[24] Beginning in 1983, there is a structural break, and a clear downward trend begins that has persisted ever since. From 1983 through 1996, the mean I/S level in U.S. manufacturing dropped from 16.28% to 12.62% (a 3.66 point drop).

The structural break in the early '80s has been noted before (see Kahn, McConnell and Perez-Quiros [2002]), and Alan Greenspan has discussed it as a reason for declining volatility in U.S. output.[25] Greenspan attributes the

[23] The start of these developments coincides very closely with the start of our sample period in '84. Regarding JIT, an article in *Fortune* ('The War on Inventories Is Real this Time', June 11, 1984, p. 20) quoted Charles Haffey, former head of the business survey committee of the National Association of Purchasing Management, as saying, 'Everybody I talk to is exploring ways to adopt it [JIT] now.' And an article in *Computerworld* ('Just in Time Gets Into Gear', March 19, 1986) called 1985 'the year of general awareness of JIT in the U.S.,' and described the marketing of logistics software systems to help implement JIT by Xerox. And, regarding TQM, *Business Week* ('The U.S. Drives to Catch Up,' Nov. 1, 1982, p. 66), quotes Joseph M. Juran as saying: '"What is happening out there is unprecedented. . . . in all those previous decades you could count on two hands the number of U.S. companies where the top management team asked me to meet with them . . ..," but in the past three years he says, "I've had more than 100 top level meetings" with executives of such companies as General Motors, NCR, Xerox, . . .'

[24] The data for both Figures 1 and 2 are from the (annual) NBER-CES Manufacturing Industry Database compiled by Bartelsman, Becker and Gray (see Bartelsman and Gray [1996] for a discussion of the 1985–1991 data). Inventories to sales were defined as inventories divided by the value of shipments. Data were aggregated to three digit SIC codes and matched with corresponding BEA industries. P and T denote business cycle peaks and troughs, respectively, which were constructed using the NBER's business cycle dates.

[25] Federal Reserve Board Chairman Alan Greenspan, in remarks before a symposium sponsored by the Federal Reserve Bank of Kansas City in Jackson Hole, Wyoming, August 27, 1999, entitled 'New Challenges for Monetary Policy', stated that '. . . the dramatic changes in information technology that have enabled businesses to embrace the techniques of just-in-time inventory management appear to have reduced that part of the business cycle that is attributable to inventory fluctuations . . .' It is worth emphasizing Greenspan's point that it is not computers *per se* that reduce inventories, but rather the use of computers to help implement JIT.

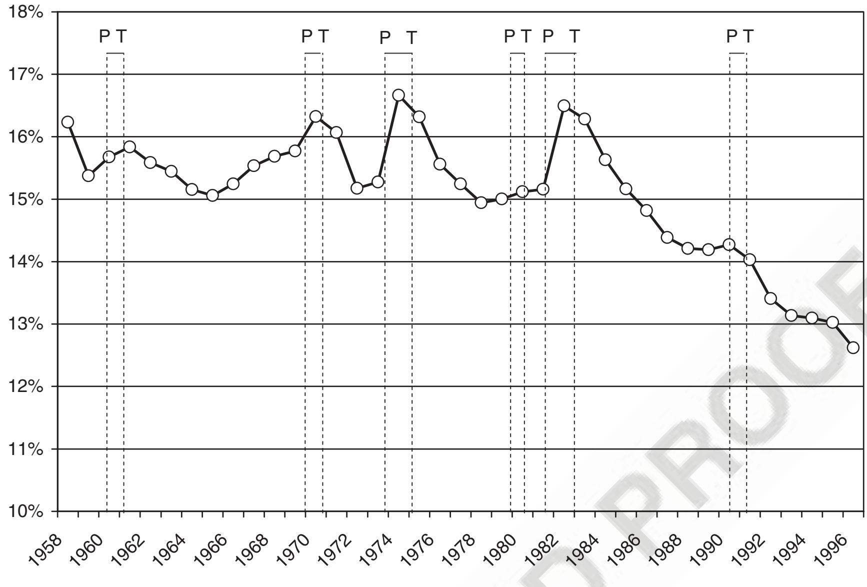

Figure 1
Inventory/sales ratios in U.S. manufacturing, 1958–1996

decline in inventory to JIT techniques, and this is certainly the consensus view in the industrial engineering literature. However, prior literature has not appeared to note the great heterogeneity across industries in the extent and timing of I/S reduction. We present evidence on this point in Figure 2.

Figure 2 presents I/S ratios for several industries over the 1981–1996 period. These industries were not chosen to be representative, but merely to serve as illustrations. In the computer industry, the drop in the I/S ratio in the early part of the period is dramatic – from 28% in 1984 to 16% in 1987 – but it is then rather flat until another sharp drop occurred in 1996. In contrast, in appliances, there is little change until the early 90s. Then, there is a sharp drop from 16% in 1990 to 11% in 1992. Interestingly, our case study of GE (see below), shows that it was precisely in this period that its appliance division made dramatic strides in adoption of JIT. Industrial machinery shows a rather steady but modest drop throughout the period, from 26% in 1984 to 22% in 1994. Non-ferrous metals shows a similar pattern. For both industrial chemicals and autos, there is steady decline in the 1984–1989 period, followed by stagnation.[26]

[26] *Chemical Week* ('How Companies Are Holding Down Inventories', Feb. 8, 1984, p. 28) describes the chemical industry's intense efforts to adopt computer based inventory management and JIT inventory control after the '81–'82 recession. The failure of the I/S ratio in chemicals to improve after 1989 may simply reflect the early adoption of these methods by this industry, so that excess inventory had been largely wrung out of the system by 1989.

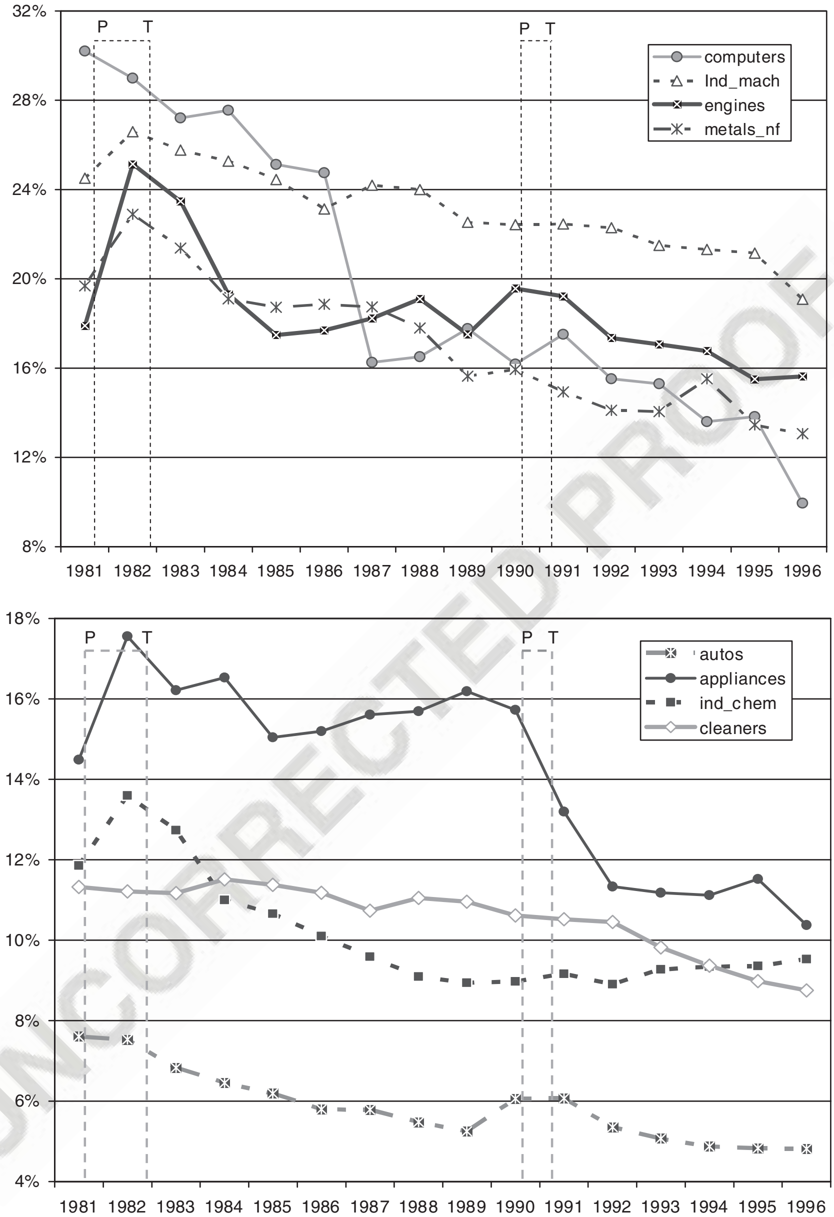

Figure 2
Inventory/sales ratios in selected industries, 1981–1996

This brings us to our second hypothesis. Based on the evidence we have reviewed, it seems clear it was JIT, rather than computers *per se*, that led to most of the I/S reductions we see in Figures 1–2. Indeed, Schonberger [1982] showed that MRP systems only lead to dramatic inventory reductions if they are used to implement JIT. And Toyota originally implemented JIT using the manual 'kanban' system, without computers. Thus, if I/S is a significant predictor of intra-firm trade, it may not reflect technology in the more traditional sense (i.e., computers running MRP systems). Rather, it may reflect logistics management practices (like JIT) that allow any given level of intra-firm trade to be conducted at lower inventory cost. Thus, our *second hypothesis* is that the JIT system led to increased intra-firm trade, rather than IT *per se*. If we find that I/S is significant while IT/S is not, we will take it as support for hypothesis two.

We now turn to a third hypothesis. As noted by Baldwin and Sabourin [2002, p.780], and as confirmed in our case studies, firms that adopted JIT also tended to adopt other advanced management practices like TQM and CE. Indeed, as we have noted, these practices are organically linked, and it is difficult to adopt one of them without the others. Thus, a declining I/S ratio really serves as a proxy for successful adoption of a whole set of advanced management practices. Our *third hypothesis* is that it may not be reduced inventory carrying costs *per se*, but rather some other aspect of the overall JIT system, that led to increased intra-firm trade and the transformation of Canadian affiliates into producers of high value added intermediates.

For instance, as we have noted, the JIT system encourages parts commonality across varieties of differentiated products. In that case, an increase in intra-firm flows of intermediates seems natural, since the components made in one plant could be used to assemble final products across many assembly plants.[27] Of course, we can't distinguish hypothesis three from hypothesis two using only I/S as an indicator for adoption of the whole JIT system in a regression analysis. But our case studies may shed light on which aspects of the system were most important. [In hindsight, based on our case studies and our reading of the operations literature, we are skeptical if it makes sense to ask how much any one aspect of the JIT system increased

[27] Indeed, according to *Industry Week* ('Retained by Ford; Now Sr. Deming is Lecturing Automakers', Aug. 24, 1981, p. 28), Ford President Donald Peterson predicted as early as 1981 that adoption of TQM and common platforms would lead to increased trade in intermediates, as auto makers sought out the highest quality suppliers on a worldwide basis. According to this article: 'Ford President Donald E. Petersen revealed that Ford intends to adopt the Deming method as part of its strategy for the rest of the century. Ford also will break many domestic bonds of dependency for . . . components sourcing . . .. ''In the long run I think that world trade in built-up vehicles will be largely replaced by trade in vehicle components,'' he predicted. ''The car of the future will be a world car not only because of common design wherever it's sold, but also because it will often be built where it's sold, from parts that will come from many countries.''' Ford executive VP Harold Poling made the same basic point in the article 'Why the Auto Parts Companies are Reeling', *Business Week*, June 15, 1981, p. 114C.

intra-firm trade, as the elements of the system are so organically linked – as opposed to being merely correlated.]

Finally, we turn to our fourth hypothesis. A frequent theme in the business press of the early 80s is that, due to market share losses, many U.S. MNCs suffered from severe over-capacity.[28] Thus, they needed to 'restructure' by closing inefficient plants, and 'rationalizing' production across the remaining smaller set of plants. MNC executives frequently emphasized that, under the new climate, every plant in the MNC would have to demonstrate it was 'best-in-class' or a 'center of excellence' in some activity (i.e., a low cost producer of some product or component) to justify its continued existence.[29]

Since Canada is a high-wage, high-skill country, it seems unlikely that Canadian firms could be best-in-class in final assembly, as production of sub-assemblies is typically a higher value added activity. Thus, it seems plausible that restructuring by MNC parents would force affiliates into an 'innovate or die' mode. That is, they had to become efficient (i.e., low cost on a worldwide basis) producers of high value added intermediates, or else they would not survive.[30]

Based on this observation, we developed our *fourth hypothesis*: namely, that the transformation of Canadian affiliates was the result of affiliate innovative activity, motivated by the threat to their existence posed by restructuring of U.S. MNC parents begun in the early 80s. To examine this hypothesis, we included in the regressions Japanese import penetration rates at the industry level, as well as measures of the MNC's sales and sales growth. That is, we wanted to see if the transformation of Canadian affiliates was more pronounced in firms that were under more import pressure, or that were experiencing less growth or even declines in sales. [In hindsight, we see that hypotheses four and two are in fact closely related, since our case studies revealed that 'innovative' affiliates threatened by parental restructuring

[28] See, e.g., 'Restructuring American Industry,' *Business Week*, Nov. 1, 1982, p. 36.

[29] See, e.g., the Ford Motor Company 1987 Annual Report, and Birkinshaw and Hood [1997, p. 351].

[30] This idea is closely related to the traditional view that the Canadian 'branch plants' of U.S. MNCs, originally established in the '20s–'50s to get around Canadian tariff walls, and designed to produce a wide range of products for the small Canadian market, were of inefficiently small scale (see Baldwin and Gorecki [1986], Caves [1990]). This led many observers to fear that Canadian manufacturing would be 'hollowed out' by trade liberalization (see, e.g., White and Poynter [1984], who state that 'Those Canadian-based subsidiaries that have pursued a strategy of tariff-protected, small scale manufacture . . . are threatened by declining import tariffs . . . Many . . . could become simply importing agents for their global parent.'). But the fear of 'hollowing out' is based implicitly on the assumption that MNCs are run from the center, and ignores the possibility that Canadian affiliates might innovate their way out of the problem (which was one strategy suggested by White and Poynter). Our case studies shed considerable light on these notions. To anticipate, it appears that many successful Canadian affiliates both adopted the JIT system, which lets one achieve manufacturing efficiency on a smaller scale, and also developed new innovative products or processes that made them more important to the overall MNC.

frequently adopted a survival strategy of using JIT manufacturing to become a low cost producer of intermediates].

We now examine these four hypotheses, first using regression analysis in Section III, and then, in Sections IV-VIII, turning to case studies of many Canadian affiliates (located in the four largest industries in terms of U.S.–Canada trade), along with reviews of the operations research (OR), industrial engineering, logistics and international business literatures.

III. REGRESSION RESULTS

In this section we discuss our regression results. Our data is from the Benchmark and Annual Surveys of U.S. Direct Investment Abroad administered by the Bureau of Economic Analysis (BEA). These confidential surveys contain the most comprehensive information available on the activities of the *population* of U.S.-based MNCs and their foreign affiliates. The data are described in detail in Feinberg and Keane [2006], so here we give just a brief overview. The data contain detailed information on intra-firm flows between parents and affiliates, as well as third party sales and purchases of materials and labor inputs. They also contain 2-digit level industry information on sales, so that appropriate tariff and transport cost data can be linked. While the data cover the whole population of MNCs and affiliates, we screen it in several ways:

First, we examine MNCs with at least one Canadian affiliate, and use 1984–1995 as the analysis period. Second, we only look at manufacturing affiliates (as intra-firm trade in intermediates is not relevant in services or wholesale and retail trade). Third, as we describe in detail in FK, much of the data on small affiliates is estimated by the BEA rather than actually reported. We deleted most of this estimated data, which accounts for 40% of the observations. Since the eliminated affiliates are small however, this does not have a large effect on aggregate statistics. Finally, we look only at single industry affiliates (so we can assign a relevant tariff), and if an MNC had multiple same industry affiliates we merge them into a composite affiliate.[31] Our final analysis data set contained 446 firms and 2,335 affiliate-year observations.

The first regression that we estimate has the cost share of Canadian affiliate produced intermediates in U.S. parents' production functions as the dependent variable. We call this the 'ND share', following FK's notation (where N denotes intermediate input and D denotes the parent production

[31] The BEA actually classifies 'affiliates' along strategic business unit lines. Thus, for example, a large firm like Ford, might be classified as having many such affiliates, some engaged in manufacturing of various types, others in distribution, etc. As a result, on average 91% of Canadian manufacturing affiliates (as defined by the BEA) had sales in only one industry. The median affiliate sells all output in one industry.

function). The regression has the form (where *i* denotes firm):

$$ND_{it} = \beta_0 + t\beta_1 + t(X_{i,83}, Z_{i,83})\beta_2 + X_{it}\beta_3 + Z_{it}\beta_4 + T_{it}\beta_5 + \mu_i + \varepsilon_{it}$$

$$t = 1984, 1995$$

Here *t* is a time trend. Its coefficient will capture our 'ignorance' (i.e., growth in the share of intra-firm intermediates that the factors included in the model cannot explain).

The key independent variables of interest are included in the vector X_{it}, which contains measures designed to test the four hypotheses listed in Section II, namely, the I/S ratio, the IT/S ratio (from Stiroh [2002]), and the Japanese import share. These variables are entered in the regression in two ways: First, we include the current level (X_{it}). This allows us to determine, for instance, if MNCs that made greater IT investments or had greater success in reducing inventories also had greater growth in the ND share. Second, the initial, 1983, level of the variable ($X_{i,83}$) is interacted with trend. This allows us to determine whether, for instance, firms that suffered a higher level of Japanese import penetration in 1983 had greater trend growth in the ND share. We also entered I/S(t) interacted with I/S(83), because this additional interaction was found to be highly significant (see discussion below).

Besides the variables of interest, we also include a set of control variables that may also influence intra-firm trade. These are denoted Z_{it} and T_{it}. The vector T_{it} contains tariffs and transport costs (at the industry level), and measures of relative factor prices for labor and materials. The vector Z_{it} includes a large set of industry and firm specific variables: the R&D intensity of the industry, the scale of the MNC (as measured by total third party sales in logs), the growth of the MNC (measured as the ratio of sales at time *t* to average sales over the sample period), and several dummy variables to capture the structure of the MNC, such as dummies for whether the affiliate sells to third parties in the U.S., whether the parent exports to third parties in Canada, and whether the parent ships intermediates to the affiliate, and, finally, the size of the MNC's worldwide affiliate network.

As with X_{it}, most of the elements of Z_{it} also have their initial levels, $Z_{i,83}$, interacted with the time trend. Given that we view this exercise as not only hypothesis testing but also as exploratory, the interaction terms $t \cdot Z_{i,83}$ may be informative. For example, if we found that intra-firm trade increased mostly in R&D intensive industries, it would give us a clue about where to look next for the explanation of the increase.

Industries dummies are also included, to account for the fact that different industries may have systematically different levels of intra-firm trade, and all specifications are estimated allowing for firm specific random effects (μ_i), to accommodate the fact that we have multiple observations per firm. The sample size is N = 1756, because only firms with positive ND shares are included. We do this because, as we show in Feinberg and Keane [2005, 2006], almost all the increase in intra-firm trade occurred on the intensive margin.

The regression results are reported in Table II, and a striking result emerges. With a few minor exceptions that we will note later, *the only variable that is both statistically significant and quantitatively important in predicting growth of shipments of intermediates by affiliates to parents is the industry I/S ratio*.[32,33] If we drop firm and industry characteristics from the model, leaving only tariffs, transport costs and factor prices, whose estimated effects are not quantitatively important, the generic trend coefficient (which captures omitted sources of ND growth) increases from .048 to .116. Thus, the factors we have included, such as I/S, 'explain' roughly 60% of the trend growth of intra-firm trade for the average firm.[34]

The quantitative magnitude of the I/S coefficients is difficult to interpret directly, as I/S enters the equation in a rather flexible way. It is entered in level form, I/S(t), and its 1983 level is interacted with trend, I/S(83) trend. Also, its 1983 level is interacted with its current level. This allows not just the absolute improvement in I/S to matter, but also its improvement relative to its 1983 level. The bottom panel of Table II clarifies the meaning of the estimates. There, we calculate the implied change in the ND share under six scenarios: The industry I/S ratio could be equal to, 4 points above, or 4 points below the 1983 average of 16.8%. And the change in the I/S ratio could be -3.66 points (the average decline) or -7.32 points (twice the average decline).

[32] This result is extremely robust to many changes in specification. It is little affected if we use the I/S ratio for the firm instead if the industry, and across a wide range of alternative specifications that involve adding or deleting other variables from the equation, or changing the functional form with which I/S is entered. Also, there is no problem of collinearity between I/S and the time trend, despite the fact that I/S trends down for manufacturing as a whole beginning in 1983. This is because there is a great deal of heterogeneity across industries (and firms) in the timing and extent of the I/S decline. This heterogeneity is apparent in Figure 2. Our results are also little changed if we simply use the ND share of total sales as the dependent variable, rather than the ND share parameter from the production function estimated by FK. These two quantities are very highly correlated.

[33] MNC mean log sales, which is an element of Z_{it}, is significant but time invariant, so it cannot explain growth of intra firm trade. The US/CA material price ratio, included in T_{it}, is significant, but FK present calculations showing its effect is quantitatively very small compared to I/S. MNCs with no arms-length imports and exports had more growth of intra-firm trade, but this is a relatively small fraction of firms, so it does not explain much variance. Finally, IT/S and sales in 1983 are significant, and we argue below that this is consistent with our main argument.

[34] For all variables that are interacted with trend, we always de-mean the variable before constructing the interaction. Thus, the generic trend coefficient retains its interpretation as the generic trend for a typical firm. This trend captures our 'ignorance', since it measures the trend in the ND share that is not explained by any variables in the model.

TABLE II
EXPLAINING THE INCREASE IN ND SHARE

Variable	Coefficient	Std. Err.	T-Statistic
Trend	.0484	.0256	1.89
Trend interacted with X(83) and Z(83):			
I/S (83)	−.0213	.0029	−7.34*
IT/S (83)	.0311	.0139	2.24*
Japan IMP share (83)	−.0017	.0038	−0.44
$R\&D/S$ (83)	−.0001	.0056	−0.02
Log Sales(83)	.0495	.0108	4.59*
No imports to US	.0985	.0305	3.23*
No exports to CA	.1127	.0494	2.28*
NF = 0	.0545	.0590	0.92
Parent industry different	−.0628	.0363	−1.73
Industry Characteristics of Interest – X(t):			
$I/S(t)$	−.1786	.0444	−4.02*
$I/S(t) \cdot I/S$ (83)	.0096	.0027	3.53*
IT/S (t)	−.3376	.1645	−2.05*
Japan IMP share (t)	.0642	.0350	1.84
Control variables for MNC structure – Z(t):			
$R\&D/S$ (t)	.0309	.0532	0.58
NF Share (t)	.0015	.0057	0.27
# worldwide affiliates (t)	.0084	.0042	1.98*
MNC mean log Sales	−.6395	.1704	−3.75*
MNC sales growth $(t/83)$	.0015	.0028	0.55
No imports to US	−.1652	.2131	−0.78
No exports to CA	.6401	.3657	1.75
NF = 0	−.1905	.4384	−0.43
Parent industry different	.2726	.2956	0.92
Tariffs, Transport costs and Factor Prices – T(t):			
US Tariff + transport cost	−.0362	.0462	−0.78
CA Tariff + transport cost	.0577	.0361	1.60
US/CA wage ratio	−.0174	.1663	−0.10
US/CA material price ratio	−.0403	.0163	−2.47*

Note: A * indicates significance at the 5% level. The regression also includes industry dummies and is estimated with random effects. Variables are de-meaned before being interacted with trend or I/S(t) (so the main effects are unaffected by inclusion of the interactions). The sample size is N = 1756 affiliate/year observations on cases where ND is positive.

EFFECTS OF CHANGES IN THE I/S RATIO ON THE ND SHARE

	Coefficient on:		Δ ND from 83 to 96 due to:			Total Δ ND from 83 to 96 if:	
$\overset{\bullet}{I/S}(83)$	Trend	I/S (t)	Trend	Δ I/S = −3.66	Δ I/S = −7.32	Δ I/S = −3.66	Δ I/S = −7.32
0.00	.0484	−.1786	.629	.654	1.307	1.283	1.936
−4.00	.1336	−.2170	1.737	.794	1.588	2.531	3.325
4.00	−.0368	−.1402	−.478	.513	1.026	.035	.491

Note: We define $\overset{\bullet}{I/S}(83) = I/S(83) - \overline{I/S}(83)$.

For an 'average' firm (i.e., average I/S ratio in 1983, average decline in the I/S ratio from 1983 to 1996), the predicted increase in the ND share is 1.283 points. However, a firm with a relatively good I/S ratio in 1983 (4 points below average), and twice the average decline in I/S (7.32 points), is predicted to have a much larger 3.325 point increase in the ND share. And a firm with a relatively bad I/S ratio in 1983 (4 points above average), and only the average decline in I/S (3.66 points), and hence no improvement in its relatively bad position, is predicted to have almost no change in the ND share. Thus, the regression model says that improvement in the I/S ratio *relative* to the manufacturing average is a strong predictor of increasing ND share.

The results in Table II imply that industries where JIT techniques have been most successfully adopted are also the industries where U.S. manufacturing parents have most increased their imports of intermediates from Canadian affiliates. In other words, industries where firms have most successfully restructured to become 'lean' or JIT producers also tend to be the ones where the Canadian affiliates have been the most extensively reorganized into the role of intermediate parts providers. It is worth emphasizing that tariffs and transport costs are not significant in the regression: these factors do not help to explain growth of intra-firm trade.

Some other aspects of the regression results seem consistent with the story that improved logistics and JIT adoption were the key factors that reduced the costs of intra-firm trade:

First, note that the coefficient on IT/S is actually negative (−.3376). There is a strong consensus in the industrial engineering literature that mere adoption of IT, without the substantial changes in management practice and organizational structure needed to implement a JIT system, does not improve, and may actually worsen, logistics management.[35] The regression coefficient on IT/S captures the effect of increasing IT investment holding I/S *fixed*. Thus, a negative sign on IT/S makes sense: if a firm adopts IT but cannot improve I/S, its logistics management is poorly organized. Such a firm could not successfully increase fragmentation of the production process across locations and increase intra-firm trade. This supports our second hypothesis: It was the JIT system, rather than computers *per se*, that reduced the cost of intra-firm trade.

Second, the interactions of time with firm size in 1983 (as measured by log third party sales of the entire MNC) and IT/S in 1983 are both positive. This implies that MNCs that were larger and more technologically advanced in 1983 tended to have larger increases in the ND share over our sample period. This is consistent with our case studies, which suggest that larger and more technically advanced MNCs tended to be the earliest adopters of advanced

[35] See, e.g., Hayes and Jaikumar [1988], Meredith [1987], Willenborg and Krabbendam [1987], Gerwin (1982). *The Financial Times* ('Computers in Manufacturing; The Factory of the Future', June 2, 1987, Survey, p. 21) provides a good discussion of the spectacular failure of GM's massive investment in computer integrated manufacturing (CIM) in the late '70s. The article observes: 'What GM seems to have failed to appreciate is that new technology has to be matched to changes in management and in the way the manufacturing process is organized . . .' See also Drucker [1990, p. 99] on GM. As we noted earlier, Toyota implemented JIT using the 'kanban' system, where physical signals, like empty boxes, are sent back up the chain to signal parts requirements, rather than using sophisticated IT (see Suzaki [1987], Ebrahimpour and Schonberger [1984]. Kim [1985] discusses computerizing the kanban system.

logistics management practices. Prime examples are companies like GE, IBM, UTC, Xerox and Ford, which sent study teams to Japan in the early 80s. By the early 90s, these firms were marketing software to implement advanced logistics management. This facilitated adoption of these methods by the smaller and less technically advanced firms that followed in their path later on.

Third, the Japanese import penetration rate in 1983 was not significant. Thus, there is no direct support for hypothesis four, i.e., that increased import pressure led to affiliate innovation that increased intra-firm trade, *independent* of JIT adoption.

Next, we turn to some additional regression results. In Table III, we use a measure of bilateral intra-firm trade as the dependent variable. That is we add intra-firm sales from affiliate to parent (ND) and intra-firm sales from

Table III
Explaining the Increase in the ND + NF Share

Variable	Coefficient	Std. Err.	T-Statistic
Trend	0.119	0.033	3.60*
Trend interacted with X(83) and Z(83):			
I/S(83)	– 0.021	0.004	– 5.62*
IT/S (83)	0.034	0.018	1.91
Japan IMP share (83)	– 0.002	0.005	– 0.36
R&D/S (*t*)	0.061	0.073	0.84
Log Sales(83)	0.063	0.014	4.56*
No imports to US	0.129	0.039	3.33*
No exports to CA	0.262	0.065	4.03*
Parent industry different	– 0.125	0.047	– 2.67*
Industry Characteristics of Interest – X(t):			
I/ S (*t*)	– 0.257	0.059	– 4.32*
I/ S (*t*) · I/S (83)	0.012	0.004	3.34*
IT/S (*t*)	– 0.571	0.214	– 2.67*
Japan IMP share (*t*)	0.158	0.043	3.63*
Control variables for MNC structure – Z(t):			
R&D/S (*t*)	0.061	0.073	0.84
# worldwide affiliates (*t*)	0.018	0.005	3.40*
MNC mean log Sales	– 0.652	0.214	– 3.04*
MNC sales growth (*t*/83)	0.000	0.004	– 0.13
No imports to US	0.077	0.273	0.28
No exports to CA	– 0.452	0.475	– 0.95
Parent industry different	– 0.041	0.372	– 0.11
Tariffs, Transport costs and Factor Prices – T(t):			
US Tariff + transport cost	– 0.048	0.060	– 0.80
CA Tariff + transport cost	0.050	0.046	1.09
US/CA wage ratio	0.001	0.002	0.29
US/CA material price ratio	– 0.049	0.021	– 2.31*

Note: A * indicates significance at the 5% level. The regression also includes industry dummies and is estimated with random effects. Variables are de-meaned before being interacted with trend or I/S(t) (so the main effects are unaffected by inclusion of the interactions). The dependent variable is the sum of ND and NF, divided by the MNC's total sales to third parties (i.e., the total sales of the parent plus those of the affiliate, minus the intra-firm sales). The sample size is N = 1616 affiliate/year observations on cases where ND and NF are both positive. The generic trend is .205 in a regression that includes only the industry dummies plus tariffs, transport costs and factor prices. Thus, the other variables included in the model reduce the trend by 42%. The mean of the dependent variable is 2% in 1984 and 4.33% in 1995. A model including all observations where either ND or NF was positive (N = 2064) produced very similar (in fact, somewhat stronger) results.

parent to affiliate (NF in FK's notation) and divide by total MNC sales to unaffiliated parties. The results of this regression look very similar to those for the ND share, so we will not discuss them in detail. We simply note that the results imply a strong correlation between improvement in the I/S ratio and increases in overall intra-firm trade.

We also ran a third regression (not reported) with the NF share as the dependent variable. Here, nothing is significant except the generic time trend. We believe this occurs because the NF share may increase for two diametrically opposed reasons: First, NF may increase as an affiliate becomes more integrated into the parent's overall production process. Alternatively, NF may increase because the affiliate is being 'hollowed out' and converted into a low valued added 'screwdriver' factory, with all high value added components imported from the parent. Thus, it is not surprising that NF is uncorrelated with advances in logistics management that enhance the role of affiliates, while ND and ND + NF are both positively correlated with such advances.

Thus, we have found empirical support for the hypothesis that advanced logistics practices like JIT increased intra-firm trade in intermediates. And, as we noted earlier, the operations research literature suggests that this finding makes sense theoretically, because JIT reduces the inventory carrying cost of intra-firm trade. Of course, it is possible that our regression result is spurious – i.e., an omitted variable correlated with I/S actually drove the increase in intra-firm trade. Our case studies will shed light on this question, either by uncovering evidence of a causal link from JIT to intra-firm trade, or suggesting candidates for the omitted variable.

But first, for our result to be credible, we need to dispel a common misperception, prevalent in the late 70s and early 80s, that JIT requires transportation to take place over short distances. This view arose because all Toyota suppliers were once located within the confines of Toyota City, and it suggests that adoption of JIT would lead to less intra-firm international trade. But subsequent developments, like Toyota's worldwide expansion in the 80s and 90s,[36] and the successful adoption of JIT by many U.S. MNCs with international supply networks, debunked this view.[37] Notable

[36] According to Bonney [1994], Toyota's assembly plant in Georgetown, Kentacky, which was producing 1,000 Camry's per day, operated on a JIT system where it received components from Japan five days a week. Liker and Wu [2000] describe how Toyota adapted JIT to the North American context by using 'milk runs' from far flung suppliers.

[37] For example, *The Japan Economic Journal* ('Business and Industrial Setup Differs; U.S. automakers appear heavily handicapped to vie with Japan', June 9, 1981, p.14) reports: 'A Ford spokesman explained, "We receive transaxles from Toyo Kogyo Co. and other parts from all over the U.S. transported by railways and trucks. It is unthinkable for us to bring in only what is necessary for a day's operation at the factory."' But, just a year later, in *Business Week* ('U.S. Automakers Reshape for World Competition', June 21, 1982, P. 82,) we see: '. . . all U.S. carmakers are switching to "just in time" supply methods, . . . the growth of the U.S. auto industry through the 1950s and 1960s left it with a superstructure that today is far from the

examples are Chrysler's assembly plants in Mexico City and Toluca, which are supplied daily from plants across North America,[38] and Ford's Hermosillo Mexico assembly plant that operates on the JIT system.[39]

Hewlett-Packard (HP) provides another excellent example. Lee, Billington and Carter [1993] describe how HP produced the Desk-Jet-Plus at its Vancouver, Washington factory. Many varieties, with power systems and software tailored to different countries, were produced. These were shipped to three distribution centers (DCs) in North America, Europe and Asia. As boat shipments to Europe and Asia take one month, and month-ahead variety specific demand forecasts are uncertain, large buffer stocks had to be held at the DCs. When an internal HP study revealed that the resulting inventory carrying costs were substantial, HP re-designed the product and the manufacturing process to reduce them. The re-design involved 'delayed customization.' Instead of finished products, HP began to ship product platforms, which could be customized by additional local manufacture. In this way, month ahead forecast errors were smoothed over varieties, and buffer stocks were reduced substantially, allowing Vancouver to move toward JIT production of platforms.[40] Physical transport costs were also reduced, since only the common platform component is shipped. This is a

concentrated auto production typical in Japan. . . . But automakers are discovering that they can put together an effective just-in-time supply network anyway, although it may stretch well beyond the 60-mi. limit favored in Japan. The solution lies in proper planning. One example: Before kanban, starter motors built in a GM plant in Anderson, Indiana, were shipped twice monthly in rail road boxcars to a GM engine plant in Flint, Michigan, 240 mi. away. Now GM ships the parts by truck twice a week.'

[38] *The Journal of Commerce* ('Chrysler's Double-Stack Service to Mexico City Set for Restart up, APC to Handle Daily Parts Shipments', Jan. 7, 1991, p. 2B) reported: 'Chrysler's consolidation center in Chicago . . . will generate about seven containers daily from several Midwestern states, truck them to the Chicago railhead and ride south on a mixed-cargo train. At Laredo, the Chrysler shipment becomes a separate train, crosses the border and takes on an FNM crew and locomotive for the final leg. A week or so later, Chrysler will add containers from its Windsor, Ont., parts center, plus more of its direct suppliers. A few weeks after that, a parts center near Detroit will join in.'

[39] *The Journal of Commerce* ('APC Inks Deal to Supply Ford Plant in Mexico, Stack Trains to Boost Output,' August 14, 1989, p. 1A) reported that: 'American President Co. has reached an agreement with Ford Motor Co. to carry 10,000 double-stack containers annually between Detroit and an automotive assembly plant in Mexico. . . . It also will provide logistics and information services and act as a partner in Ford's Just-in-Time inventory system. . . . The move represents a dramatic boost in production at the Hermosillo plant. Output will increase 225 per cent by late 1990 to about 700 vehicles a day from 280 at present. . . . APC will use production reports from Ford to even out shipping flows and will prepare customs documentation. APC's database will be linked with Ford's Daily Material Requirement System. . . . APC will be heavily involved in Ford's inventory and making sure it stays low.' *The Journal of Commerce* ('Mexican Carpets Roll Into Canada by Rail, Ford Saves with Backhaul,' March 15, 1991, p. 1A) also reports that 'The stack operation begins with Ford collecting container loads of auto parts from the upper Midwest and Canada to build the southbound train at APD's facility at Woodhaven, Mich., outside Detroit.'

[40] For example, the buffer stock at the Asian DC could be reduced from 13.4 weeks to 10.6 weeks.

good example both of JIT in a worldwide supply chain, and of JIT logistics causing increased intra-firm trade in intermediates. The case studies in the following sections provide additional examples of JIT networks spanning large distances.

Thus, the idea that a JIT approach reduces the buffer stock of inventories necessary to support any given level of intra-firm trade is just as relevant when long distances are involved. Our view is supported by McGrath and Hoole [1992], who argue that: 'Multinationals . . . can . . . integrate far-flung plants into tightly connected, distributed production systems.' They go on to discuss worldwide coordination efforts undertaken by Xerox, DEC and other firms in the mid-80s to early 90s. They describe their efforts at 'tightening the connection between scattered final assembly, subassembly and component plants', and conclude: 'We have found that *creating a global system analogous to single-plant, just-in-time inventory management ensures the tightest connection*' [emphasis added]. Interestingly, McGrath and Hoole also note that Xerox' decision to rationalize operations globally – which included adoption of JIT, CE based on global design teams, and global parts standardization – was driven by intense competition from Canon and Ricoh during the 80s. Consistent with our results, tariffs are not mentioned as a factor.

Another issue is that adoption of advanced logistics should also reduce coordination costs of transacting with third party suppliers. Thus, why wouldn't it lead to more outsourcing, rather than more intra-firm trade? Of course, our results only imply that JIT increased intra-firm trade. Outsourcing may have increased as well (it is not an either/or proposition). Indeed, our case studies show that increased intra-firm trade and outsourcing were closely related phenomena.

In summary, our regression results support hypothesis two – that MNC adoption of JIT techniques increased intra-firm trade – and the operations research literature also supports this hypothesis, by showing how JIT reduces inventory carrying costs of intra-firm trade (suggesting a plausible causal mechanism). In the remainder of the paper, we turn to the case study evidence, looking at several firms in each of the four largest industries in terms of U.S.-Canada trade.

Four key questions are of interest: Do case studies confirm that tariff reductions did *not* motivate MNCs to increase intra-firm trade? Do they enhance our confidence in hypothesis two, by providing specific examples of a causal link from JIT adoption to increased intra-firm shipments, dispelling concerns that the strong correlation between I/S reduction and intra-firm trade is merely spurious? Do case studies distinguish between hypotheses two and three, clarifying whether JIT adoption *per se*, rather than some other aspect of the JIT system, increased intra-firm trade? Finally, do case studies shed light on *why* affiliates adopted JIT techniques? Was it a survival strategy in the face of competitive pressure on parents, reconciling hypotheses two and four? As we'll see, the cases shed considerable light on these questions.

IV. THE COMPUTER INDUSTRY: IBM CANADA

The story of IBM Canada provides an excellent illustration of how several factors, including adoption of JIT methods and affiliate technical innovation, transformed the affiliate into a supplier of high-tech intermediates for the U.S. parent. An article in *The Financial Post* ('IBM's Child Makes Its Own Way,' May 20, 1995, p. 10) describes the situation that confronted IBM Canada's manufacturing plants in Toronto and Bromont in the 1980s:

> By the 1960s, IBM Canada was an insular operation, making a little bit of everything from clocks to typewriters, mostly for the Canadian market. When the parent started to rationalize manufacturing operations in the late 1960s, the subsidiary's initial mandate was to make key punches, printers and display terminals. Bromont, meanwhile, began to manufacture typewriters. From the 1970s to 1988, the company changed its stripes again and focused on the final assembly of products until it became evident to management that this wasn't a winning strategy.
> . . . Faced with the very real possibility of having both facilities shut down as IBM Corp. dealt with its massive restructuring program, the Canadian executives launched a concerted effort to establish a new mandate. *Part of the problem was that the plants were what's known as 'tops on bottom' – most of the activity involved final assembly as opposed to actual manufacturing of high-tech components* [emphasis added] 'There was no doubt about the fact the plants might have been closed', said Bill McClean, vice-president of manufacturing.
> In 1990, IBM had more than 40 worldwide manufacturing plants and too much capacity. 'We used to double-source and maybe even triple-source things.' McClean . . .. started to lobby for a dramatic change in Canada's manufacturing mandate. . . . The urgency to reinvent itself intensified when the parent decided its manufacturing plants had to compete with each other and with outside players for IBM contracts. . . .

Notice that IBM had already 'rationalized' its North American operations in the 60s and 70s, converting the Canadian subsidiary from 'making a little bit of everything from clocks to typewriters, mostly for the Canadian market' to a manufacturer/assembler of a small number of final products (e.g., terminals, typewriters) for the whole North American market. Tariffs were already low enough by the 70s (i.e., only about 3%) to have encouraged this reorganization.

But then, in a further massive restructuring, the Canadian affiliate was converted to a producer of high-tech intermediates (memory boards, power systems, PCMCIA cards) in the early 90s. In *Instrumentation and Control*

Systems ('Survival at IBM Toronto: Flexibility is Key to Global Competitiveness,' Aug., 1992, p. 45), the managers of IBM Canada described how the transformation was brought about:

> In the mid 1980s, IBM Canada's Toronto manufacturing plant was on the verge of being closed. The company had been building a variety of finished products for IBM – products that included small systems, printers, data collection and display terminals, and printed-circuit boards. Unfortunately, most of the products were nearing the end of their life cycles. At the same time, IBM Corp. was working on eliminating some of its excess manufacturing capacity and considering a number of plant closings throughout North America. This combination of circumstances put the Toronto plant in serious jeopardy.
>
> Determined to stay in business, our management took aggressive steps to make our plant the most competitive manufacturer in the industry, based on the competitive edge of exclusivity. *We phased out most of our existing product lines and explored specialization in the manufacture of electronic card assemblies*. . . to succeed . . . we had to re-engineer our entire business to compete not only within IBM, but also globally based on product quality, delivery, and cost. . . .
>
> The transition, over the past seven years . . . required extensive innovation and automation of several processes. For example: *We pioneered full double-sided surface mount within IBM*. A simple, cost-effective process has been developed that yields high-quality results . . . Advanced automation and information systems have been instrumental in our plant's successful transformation . . .Computer-aided design/computer-aided manufacturing (CAD/CAM) . . . enable us to speed up product design. *Concurrent engineering, continuous-flow manufacturing (CFM) and just-in-time (JIT) inventory systems have been implemented to cut cycle time and manufacturing costs* . . . [emphasis added]. Communications with suppliers and customers are now expedited via electronic data interchange (EDI).
>
> . . . we have installed flexible production lines that can be changed as quickly as products change – overnight, if required . . . We have developed what we call focused mini-factories. These consist of assembly lines dedicated to product families. We have grouped the equipment needed to produce these families on the lines while retaining the flexibility to adapt to product changes very quickly . . . This allows us to tune the line to achieve optimum cycle time, inventory turns and improved quality.
>
> To establish mini-factories that would improve our cycle times, we needed just-in-time parts deliveries. This, in turn, required supplier quality certification. To prepare for the introduction of JIT in our plant, we spent more than two years implementing process control methods in our suppliers' plants. This effort was necessary because, with suppliers now delivering parts directly to our production lines, the parts need to be defect-free to avoid disruptions to the production flow . . . .
>
> The results of the transformation process begun in 1986 have amply

> justified our approach to plant re-engineering and [computer-integrated-manufacturing] CIM implementation. Productivity at the Toronto plant has improved dramatically. Plant support headcount has been reduced, from 1,200 in 1982 to just more than 400 in 1991, while production has increased. Production volume today is more than four million electronic card assemblies per year, quadruple what it was in 1986. The number of customers also has grown four-fold or more, and so have the number and complexity of our products – from 400 finished part number assemblies in 1986 to more than 5,000 in 1991. Finally, Toronto plant output, as measured by revenue, also has been on a very strong upward trend, from $350 million (U.S.) in 1986 to $1.2 billion (U.S.) in 1991.

Following its transformation into a producer of high value added intermediates, the Canadian affiliate played a much more important role within IBM. According to *Newsbytes* ('IBM Toronto Plant Sets Export Record', Feb. 8, 1990), 'IBM Canada's Toronto factory . . . exported C$1.085 billion worth of memory cards and power systems last year, including the first cards to use IBM's four-megabit memory chips. The plant's production is used across most of IBM's product range. Most of its output is shipped to the United States where it is incorporated into finished systems', and, according to *Canadian Corporate News* ('IBM Invests $150 Million in Bromont Plant,' Nov. 29, 2000), '. . . Bromont is IBM's largest microchip assembly facility worldwide. It performs the majority of IBM's value-added internal assembly and test operations for its most technologically complex products. Tens of millions of chip packages were produced in Bromont in 1999, making IBM Bromont one of Canada's major exporters.'

The key role of JIT in these developments is well captured by the following excerpt from an article in *The Globe and Mail* ('The Borderless World', July 6, 1996, p. D1, by Greg Ip):

> Every few hours, a tractor-trailer loads up with microprocessor chips – the personal computer's 'brains' – at IBM's plant in Burlington, Vermont, and heads up the highway to Bromont. There, engineers and technicians, clad in white and blue lab coats and masks' working in space-age 'clean' rooms, install each chip in the dense, electronic packaging that will connect it to the rest of the computer. When the chips have been packaged, the majority are sent back to Burlington for further installation in computers. *There is no warehouse, no inventory* [emphasis added]. Doug Gregory, an IBM spokesman, says: 'We look at it as one long production line, 160 miles long, and it just happens to have an international border between one end and the other.'

Sullivan and Fordyce [1990] describe the complex logistics system used by Burlington to regulate the progress of batches of chips. This computerized dispatching system insures that batches are processed and shipped to customers (like Bromont) on a just-in-time basis.

In summary, the IBM case is an excellent example of our basic argument. Tariffs are never mentioned as a reason for restructuring the Canadian affiliate. Rather, IBM's global excess capacity created pressure on the affiliate, which induced both technical innovation and a shift to efficient JIT production. Both these factors transformed the affiliate into an efficient supplier of high value added intermediates to the parent. The IBM case illustrates why we can't separate the roles of JIT and affiliate innovation, as proposed in hypothesis four. The Canadian affiliate realized that, in order to survive, it had to develop a new product *and* use JIT to produce it efficiently. We cannot sensibly say that one factor or the other increased intra-firm trade.

V. THE AUTO INDUSTRY: FORD MOTOR COMPANY

As tariffs on autos and auto parts were eliminated by the 1965 Auto Pact, Ford operations had long been 'rationalized' on a U.S.-Canada basis. In the 80s, Ford Canada made cast iron engine blocks and produced V6 and V8 engines at casting and engine plants in Windsor, Ontario, and assembled the Tempo and Topaz in Oakville, Ontario. Most of these engines and cars were shipped to the U.S. But Ford Canada was transformed in the early 90s, becoming a far more important supplier of intermediates – engines and engine blocks – to the parent.

Major auto assemblers outsource production of many parts, but they generally view the powertrain as 'strategic' (i.e., a core competence), and develop and manufacture it in-house.[41] In 1990, Ford began to invest billions of dollars in new, state-of-the-art aluminum casting and engine production facilities in Windsor. This led to substantial increases in intra-firm trade. By 1996, the Windsor engine plants were producing roughly 60% of the engines for all Ford cars and trucks assembled worldwide, shipping to 10 assembly plants in North America, Europe and Australia. More importantly, these engines powered Ford's most popular vehicles, such as the F-series pickup trucks.[42] By 1994, the Windsor aluminum plant produced engine blocks for Ford engine factories in Windsor, Cleveland,

[41] A prime example of a 'non-core' activity outsourced by Ford was painting of cars assembled at Oakville. In 1991 they contracted out the entire operation to the Swedish conglomerate ABB. But, as Frey and Schlosser [1993] describe, this was far from an arms-length, purely market mediated transaction. ABB built a $300 million dollar plant directly connected to the Ford plant, and the arrangement involved tremendous sharing of information and personnel (consistent with our characterization of much of the outsourcing of the '80s and '90s in the introduction). Q6

[42] See 'Ford Plans $2 Billion Spending Spree,' *The Financial Post*, April 14, 1992, p. 3, and 'Ford Readies Engine Plant,' *Plant*, April 4, 1994, p. 11.

and Romeo, Michigan. The Cleveland plant, in turn, made the engines for Ford's new 'world cars', whose important strategic role we discuss below.[43]

Why did Ford decide, in the late 80s, to locate these important new facilities in Windsor? Clearly, no tariff reductions suddenly made it desirable to concentrate production of engines in Canada. Ford already had an engine plant in Windsor (No. 1), which at its peak in 1978 produced roughly half a million engines a year[44]–already a substantial share of all Ford engines, though far short of the combined 1.5 million engines per year that it and the new plant (No. 2) would eventually achieve (by 1999).[45] Fixed specific capital assets cannot explain the decision either, as existing outdated Windsor facilities were demolished to make room for the new plant. We now describe the factors that led to the choice of Windsor, and explain how they are related to JIT.

To begin with, Windsor had three location-specific advantages for aluminum casting and aluminum engine manufacture: First, since Ford had casting and engine plants in Windsor since the 1920s, there was a skilled labor force, including both blue collar workers and engineers, with experience in casting and engine production. Second, Canada's substantial endowment of aluminum, and Ontario's cheap hydroelectric power, make it a good location for aluminum casting. Third, engineers at Ford's Cast Aluminum Research and Development (CARD) facility in Windsor made a key technological advance that helps explain the choice of Windsor.

In 1990, CARD engineers, in a joint project with Cosworth in England, invented a mass-production process for aluminum blocks.[46] Previously, Cosworth had produced aluminum blocks on a small scale, to make high-performance engines for Formula One racecars. The advantage of aluminum (as opposed to iron) is to reduce engine weight (by 50 to 60%), which increases gas mileage. As this engineering expertise and a skilled labor force were both based in Windsor, it made sense for Ford to build the world's most advanced aluminum casting plant there in 1990.

Within just a few years, production of aluminum blocks in Windsor exceeded 1 million per year, and these became the basis for Ford's new 'modular' aluminum engines.

The technology of the modular engine is the next thing we need to explain in order to understand how Ford's engine production became so

[43] See 'Ontario Premier Dedicates Ford Windsor Aluminum Plant,' *Canada Newswire*, Oct. 5, 1994, and 'Ford Plant Gets Product Mandate,' *The Financial Post*, Feb. 18, 1994, p. 6.

[44] See 'Engine Tribute Marks Plant Closing', *Canada Newswire*, Nov. 15, 1996.

[45] See 'Ford Establishes New Record with 1.5 Million Made-in-Canada Engines,' *Canada Newswire*, Jan. 6, 2000.

[46] See 'U.S.: Ford Eyes U.K. Techniques for Aluminum Auto Engines', *Advanced Manufacturing*, Feb. 26, 1990, 'What a Difference an Engine Mold Makes', *Plant*, May 22, 1995, p. 10, and 'Ford Bets Big on Cosworth Process for New Castings', *Automotive News*, May 3, 1993, p. 4.

concentrated in Windsor. Prior to the early 1990s, one Ford engine plant would produce one type of engine. Changeovers needed to produce a different type of engine were so expensive and so time consuming that they did not make sense, unless they were meant to be permanent. But in the early 1990s, Ford developed modular engine technology. A modular engine is one where cylinders are attachable. Thus, by using FMS in conjunction with modular technology, one can produce V6, V8 or V10 engines on the same production line, with fairly quick and inexpensive changeovers between types.[47,48]

Now, a key point is this: The desire to adopt JIT is what motivates the development of modular engine technology, and the greater production flexibility it allows.[49] Say Ford produces trucks that use V8 or V10 engines, and a car that uses the V6. Using traditional methods, if the trucks sell well but the car does not, it leads to excessive inventories of V6 engines, or the parts used to make them, since the product-cycle for the car would have begun many months earlier – with parts orders based on sales forecasts. In contrast, with modular engine production, one can switch over the plant to produce more V8s and V10s and fewer V6s, thus avoiding inventory buildup. Of course, the fact that Ford chose Canada to place this flexible plant – which produces engines for so many different cars and trucks – led to increased intra-firm trade.

Ford's decisions to locate aluminum casting and modular engine plants in Windsor can also be viewed as part of a larger strategy, which included both adoption of JIT methods and a more globally optimized production process. According to Ford's 1987 annual report:

> The foremost charge of the Ford Automotive Group is to . . . become a low-cost producer of high-quality products . . . Ford operations plan to share the strengths of worldwide 'centers of excellence', wherever they may be. A vehicle or component will be developed by the company or supplier operation best equipped to handle the job.

[47] As Stecke and Raman [1995] note, there are many definitions of FMS in the literature, and many dimensions of 'flexibility' (i.e., they list 11 possible dimensions). By some definitions, the Windsor plant might not be viewed as an FMS because it can only produce a few types of engine (i.e., it lacks the flexibility to produce a completely new type of engine without major investments). We adopt the broadest definition, by which FMS just means a system with low changeover costs between several pre-specified varieties.

[48] Ford developed the flexible manufacturing system (FMS) used at the Windsor aluminum plant in conjunction with Lamb Technicon, a machine tool maker based in Warren, Ontario (see 'Engine Propels Big Deal: Lamb's Ford Pact Sets Record', *Crain's Detroit Business*, July 25, 1994, p. 1). Such FMS technology was rare to nonexistent in the U.S. prior to the mid '80s (see, e.g., Jaikumar [1984]).

[49] As discussed by Shingo [1989], rapid changeovers are central to successful JIT implementation. Willenbourg and Krabbendam [1987] find that most firms view FMS as a *means* for implementing JIT, rather than an end in itself.

In an interview in *Modern Purchasing* ('Lighting the Way to the Future,' Jan./Feb. 1993, p.15), a senior executive at Ford Canada stated:

> The . . . program of expansion and modernization we have launched in Windsor and Oakville . . . were not handed to Canada on a silver plate. . . Our team earned it. As you can appreciate, multinational companies such as Ford have many choices . . . where to assign the production of new products.

Thus, in Ford's 'centers of excellence' strategy, Ford Canada in Windsor was chosen as the global supplier for Ford's most important engines. But, as Quinn and Hilmer [1994] note, under this same strategy Ford also outsourced many activities to third party suppliers.

A closely related development was Ford's strategy to globally standardize components (i.e., the 'product platform' strategy), announced in the 1989 Annual Report:

> In the past, Ford developed different products for individual markets. Now the strategy is turning toward common product-development programs. The objective is to design and engineer vehicles with common platforms and powertrains whose driving characteristics and exterior and interior designs can be easily modified to meet the needs of different markets.

Ford referred to this strategy as the 'world car' program.[50] The first product of this strategy was the Mondeo, introduced in 1992. According to Ford's 1993 annual report:

> Global product development allows us to build essentially common products for a variety of markets from one basic platform, using the best practices from around the world and eliminating duplication of effort. For the customer, that will mean a greater variety of higher-quality vehicles, with more features and better value, introduced at a faster pace . . . in today's world, development of truly 'global' vehicles – cars and trucks that minimize duplication and maximize resources across continents – is becoming essential. If we produce cars for consumers in New York and Tokyo, Frankfurt and Mexico City, *we can reduce development costs by using common components and the same basic platforms*. [emphasis added]. In 1994, the Ford Contour and Mercury Mystique, which, along with Mondeo, are the result of Ford's global development program, will debut in North America. They will be powered by two new engines, the four-cylinder 'Zetec' and the V-6 'Duratec.'

[50] Lee, Billington and Carter [1993] refer to this strategy as 'delayed customization.' Lee [1996] notes that the concepts of delayed customization, design for manufacture and part commonality (the product platform idea) are all closely related, and discusses how part commonality and delayed customization lead to reduced inventories.

It is important to note that the Duratec was a modular aluminum engine produced in Ford's Cleveland, Ohio' engine plant, using aluminum engine blocks cast in Windsor.[51]

Consistent with its moves towards global sourcing, in 1995 Ford took the step of merging its worldwide automotive operations. According to the 1994 Annual Report:

> We merged our North American . . . and . . . European Automotive Operations into a single organization, Ford Automotive Operations . . . on January 1, 1995. . . . We made this change because we foresee a fiercely competitive environment that will demand higher standards of performance in the future. We can't allow human and financial resources to be wasted duplicating vehicle platforms, powertrains and other basic components that serve nearly identical customer needs in different markets. For example, in the future we'll have one small-engine family in Europe and North America, instead of two separate families that power the same kind of car for the same kind of customer . . . This doesn't mean we're going to ignore . . . local customer preferences. Even with under-the-skin components that may be identical, the design and feel of our vehicles can be made very different to suit local tastes. But instead of organizing ourselves by geography with regional profit centers, we're organizing our global automotive business by product line.

As Ford's statements consistently make clear, it was intense international competition (especially from Japanese firms), which drove its overall strategy. To compete, Ford needed to: (1) shorten new product development cycles, (2) raise quality, and (3) lower costs. This led Ford to adopt CE and the platform approach to new product development, standardize strategic components, and adopt the 'centers of excellence' approach to global sourcing. It also led Ford, like the other U.S. automakers, to implement JIT techniques to reduce costs and raise quality. All these developments are closely linked. As we've noted, JIT requires quick changeovers, so the global parts standardization that resulted from the 'world car' program didn't just speed new product development – it also facilitated JIT. Thus, the decision to concentrate engine production in new flexible manufacturing facilities in Windsor in the early 90s was one manifestation of a general strategy that linked JIT, CE and global part standardization. No statement we can find, by Ford executives, or any industry observer, ever mentions tariffs as a factor in these decisions.

[51] At the time, the Duratec was considered a significant advance. According to *The Financial Post* ('Ford Adopts "Think Small" Strategy for Engines', Nov. 5, 1994, p. A16), '"It is very significant in that it is the first smaller V-6 that is a high-tech engine built by the Big Three," says Brett Smith, research associate with the University of Michigan's Office for the Study of Automotive Technology. "It is the first engine to really be on a par with things done by the Japanese in this class."'

The following statement by Ford CEO Alex Trotman on March 9, 1995, illustrates the central importance of more rapid new product development to Ford's strategy:

> Ford now has more new or significantly improved products in its development pipeline than at any time in its history. Because of our new global alignment, we've already been able to increase our product development capability substantially . . . We're also making major progress in shortening our product development cycles and reducing development costs.

Technical advances in communication technology made during the 80s facilitated the 'world car' strategy. Central to Ford's plan to speed new product development was CE using *global* cross-functional design teams. Ford understood that a local team could not design a 'world car.' To understand how to tailor a product to local tastes in a number of target markets, the design team needed representatives from many geographic regions. Fortunately, in the mid-80s, CAD and advanced communication techniques (like video conferencing) were making it possible for worldwide teams of marketers, engineers, assemblers, etc., to collaborate on producing 'global products.' Ford's 1988 and 1989 annual reports describe the implementation of these systems, which were installed in autumn 1987. According to the 1989 report:

> Ford's global new-car programs are aided by the Worldwide Engineering Release System (WERS), a computerized global communications network. Through WERS, approximately 20,000 Ford people around the world share design and manufacturing information as they develop new products. The system expedites communication, reduces paperwork and travel, and cuts the time it takes to bring products to market.[52]

The Ford annual reports from '95 through '97 describe how the 'world car' strategy led to dramatic increases in the number of common components across Ford vehicles,[53] enabling the company to cut product development time substantially and introduce many new models, while generating

[52] Harris [1995] discusses how reduced communications costs can lead to increases in intra-firm trade in services, in this case, engineering services. He emphasizes that much of the cost of communications is fixed – as in this case where Ford bears a fixed cost of installing the WERS system, after which the marginal cost of communication is low. We are making the additional argument that lower communication costs also increase intra-firm trade, since international design teams develop products with more common components. Jones and Kierzkowski [1990] also argue that reduced communicated costs can lead to increased intra-firm trade in intermediates.

[53] For example, according to the 1997 annual report, '. . . the new Mercury Cougar has a unique New Edge design to help it attract younger buyers . . . But Cougar was. . . based on the Mondeo/Contour/Mystique platform and shares about 70 per cent of its components with those vehicles. That makes it a very cost-effective investment.'

substantial cost savings. Over this period, Ford's nominal costs of production actually fell, despite increased volume and product variety.[54] Miller [1994] interviewed 41 senior executives at 20 auto firms, and concluded that a drive towards faster new product development and greater product differentiation led most of the world's auto firms to adopt CE, a world car strategy, and common platforms in the early 90s. Haddad [1996] and Womack and Jones [1994] describe Chrysler's adoption of CE, common platforms, and other aspects of the JIT system, in 1990. Thus, what we are saying about Ford generalizes to many other auto firms.

The Ford case, like that of IBM, illustrates how adoption of JIT went hand-in-hand with other industrial engineering innovations like FMS, CE, product platforms, and global component standardization, as well as affiliate technical innovation. All these factors work together to increase the integration of the affiliate in the parent's production process, increasing intra-firm trade. As in the IBM Canada case, Ford Canada needed to both innovate (i.e., develop the new aluminum block) *and* adopt JIT (to become the low cost producer) in order to become the key strategic source of engines to the parent. Thus, like the IBM case, the Ford case illustrates why one cannot pinpoint just one of these factors as the sole 'cause' of increased intra-firm trade.

Nevertheless, we again emphasize that the JIT philosophy links all these factors. Indeed, CE can be viewed as the extension of JIT to the new product development process. A central idea of JIT is to organize the production process to achieve 'single piece flow' – that is, to organize the plant around products rather than grouping machines by function. Applied to the organization as a whole, this means breaking down functional barriers to organize people around products. This is precisely what is done in the CE approach to product development. That JIT leads to such broad systemic

[54] A drawback of Ford's strategy was revealed in 2002, when they tried to shut down their Oakville, Ontario' assembly plant. According to *The Detroit Free Press* ('Plant Gives Canadian Union Leverage in Upcoming Talks with Ford,' Sept. 24, 2002), '. . . Ford Motor Co. is between a rock and a hard place in the coming Canadian Auto Workers talks. . . *Ford's Windsor Engine plant . . . feeds into about 10 North American Ford assembly plants, from Michigan to Mexico to Missouri* [emphasis added]. If it were to shut down as part of a CAW-wide strike, assembly on most of Ford's most profitable and popular vehicles would grind to a halt within days. F-series pickups, luxury sport-utility vehicles like the Navigator and Expedition, and the Econoline full-size van all get their engines from there. "It is singularly the most important engine plant that Ford has in the world," says Michael Robinet, vice president of global forecasting for CSM Worldwide, a Novi auto-research firm. . . . Ford Motor Co. President . . . Nick Scheele acknowledged . . . "If we are struck in Canada for a protracted period of time we essentially shut down North America."' In fact, in the new contract announced on October 7, 2002, Ford not only agreed to keep the Oakville assembly plant open, but to invest $379 million U.S. to modify it to produce the next-generation Ford Windstar and the new Mercury Monterey.

change has been stressed by Drucker [1990], among others, and is well illustrated by the case study in Kachur [1989].[55]

VI. THE CHEMICAL INDUSTRY

The chemical industry has a relatively high level of intra-firm trade (see Kobrin [1991]), and Table I shows that industrial chemicals had a large increase in the ND share. Furthermore, this industry also exhibited a substantial decrease in inventory/sales ratios in the post-82 period. Thus, we decided to examine several large firms in this and related industries in some detail, as well as examining the evolution of the industry in general. In the late 70s and early 80s, the chemical industry faced problems of excessive inventories and low capacity utilization similar to those experienced by the auto industry. An article in *Business Week* ('Restructuring American Industry', Nov. 1, 1982, p. 36) provides a good description of the situation:

> Eighteen months ago, chemical-company executives were lamenting the industry's idle capacity; in 1980 and 1981, capacity utilization fell below 80% . . .. Some began wishing that competitors would close their plants. But now, with facilities operating at about 70%, the wishing has given way to action. Chemical producers are shutting down archaic facilities and shedding noncompetitive business. Dow Chemical Co. has closed ethylene plants in Plaquemine, Louisiana, and Freeport, Texas. . . .. By one estimate, no fewer than 17 U.S. chemical firms are in the process of restructuring their operations to improve profitability.

The article goes on to describe the predictions of Paul Oreffice, president and CEO of Dow Chemical, for the future course of the industry:

> Lured by relatively inexpensive feedstocks, *U.S. chemical companies will be shifting some basic-chemical production capacity from this country to Canada, Saudi Arabia, Mexico and other lands*. 'That doesn't mean', he advises, 'that the U.S. is going to shrivel up and disappear as a chemicals and plastics force.' Rather, *domestic chemical plants will shift farther downstream in the production process* – concentrating more on products like agricultural chemicals, pharmaceuticals, and household items [emphasis added].

[55] According to Drucker [1990], '. . . with just-in-time deliveries, the plant . . . must be redesigned from the end backwards and managed as an integrated flow. . .. Just-in-time delivery . . . forces managers to ask systems questions.' He goes on to say: '. . . it becomes clear that producing does not stop when the product leaves the factory. Physical distribution and product service are still part of the production process and should be integrated with it. . . . Servicing the product must be a major consideration during its design . . . [these considerations lead to] a parallel team organization . . . which brings various functions together from the inception of a new product . . .'

This scenario of basic-chemical production shifting to Canada, and U.S. plants shifting further downstream, is consistent with the increasing ND shares we see for the chemical industry in our data (see Table I). As was the case with autos and computers, restructuring was not driven by tariff reductions, but rather by a state of inefficient organization and excess capacity that existed in the early 80s. To understand the scenario, one needs a bit of background on the chemical industry.

Much of the modern chemical industry involves conversion of petroleum 'feedstocks', such as natural gas, into ethylene and propylene. These intermediate petrochemical feedstocks are subjected to catalysis, to convert them into polymers (i.e., polyethylene and polypropylene plastics or resins). Tremendous advances in polymer chemistry occurred during the 80s and 90s. For instance, a key development was the so-called 'metallocene revolution', which began with Ewen [1984].[56] As described by Ewen [1997], this and other fundamental advances have allowed chemical engineers to design plastics with an amazing range of properties (e.g., strength like metal, heat resistance, lightness, flexibility, rigidity, conductivity, etc.). For example, according to GE's 1987 annual report, 'a joint project with BMW . . . created the world's first production car with all vertical body panels made with thermoplastics. The GE materials provide lighter weight, more design flexibility and better resistance to impact and corrosion than metal.'

Demand for polymers grew far more rapidly than GDP during this period. This translated into rapidly expanding derived demand for ethylene and propylene, and the feedstocks from which they are derived. This is where Canada comes into the picture, as, in the 80s and 90s, Alberta was the best place in North America to obtain these petrochemical feedstocks.[57] Thus,

[56] According to his citation for the 2001 National Medal of Technology: 'John A. Ewen's basic discoveries and inventions in the field of metallocene catalysis have revolutionized the production of polyethylene and poly-propylene plastics . . . stimulating the growth of the entire industry. . . . Before Ewen's work . . . chemists had little control over the features of the polymers they made. Ewen made new catalysts . . . that gave chemists precise control . . . Catalysts can now be confidently designed to yield polymers having a wide array of desirable properties for several specific applications. Ewen's publications and patents since 1984 have been largely instrumental in . . . this profound technological change in the plastics industry.' ExxonMobil first commercialized metallocene catalysis for the production of polyethylene plastics at its Baton Rouge plant in 1991. Another key event was Dow Chemical's development of the Insite® constrained geometry metallocene catalysis process in the early 1990s, allowing greater control over the polymerization process. By 1993, Dow's polyethylene production facility in Freeport, Texas, was converted to produce polymers using the Insite® process (see Dow's 1993 annual report). Interestingly, Dow emphasized that the strategy used to develop the technology – concurrent engineering – was just as revolutionary as the technology itself. They called it 'Speed Based Development.'

[57] Unlike oil, which is traded globally, natural gas has historically been a regional commodity with wide variation in price across regions. Historically, Alberta has had relatively low natural gas prices (although this has not been true recently). Recent advances in liquefaction are beginning to make transport of natural gas easier.

the chemical industry made massive investments in new 'world scale' ethylene and propylene plants in Alberta in the 80s and early 90s. For instance, according to Dow's 1988 Annual Report:

> The company is . . . taking steps to assure reliable, low-cost supplies of basic products. Between now and the mid-1990s . . . it will add about two billion pounds of ethylene capacity in new 'world scale' facilities in North America. The increased output will be used to meet the company's internal demands for ethylene, which is a basic building block of many of its products . . . Dow Canada announced that it would proceed immediately with engineering for a world-scale ethylene plant . . . in Fort Saskatchewan, Alberta.

When the Chemical Institute of Canada chose the top 20 Canadian chemical engineers of the 20th century, one was James Miller Hay, described as 'the Dow executive directly responsible for the . . . design . . . of new world scale plants to produce ethylene. . ., chlorine, caustic soda, vinyl chloride, polyethylene, ethylene oxide and ethylene glycol . . . at Dow's Fort Saskatchewan, Alberta, site. These facilities were key to developing Alberta's world scale petrochemical presence.'[58]

These developments had major effects on U.S.-Canada trade. According to *Canadian Chemical News* ('Deloitte & Touche Report on Canada's Chemical Sector,' Oct., 1996, p. 10):

> In 1994, imports made up 49% of the domestic market, rising to 53% in 1995; they were composed largely of *specialty and formulated chemicals tailored for specific end uses. Exports tend to be commodity products*, accounting for 39% of factory shipments in 1994 and 38% in 1995. The U.S. is the primary recipient of these exports, receiving over 78%. In turn, the U.S. accounts for 77% of Canada's chemical imports. . . . Over the ten year period 1985–1995, the volume of both imports and exports grew. Imports from 29% to 53% of the domestic market, while *exports went from 24% of factory shipments to 38/39%* [emphasis added]. These trends . . . reflect the ever-increasing globalization of the chemical industry.

And *Canadian Chemical News* ('Canadian Synthetic Resins Industry,' June, 2000, p. 29) noted:

[58] See 'Century of Achievement Award Recipients', *Canadian Chemical News*, Jan. 2000, p. 28. The reader may be surprised that we discuss individual plants. But it should be emphasized that the output of such 'world scale' plants is so vast that bringing one on line substantially moves the trade numbers. For example, according to *Chemical and Engineering News* ('Canada', Jan. 10, 2005, p. 19), total ethylene production in Canada was 9 billion pounds in 2000. A single 'world scale' ethylene plant produces at least 1.5 billion pounds per year, and according to Dow Canada's web site, the Fort Saskatchewan facility produces 2.4 billion pounds per year. In contrast, total ethylene production in Canada in 1983, prior to the opening of the new Alberta plants, was only 2.6 billion pounds (see 'Canadian Chemicals See Rising Demand', *Canadian Chemical News*, April 16, 1984, p. 21).

> Canadian exports of synthetic resins have grown dramatically during the 1990s, from 40 per cent of total shipments in 1990 to 64 per cent in 1999. Canadian imports of resins have also increased significantly during this period and by 1999 captured about 68 per cent of total domestic consumption. *This growth in two way trade reflects rationalization and specialization of the resins industry on a North American basis, and the increasing use of complex, higher-performance engineering resins that are not manufactured in Canada* [emphasis added] . . . Companies are investing heavily in new resin capacity in Alberta due to a feedstock price advantage compared to other North American locations.

As these statistics highlight, the forecast by Dow's Paul Oreffice basically came to pass. The chemical industry was rationalized on a North American basis in the 80s and 90s, with the Canadian plants focusing on commodity chemicals while U.S. plants produced more downstream products. Efforts to shift into production of more 'value added' or 'specialty' plastics are noted in the annual reports of all chemical firms we examined in detail, including Dow, DuPont, GE Plastics, Ethyl, Exxon/Imperial, Chevron and Texaco. Meanwhile, several firms (especially Dow, but also Shell, Union Carbide, NOVA and others) invested substantially in increased ethylene, ethylene glycol and propylene capacity in Alberta. In Appendix B, we document specific instances where this led to increased intra-firm trade (particularly of propylene, which Dow ships from Alberta to the U.S. Gulf Coast by rail, polystyrene, and methyl tertiary butyl ether).

Thus, the growth in intra-firm and intra-industry trade in chemicals in the 80s and 90s reflects, in part, what one might call 'traditional' technological factors – i.e., advances in polymer chemistry that increased demand for the propylene and ethylene feedstocks with which Alberta is richly endowed. But, as we now describe, it also reflected strategic factors similar to those at work in other industries – i.e., severe overcapacity in the early 80s led to rationalization of production facilities on a North American basis and adoption of JIT logistics.

The restructuring of chemicals in the 80s and 90s was similar to that of autos, in that it included not only closing of outdated plants, but also the global standardization of products and processes, and adoption of JIT supply chain management. Indeed, the chemical industry was in the vanguard of adopting JIT. Motivating the change was not only a desire to lower inventories, but also that major customers, like the auto firms, began to demand just-in-time delivery of products. According to *Chemical Week* ('How Companies Are Holding Down Inventories,' Feb. 8, 1984, p. 28), DuPont had by 1984 already developed the ability to track the location of train shipments. The article notes: 'For the customer . . . the system reduces the need for an inventory cushion. DuPont can telephone a warning if a shipment is delayed, and can try to take quick corrective action, such as rushing a shipment by tank truck.'[59] The idea of adding value through distribution is also illustrated by this quote from Dow's 1991 annual report:

> We supply the majority of our own raw materials and participate in the marketplace all the way from commodity products through consumer goods. . . . this integration of raw materials production with downstream derivatives improves our ability to control quality, giving us a competitive advantage.
> To enhance this competitive edge, we capitalize on our global infrastructure. A worldwide sourcing system, for example, identifies the site that can most efficiently meet each customer's needs . . . Even in what are commonly viewed as 'commodity' products, value can be added by answering customers' specific needs. Rather than treating polyethylene as a generic product, for example, we manage it as a group of approximately 350 custom-made products for 150 different applications.

The importance of distribution and service was also noted by Kurt Landgraf, formerly Chief Operating Officer at DuPont, who said: 'Offer just-in-time delivery or global support or input into new product research, and you could set a piece of wood apart from the pack.'[60] Indeed, the importance of service was stressed by all chemical industry executives we interviewed as part of this study. For instance, Jacob Shapiro, former head of coatings at ICI Canada, stated:

> 'Today, it's standard practice to have paint company employees to work on the customer site. I mean they report to work there. . . . I mean, they don't call and say, "We have a problem, could you come in?" They're there. They spot the problems even before the customer spots the problems.'

The industry executives repeatedly stressed that North American integration (between affiliates and parents) was not primarily driven by tariff reductions. Rather, they pointed to global standardization of chemical products and processes as the key. This, in turn, stemmed largely from two factors: (i) global sourcing on the part of major customers, particularly the automakers, and (ii) environmental regulation. As Jacob Shapiro of ICI Canada indicated:

[59] This article discusses JIT adoption by many chemical firms in the early '80s. See also our discussion in footnote 10.

[60] See 'Sticking to the Formula; DuPont Insists Mundane and Exotic Products Mix Well', *The New York Times*, March 3, 1998, p. D1. Ethyl's 1994 Annual Report also contains a good description of the value added in distribution: 'Shorter product life cycles . . . caused customers to . . . make longer-term commitments with fewer suppliers and require . . . services of greater value . . . Ethyl and its customers share in-depth knowledge of one another's business to seek continuous, mutual improvement . . . [that] include economical formulations, faster development of new products . . ., improved product quality, *reliable and efficient supply . . . lower and just-in-time inventories . . .*' (emphasis added).

'. . . environmental regulations in the U.S. and . . . Canada are driving the technology for coatings . . . you have to make an investment in technology – a huge investment . . . you can't do that in every country . . . so what you have to do is try to operate globally. . . . The globalization of customers is also important . . . Ford has now gone completely global. . . . what you had in Canada were fairly independent operations of MNCs . . . the Canadian auto industry . . . was . . . fairly different and so the coatings in Canada were somewhat different. . . . What's happened more recently is that the coatings that are being supplied in the U.S., in Canada and in Europe . . . are very similar . . . because the environmental regulations are the same, the clients are the same, and their specifications are the same.'

Similarly, Jeff Harrison, manager of marketing and technical sales for auto coatings at PPG Canada, stated:

The Fords GM's and Chryslers are becoming more international. They've gotten more into world sourcing, as opposed to geographic. . . . I don't think there is any way you can operate without being integrated, because decisions by Ford in North America affect both Canada and the U.S.

But the globalization of products did not mean concentration of all production in the U.S. Harrison also noted that:

[At] our Clarkson manufacturing facility . . . we produce paint for all 13 automotive plants in Canada . . . We also have U.S. sites that produce certain component products. And we supply certain products from here to the U.S. plant, so there's kind of a mix and match . . .

Similarly, Bill Miller, marketing manager for industrial coatings at PPG Canada, noted:

Electro-coat is . . . a primer for our cars that's also used to paint all these under hood parts. . . . it's a two component system. We bring the resin from the U.S. because they do it very effectively. We have a very efficient system for making the paste in Canada. So we do the paste in Canada.

This is an excellent example of rationalization of production on a North American basis. Of course, the benefits of such a rationalization cannot be achieved without the advanced logistics management systems that the chemical firms were putting in place in the 80s.

When asked if tariff reductions had a big impact on decisions about where to produce specific components, chemical executives generally said no. For instance, Harrison responded:

Not substantially. It's more tied to technology than it is to free trade [or] geographic [considerations]. We have supplied product to California,

> California has supplied product to us here from PPG plants. . . . Technology really drives what your manufacturing capability is in a plant.

When asked about the effect of tariff reductions on the location of capacity, Harrison added:

> '. . . limited. Usually by the time you go through the whole scenario . . . you really didn't save any money . . . the last major change was probably five or six years ago. We moved a lot of primers . . . to this plant in Clarkson. And that was primarily because we already had a large volume of the business in Canada and we had open capacity and equipment. Other plants that were producing the smaller pieces spread out would have . . . been underutilized. So it was done more for consolidation purposes. And that tends to be the basis.'

Again, we see the common theme that reorganization of production on a North American basis was driven primarily by strategic and technological factors, not by tariff reductions.

VII. MAKERS OF ELECTRICAL EQUIPMENT, ENGINES, APPLIANCES, AIRCRAFT

We turn next to the industries that produce electrical and electronic equipment, industrial machinery, appliances and aircraft and aeronautical equipment.[61] Many had large increases in ND (see Table I), so we wanted to investigate what common factors affected them. We examined several large makers of electrical and mechanical equipment, especially General Electric (GE), United Technologies (UTC), Westinghouse, Whirlpool, and Black & Decker.[62]

As in the computer, auto and chemical industries that we discussed earlier, many firms in the electrical/mechanical equipment industries suffered from excess capacity in the late 70s and early 80s. Intense competition, especially from the Japanese electronics firms, had resulted in loss of market share, and this again led to (i) restructuring of production facilities on a North American basis and (ii) widespread adoption of Japanese production techniques.

Turning to specifics, we start with Canadian General Electric (CGE). *Business Week* ('Canadians Merge to Fight Imports,' Nov., 29, 1976, p. 31), describing the 1976 merger between the appliance operations of CGE,

[61] We group these industries together because the large U.S. multinationals that engage in any one of these activities, such as General Electric (GE), United Technologies (UTC) and Westinghouse, tend to engage in several of them.

[62] We choose these firms because they are large. This does not imply they had large ND increases in the BEA data, which is confidential information. In fact, we chose the firms whose histories we study in this paper without looking at their levels of intra-firm trade reported in the BEA data.

Westinghouse Canada and GSW (the only Canadian owned producer at that time), states: 'GSW and CGE's . . . aim is to modernize their five plants, gearing them to specialize in one or two appliance lines.' The article attributes this specialization to declining Canadian protective tariffs on appliances, which led to rising imports. This is similar to what we saw with IBM: tariffs were already low enough by the 70s for the Canadian affiliate to specialize in a few final products for the whole North American market.

Consistent with this view, *The Financial Times* ('Bigger Appetite for High Technology,' Sept. 8, 1982, Section III, p. 3) reported that:

> A steady trend for companies with foreign parents is . . . to evolve from makers of a full range of products for the Canadian market to producing a limited range for the conglomerate's world markets. The buzz phrase is 'world product mandating.' Canadian General Electric . . . has about 25 such mandates at the moment for equipment and products which include hydro-electric turbines and generators, controls for papermaking machines, reinforced plastic ducts, traffic controls and some lamps. The strategy goes right through to more mundane products with CGE making all GE's worldwide supply of electric kettles and frying pans while importing other consumer appliances.

Again, note that this refers the situation in 1982, two years *prior* to the start of our data.

Despite the range of world product mandates it held by 1982, CGE was severely hit by the 1981–82 recession, and a major restructuring occurred over the next five years. According to *Business Week* ('Industry's Surprising Revival North of the Border,' July 27, 1987, p. 38),

> Canada's 1981–82 recession forced rigorous cost-cutting and payroll-shrinking that boosted efficiency. Canadian General Electric Co. (CGE), for example, cut back from 21,000 employees to 11,000 in five years. 'I think Canada has demonstrated that it can deal with massive restructuring', says Chairman William R. C. Blundell. . . .
> And Canadians are turning their experience in producing for a relatively small market to advantage. 'Canadians are good at high-end, low-volume products, where you need more flexibility in the manufacturing system', says Blundell. 'The idea is that you gradually work your way to the point where there's only one source in North America.'
> CGE is doing just that at its plant in Oakville, Ont., which produces all of GE's 40-watt light bulbs for the U.S. and Canada. . . . *In high technology, CGE is now supplying rotor blades for all GE jet engines sold anywhere in the world from the company's factory in Bromont, Quebec* [emphasis added].

Notice that CGE's world product mandates for final goods like light bulbs and some appliances were already in place before 1982. But the supply of high-tech intermediates from the state-of-the-art facility in Bromont, Quebec, is a more recent phenomenon.

The CGE Bromont facility mentioned in the quote is important, because it was one of the pioneering FMS facilities in North America. When it was opened in August, 1983, it was GE's first experiment in CIM, FMS and JIT techniques.[63] An article in *Industry Week* ('Integrated Manufacturing II: Team Approach Pays Off,' Sept. 29, 1986, p. IM1) provides a good description of the intense interest in new technologies and management practices like CIM and JIT that was taking off in the mid-80s. It goes on to describe several early attempts by U.S. MNCs to implement these practices. The article stresses, however, that many firms were failing to reap the benefits of CIM because computers are not enough – the promised increases in productivity also require changes in management structure and human resource policies. The article then goes on to describe GE's experiment in Bromont, Quebec, in some detail:

> At the August 1983 opening of Canadian General Electric Co.'s $100 million factory at Bromont, Que., Alton S. Cartwright, chairman and chief executive officer, set the tone: 'We concluded that the traditional theories and structures of organization, management, and compensation were incompatible with our "socio-tech" objectives. A more flexible system, designed for change and adaptability, was required. . . .'
> Destined as a sister plant to a GE facility in Rutland, Vt., the Bromont plant goes a step further with the horizontal integration of three, traditionally separate' organizational systems: human, technical, and management. The purpose was to achieve target costs 24% lower than those at the Rutland facility, which is currently believed to be one of the most cost-effective plants of its kind today.
> The process involves precision forging, grinding, and turning blades and vanes for the GE turbofan engines powering such planes as the McDonnelll Douglas DC-10, the Boeing 747, and the A-310 Airbus . . .
> At first glance, the state-of-the-art human-resource practices are not as evident as the investment in automation. . . . An automated material-handling system controls inventory . . .., and, in communication with the scheduling system operated by the main computer, dispatches work to various operations as needed. Robotic ground transporters move material from the central storage area to the workstations and back again . . ..
> . . . while the automated equipment helps, the company is betting heavily on its unique organizational design program. 'The basic philosophic assumptions underlying the system are that people are basically honest, hardworking, self-disciplined, and wish to do a good job', says Bruna

[63] According to *Industry Week* ('Catching on; Can Kanban Ban Inventory Blues?', July 26, 1982, p. 21), GE sent a team to Japan to study kanban in 1979. The article stresses, however, that implementation of JIT in U.S. plants was just beginning in the early '80s, and that many U.S. firms were having difficultly. David Kinney of GE is quoted as stating that just a few units of GE were practicing elements of kanban 'in small pieces' but that full implementation would take some time. Bromont was the first attempt at full-blown FMS installation in North America.

> Nota, Bromont's manager of human resources. Everyone is on salary – even secretaries – and salaries are based on the number of skills learned. There are no time clocks, no foremen, and no quality-control inspectors. Five teams run the plant and the senior management team works on the factory floor at least one day a month.

As we will discuss further below, the successful Bromont experiment had a major influence not just on CGE, but on the rest of GE, as well as on many other firms like United Technologies, IBM, Westinghouse and Black & Decker, who imitated the Bromont effort. According to *The Financial Times* ('Marketing is the Challenge,' Nov. 12, 1996, Survey – Quebec, p. 5), '. . . in some fields Canada leads the U.S.: General Electric Canada pioneered computer-integrated manufacturing-administration at its Quebec airfoils unit.'

For CGE, the increase in intra-firm sales of rotor blades from the Bromont plant to the U.S. parent contributed to a massive increase in the share of its output that was exported. Describing the evolution of CGE in the 1981–1987 period, *The Financial Post* ('GE Canada Revamps for Global Focus,' September 14, 1987, p. 8) notes that:

> GE Canada now focuses on three main business segments: 'Global' businesses in which the U.S. parent specializes, such as aircraft engines, . . . Its plant in Bromont, Que., for example, makes blades and vanes for certain models of the large jet engines sold by its parent. Consumer goods for the Canadian market, including light bulbs, lamps and major appliances. . ..[and] GE 'world product mandates', including large motors, hydro generators and turbines, and CANDU nuclear technology. These Canadian-made goods are sold by GE worldwide.
>
> Pointing out that much of the company's sales growth now comes from outside Canada, Blundell says exports have already jumped to $214 million in 1986 from $25 million six years ago. . . .
>
> When Blundell became chairman in January, 1985, the company's ROE was only 8%. At that time, *the Canadian subsidiary was on the U.S. parent's 'fix, close or sell' list* [emphasis added]. To reduce GE Canada's chances of being axed, Blundell aimed to push ROE to 15% within three years . . .. 'Mature' businesses (those whose rate of return did not measure up to the goal) have been put on the block. GE Canada no longer manufactures or markets products that accounted for 30% of its 1982 revenues.

CGE was renamed GE Canada in 1987. If we track the progress of GE Canada over the next few years, we see that capacity was expanded by 50% in the Bromont facility in 1989–1991, while GE shut down its light bulb plant in Montreal in 1989.[64] This is consistent with the general pattern of affiliates

[64] See 'Boomtown Canada: Good Times have Arrived in Some Surprising Places,' *The Financial Post*, May 15, 1989, p. 17, and 'GE to Close Montreal Lamp Plant and Lay Off 200 Workers by July,' *The Financial Post*, Nov. 29, 1989, p. 4.

being reoriented away from final goods production toward more production of high-tech intermediates for shipment to parents. Indeed, according to *The Financial Times* ('U.S. Trade Pact a Two Edged Sword,' Jan. 18, 1988, p. 22), 'General Electric Canada . . . has stated that it plans to focus on businesses "where value is added through knowledge."'

In summary, the restructuring of CGE was not driven by tariffs. Rather, the affiliate was in danger of being shut down in the mid-80s, and in response took the initiative to implement advanced manufacturing methods, like the JIT system, in order to become the low cost producer of a key intermediate (rotor blades) for all of GE.

Next, we look at Black & Decker. This firm provides an excellent example of how advances in logistics were driving globalization of manufacturing operations in the 80s and 90s. According to *Computerworld* ('A Global Standard at Black & Decker', March 19, 1986, p. 39):

> The Black & Decker Corporation is on track toward its goal of becoming a global manufacturing company through a strategy of integrating computers and manufacturing processes. The diversified company . . . in many ways is already global, operating manufacturing facilities in England, Continental Europe, Singapore, Brazil, Mexico and Canada. *These countries have operated autonomously in the past*, producing products geared to the variations in regional markets and installing their own manufacturing systems and computers. This has worked admirably, but it has produced some inefficiencies the company intends to remedy with its concept of globalization.
>
> In January 1984 . . . the Manufacturing Planning Control System (MPCS) project was given high priority. . . . MPCS will be one of the prime vehicles in *the company's push to derive long-term benefits from global standardization*. As the natural boundaries between the company's products fade, standardization across the board is making sense. . . . the MPCS . . . will put in place global commodity coding methods, part numbering methods, charting of accounts, catalog numbers and product costing methods and other global coding and classification methods. . . . such *standardization will enable someone sitting at a terminal in North Carolina to inquire about the status of certain parts they are getting from a plant in France* [emphasis added].

The article also explains what motivated Black & Decker to implement the MPCS computerized logistics system in the first place:

> Since about 1982, the company . . . had . . . been making the transition to a Just-in-Time type of manufacturing environment . . . The push to Just in Time was . . . placing a strain on existing manufacturing software that had been developed in-house in the 1960s and 1970s. . . .

Thus, the global standardization of parts and processes, and the ability to track parts globally, developed out of the need to computerize logistics to facilitate implementation of JIT.

This again highlights why our hypothesis three – that it may not be reduced inventory carrying costs *per se*, but rather some other aspect of the overall JIT system, like parts commonality, that led to increased intra-firm trade – is not well posed. The problem is that these factors are so organically linked that they cannot sensible be separated.

Finally, we also looked at Westinghouse and United Technologies (UTC). We discuss their cases in more detail in Appendix C. In short, their stories look strikingly similar to those of the firms that we have examined already. Westinghouse suffered from severe excess capacity in the late 70s, due largely to Japanese competition. UTC did not face overcapacity problems until 1990–91, when it was severely impacted by high oil prices and declining military spending. Westinghouse adopted the JIT system in the early 80s,[65] while UTC did so in the early 90s.

Like CGE, Westinghouse Canada had already 'rationalized' its operations by the early 80s. It had world mandates for steam and gas turbines and airport lighting regulators. But in the early 80s it faced the challenge of surviving in an environment where the parent suffered from severe excess capacity. Like CGE, its strategy involved innovation, enhanced manufacturing efficiency (including JIT production) and emphasis on higher value added products. As a result, its export share of total output grew from 5% in the late 70s to 36% in 1988.[66]

UTC's subsidiary, Pratt & Whitney Canada (PWC), was 'rationalized' very early, being converted to the production of small aircraft engines for the world market in 1963, when it began making the PT6 turboprop engine (the industry standard for small planes). A striking aspect of the UTC story is that, while declining military demand induced the parent to implement a drive towards JIT production company-wide in 1991, PWC started to implement JIT several years earlier. According to *The Financial Post* ('Nova Scotia High Tech,' April 10, 1989, p. 16):

> . . . Pratt & Whitney Canada has built an engine-parts factory beside Halifax Airport that has visitors streaming in from all over North America. It all began about five years ago when officials at Pratt & Whitney looked at their existing operations and wondered why it took so many people on the shop floor so long to produce anything. After analyzing their factory at Longueil, Que., they decided to be more productive by adding more value with fewer people working faster. . .
>
> . . . Pratt & Whitney decided to use a computer-assisted manufacturing method and bought the latest technology. But to run the new machinery,

[65] According to *Industry Week* ('Catching on; Can Kanban Ban Inventory Blues?,' July 26, 1982, p. 21), Westinghouse started to experiment with Toyota's 'kanban' or JIT system at its Bloomington, Indiana plant in Nov. 1981. This was one of the earliest attempts in North America.

[66] See 'Products Mandates for Branch Plants May Hurt, Not Help', *The Financial Post*, March 13, 1989, p. 6.

> the company needed highly trained people, the sort not readily available locally. The Nova Scotia government agreed to establish a computer integrated manufacturing cell at the Nova Scotia Institute of Technology in Halifax, at a cost of $15 million. The students are required to have a good mechanical background before being admitted to the 40-week course. Most of the 90 graduates NSIT has produced so far have gone to Pratt & Whitney. . . .
> The factory has been open for a little more than a year, and is operating at about 25% capacity as it gradually adds complex computer manufacturing systems. By year end, there will be 188 workers; by 1991 there will be 500. . .[67] What is exciting about the Halifax plant is that it is serving as a model for other plants elsewhere in North America. . . .

The Financial Post ('Aerospace Takes off in Nova Scotia,' August 31, 1987, p. 9) also noted:

> Nova Scotia moved one step closer to becoming a regional aerospace centre earlier this month when Pratt & Whitney Canada, Inc., shipped the first engine parts from its new $125-million plant at Halifax International Airport. The nonunionized P & W plant manufactures light alloy castings for small gas turbine engines which are shipped to another P & W factory in Longueil, Que., for assembly. P & W's small engines are fitted to executive jets such as the Cessna Citation and commuter aircraft such as de Haviland's Dash 7 and Dash 8. . . . The provincial government has offered a training course customized to meet P & W's needs. A miniature P & W plant has been built at the Nova Scotia Institute of Technology. . . . *Because P & W's Nova Scotia plant will produce a variety of parts in small quantities, students are taught to program machines for flexible manufacturing* [emphasis added]. Retooling, which would take hours by hand, can be done by computer in minutes. The province hopes its training in automated manufacturing technology will be a drawing card for other high-tech companies shopping for locations. . . . The Nova Scotia facility is an experiment for P & W, both in terms of technology and corporate structure. According to general manager Renton, 'There's a lot of freedom here – no time clocks, no supervisors, flexible working hours, they choose their own vacations and shift rotating patterns, . . .'

The PWC Halifax plant is still considered a 'world class' FMS installation. According to *The Financial Times* ('Start-Up for Helicopters,' June 9, 1987, Aerospace Survey, p. X), its construction was influenced by Canadian General Electric's earlier experiment in Bromont, and was part of a general strategy to implement flexible manufacturing throughout PWC:

> Based partly on a pioneering Canadian General Electric airfoils plant at Bromont, near Montreal, PWC is gradually adopting computer-

[67] PWC's total employment in 1991 was about 8,500.

> integrated manufacturing for its principal engine assembly and testing operations. In Montreal especially, this will mean a complete restructuring of the manufacturing function over the next ten years. PWC has built a parts plant at Halifax, Nova Scotia, to get practical experience.

In summary, for GE, Westinghouse and UTC, we see the same basic patterns as we saw at Xerox, IBM, Ford, and the chemical industry. The restructuring of the 80s and 90s was driven by intense competition, particularly from Japanese manufacturers, as well as more specific factors (e.g., declining military spending), that led to severe over-capacity. In order to compete, GE, UTC and Westinghouse adopted JIT methods, global parts and process standardization, and global sourcing, and more closely integrated their manufacturing operations on a worldwide basis. The fact that competitive pressure often induced JIT adoption is why one can't meaningfully distinguish hypotheses two and four. (Similarly, Schmitz [2005] emphasizes the close link between competitive pressure and process innovation in the domestic U.S. context.)

VIII. GENERAL PATTERNS

We examined the histories of a large number of Canadian affiliates beyond the several discussed in the previous three sections. In this section we describe some key patterns that we find recurring across nearly all the industries and firms we examined.

VIII (i). *North American 'Rationalization' Largely Completed by 1984*

Our first general observation is that, by 1984, the 'branch plant' model of Canadian affiliates was already largely outdated, as most U.S. MNCs had already 'rationalized' their Canadian operations. That is, tariffs were already low enough by the late 70s that the branch plant model had been abandoned in favor of assigning affiliates small sets of products.[68] For example, Xerox Canada was assigned to produce document handlers in the late 70s; Burroughs Canada (later Unisys) specialized in making disk drives and test equipment as early as '82;[69] UTC subsidiary Pratt and Whitney Canada got the mandate to produce small engines in 1963; Westinghouse Canada had worldwide responsibility for certain steam and gas turbines, among other products, by the early 80s; Litton Systems Canada had world

[68] White and Poynter [1984] present data on Canadian tariffs in the post-war period. The average tariff fell from roughly 10% in '63 to 5% in 1977. Most of this reduction had already occurred by about 1969, when the average tariff had already fallen to roughly 6%, following the Kennedy round of the GATT ('63–'67).

[69] See 'Burroughs Realignment', *PR Newswire*, March 1, 1982.

responsibility for inertial navigation systems by the 70s;[70] Allied Signal was fully rationalized in the 60s; Navistar had produced its large trucks in Canada (and small to medium trucks in Ohio) since the 70s;[71] and, by 1984, Black & Decker Canada had world mandates for electric kettles, electric lawnmowers, heaters, frying pans, sanders and Workmate portable workbenches.[72] Canadian GE had about 25 world product mandates in 1982, two years *prior* to the start of our data (see Sect. VII).

We are certainly not the first to challenge the relevance of the 'branch plant' model to Canada in the early 80s. For instance, Rugman [1988] presented export performance data that called into question the view that Canadian affiliates were merely 'tariff factories.' The fact that so many U.S. MNCs had already rationalized their Canadian operations prior to 1984 helps explain why we find little effect of the modest post-'84 tariff reductions on affiliate organization.

Among the many MNCs whose histories we studied, we found only two cases of firms that rationalized production on a North American basis after the FTA, namely, Whirlpool and DEC. However, a careful examination of these cases revealed that the restructuring had little to do with tariff reductions. The Whirlpool case is described in Appendix D. The DEC case so well illustrates the impact of advanced logistics on intra-firm trade that we describe it here.

According to *The Financial Post* ('Fighting for Investment in the Era of Free Trade', June 17, 1995, p. 17), Digital Equipment Corporation (DEC) closed its PC plant in Springfield, Massachusetts in 1992 and concentrated all PC production for North America in its Kanata, Ontario, plant. This seems consistent with the notion of FTA tariff reductions leading to concentration of production in one place. But closer inspection reveals that the move had little to do with tariffs.

Arntzen *et al*. [1995] describe how the shift in demand from mainframes towards PCs in the late 80s left DEC with massive excess capacity, and a $3 billion loss in 1991. DEC, which was heavily vertically integrated, had 33 manufacturing plants in 13 countries. To deal with the problem, it began a global rationalization of its plants in 1989, reducing the total to 12 by 1994. DEC also spun off a number of activities, and focused more on PC manufacturing. Interestingly, the reorganization was done with the assistance of a complex linear programming model called the 'global supply chain model', which helped DEC determine the optimal location for each production activity. Interestingly, the inventory carrying cost of intra-firm trade plays a key role in the model. According to Dan Jennings, VP of worldwide manufacturing, the reorganization saved DEC roughly $500

[70] See Crookell [1987] on Westinghouse, and Science Council of Canada [1980] on Litton.
[71] See 'U.S. Trade Pact a Two-Edged Sword', *The Financial Times*, Jan. 18, 1988, p. 22.
[72] See 'Better Deal for Retailers Aim of B&D', *The Financial Post*, May 18, 1985, p. 15.

million in operating costs in 1992–1993. Half the savings were ascribed to reduced manufacturing costs, and half to reduced logistics costs.

Thus, tariffs were not a motivating factor in the reorganization, and played only a minor role in decisions about where to locate the remaining production facilities. Indeed, *The Financial Post* (op cit.) noted that:

> 'With all the downsizing going on, we were obviously very concerned about what we'd be doing longer term', says Kanata plant manager Dale Reid. 'We were looking for a longer-term mandate.' . . . when DEC announced it would close its PC plant in Springfield, Mass., and consolidate manufacturing for North and South America in one place . . . Reid . . .. put together a proposal for transferring production to Kanata, touting *the plant's track record of quality and efficiency*, [emphasis added]. Shortly afterwards, they won.

Thus, affiliate initiative and manufacturing efficiency earned it the product mandate.

VIII (ii). *Canadian Comparative Advantage in Lean Production*

When U.S. MNCs built plants that use JIT, flexible manufacturing (FMS) and other aspects of the Toyota system, they often did it in Canada first. The FMS facility opened in 1983 by General Electric in Bromont, Quebec, to makes blades and vanes for GE turbofan engines, was GE's first experiment in this area, and one of the first successful FMS installations by a U.S. MNC in North America.[73] GEs Canadian appliance manufacturing affiliate, CAMCO, was also an early adopter of JIT. According to GE's 1992 Annual Report, 'Quick response . . . a cycle time reduction technique we adapted from our Canadian affiliate . . . has taken GE Appliances from an 18-week order-to-delivery cycle to a 3 1/2 week cycle . . . on the way to three days. Quick Response has reduced average inventory in GE appliances by 50% . . .'[74,75]

[73] Jaikumar [1984] argues that, while there were FMS installations in place in the U.S. by 1982, none of them were being managed for flexibility. Instead 'U.S. companies used FMS in the wrong way – for high volume production of a few parts rather than for high-variety production of many parts at low cost per unit.' Mansfield [1993] discusses the slow diffusion of FMS up through 1988.

[74] 'Quick response' is basically the JIT idea, extended past manufacturing all the way to the processing of orders.

[75] *The Toronto Star* ('Appliance Maker to Cut Production Costs by 20%', May 14, 1991, p. B1) quotes Camco president Stephen Snyder, who became GE Canada chairman in 1992, as indicating that 'Canadian factories are in the vanguard of General Electric operations in manufacturing to order, eliminating inventories of finished products, and giving shop-floor workers the power to design their own jobs and work with minimal or no supervision. . . ''(A $26 million saving in inventory costs during 1990) is one area where I am extremely proud of Camco's team for their accomplishment,'' Snyder told shareholders.'

Similarly, while United Technologies began to embrace wholeheartedly the Toyota system in 1991, its Canadian affiliate 'Pratt&Whitney Canada, began operating one of the world's most advanced FMS facilities at Halifax, Nova Scoha, in 1987. Black&Decker introduced lean production methods at its Brockville, Ontario plant in 1990. Chrysler's first plant to adopt the JIT system was the strategically vital mini-van assembly plant opened in Windsor in November, 1983.[76]

Some observers argue that Canada has key advantages for implementing lean production. *Business Week* ('Industry's Surprising Revival North of the Border,' July 27, 1987, p. 38), noted that: 'Canadians are turning their experience in producing for a relatively small market to advantage,' and quotes CGE Chairman Blundell as stating: 'Canadians are good at high-end, low-volume products, where you need more flexibility in the manufacturing system.' And, Jim Barton, head of finishes at DuPont Canada, whom we interviewed in 1995, indicated:

> 'Although the Canadian plant [in Ajax, Ontario] is smaller than the U.S. plant, its productivity is equal or greater . . . This is because DuPont Canada has been able to reap the benefits of smallness and high-performance work systems. There is a community environment in the plant. There are only three hundred or so people as compared to the eight to nine hundred people in the big U.S. plants. Everyone knows each other and talks about problems/issues that come up . . . DuPont Canada's engineering polymers plant is 1/6th the size of the U.S. plant but more productive. . . . the plant is small, fast, flexible and responsive. . . . DuPont Canada is also a testing ground for corporate-wide systems changes. Because it is small . . . but fully integrated . . . it's easy to install new systems.'

The basic argument here is that Canadian workers had experience with producing a large number of differentiated products under the branch plant system, giving them more versatility. This versatility is exactly what is needed to implement the JIT or lean system. Finch and Cox [1986] argue: '. . . many small manufacturers have naturally organized their shop on the basis of similarity of parts produced rather than on functions of machines', and

[76] See 'Chrysler: New Van and Plant', *The New York Times*, Oct. 29, 1983, p. 35. This article describes the essence of the JIT system quite succinctly: 'Most American auto plants have stockpiles of partly finished cars at different stages of the assembly process. Such accumulation of inventory is designed to keep the assembly line moving if any part of it breaks down and cuts off a supply of parts, and to provide a place to hold slightly defective units awaiting repair. These inventory banks have been eliminated at Windsor, said Richard E. Dauch, Chrysler's executive vice president for factory operations. ... a process, Mr. Dauch said, that would put a premium on doing things right the first time . . . "In the old days you could set a problem aside for two or three days," he said. "With this system, you have under an hour to get it right or the whole plant shuts down. This puts a sense of urgency in the system and tends to expose problems rather than hiding them."'

this is a central idea of the JIT system. Related arguments are that Canadian workers are better able to adapt to the system because they are better educated, more adaptable, better at teamwork, and so forth.[77]

Perhaps a simpler explanation is that a shift from batch-and-queue to JIT production leads to changes in plant layout that reduce optimal plant size substantially. With production organized around a 'single piece flow' model, most storage space for work-in-progress and finished goods inventory is no longer needed (see Suzuki [1987] chapter 4). Indeed, Automotive Industry Action Group [1983] noted that a typical Japanese plant was only a third the size of an American plant producing the same output. Steven Van Houten, president of the Canadian Manufacturers' Association, wrote in *The Financial Post* ('Rapid Change Challenges Canada's Manufacturers,' Sept. 30, 1995, p. 21), 'Customization is replacing standardization . . .. There is a revolution occurring in manufacturing worldwide. . . The *lack of scale of Canadian plants, which used to be considered a competitive weakness, is becoming a strength* in an era where the premium is on fast to produce and fast to market. . . The share of Canadian industrial production which is exported has more than doubled since 1980 . . .' [emphasis added].

Thus, it seems plausible that the shift to JIT and flexible manufacturing systems that began in the early 80s rendered Canadian plants more efficient vis-à-vis U.S. plants, due to a combination of their smaller scale and more flexibly trained workers. This may explain (in part) why affiliates have became more important in the parents' overall production function in those industries where JIT implementation is more prevalent.

Interestingly, country specific advantages for JIT implementation have also been invoked to explain U.S. automakers' investments in Mexico in the 80s. These investments led, in-turn, to substantial increases in U.S.-Mexico intra-firm trade, suggesting the impact of JIT on intra-firm trade extends beyond the US-Canada context. We describe this argument in Appendix E.

VIII (iii). *Affiliate Initiative and Technical Innovation Were Important*

Affiliate technical innovation was a key factor leading to increased intra-firm trade. We already described the role of innovation in turning the Canadian affiliates of IBM, Ford, GE and UTC into suppliers of high-value intermediates to their parents. Similarly, Crookell [1987] notes that

[77] For example, *The Financial Post* ('Nova Scotia High Tech', April, 10, 1989, p. 16), commenting on PWC's Halifax plant, notes: '. . . the salaried workforce is organized into self-regulating teams with rotating coordinators and leaders. The objective, in the words of Doug Renton, the plant's manager, is "to produce entrepreneurs within a big business." He finds that Nova Scotians are a good natural fit . . . being by nature more independent-minded and thus more apt to take responsibility. Pratt & Whitney spends a lot of time on recruiting, looking not only for the requisite academic and technical skills, but also a team attitude. Young people who have played team sports are seen as good candidates.'

Westinghouse Canada received the mandate for certain types of gas turbines through R&D activity that improved their design. Another good example is HP Canada. HP had negligible manufacturing operations in Canada prior to 1984. But in 1984, the affiliate began R&D activity in conjunction with researchers at the University of Waterloo that led to the creation of the HP X-terminal and associated software. This innovation led to the affiliate receiving the worldwide mandate for 'thin-client' technology within HP.[78]

Technical innovation can also take the form of process improvements that enable the affiliate to become the low cost producer (i.e., 'center of excellence') for a particular good or component. Good examples of this are the process improvements at GE Canada that we discussed earlier. Another example is the DEC Canada case discussed earlier, where the Kanata, Ontario, plant receiving the mandate to produce PCs for the whole North American market due to superior manufacturing efficiency. Yet another example is DuPont Canada, which developed an efficient process for low volume production of resins in the 70s (see White and Poynter [1984]).

Birkinshaw and Hood [1997] interviewed managers at six large Canadian affiliates that had 'world mandates' in some area (i.e., worldwide responsibility for producing an intermediate or final good).[79] All 6 were set up originally as branch plants to circumvent tariffs, mostly in the 1930s. Four of the firms, in the industrial products, chemicals, control systems and industrial systems industries, had world mandates for production of an intermediate input for the parent. Two firms, in the electronics and computer industries, had world mandates for a final product. Birkinshaw and Hood conclude that: 'The mandate process indicated a rather passive role for the parent company.' They argue that affiliate initiative was consistently the key factor.

For example, describing the evolution of 'Alpha' in the industrial products industry, they note: '. . . over the period 1980–1990 Alpha Canada became the leader (within the corporation) in flexible, small-volume manufacturing . . . through a host of small initiatives all focused on

[78] See 'HP X-Terminal Traces its Roots to Waterloo', *The Financial Post*, March 5, 1994, p. S21. The HP Canada case also provides a nice example of the complexity of intra-firm flows of intermediates. According to *Industry Week* ('Networking with the Neighbors: A New Trading Bloc?', May 6, 1991, p. IM3), 'HP Canada's Panacom Div. . . . designs its X Terminals and then transmits engineering data to HP's Loveland, Colorado, plant, where printed-circuit boards (PCBs) are made. PCBs developed in Loveland for the X Terminals are then shipped back to Canada, where they are tested and assembled into computer "boxes." From Waterloo, the boxes travel to one of three worldwide distribution centers in California, France or Singapore. There, they are matched for various markets with keyboards made in HP Singapore. Monitors, sourced from a third party, are added to complete the product.'

[79] Firms were chosen by searching the *Financial Post 500* to find 40 Canadian affiliates with mandates. Of these, 10 were randomly chosen to be interviewed, and 6 agreed to participate. Interviews were conducted in 1993–94.

convincing U.S. division managers to invest in Canada', and 'the nature of these initiatives was very much consistent with their existing resources, in that they sought out relatively short-run, high-specification, manufacturing operations from elsewhere in the corporation.'

The work by Birkinshaw and Hood is part of a growing literature on MNC structure, exemplified by Ghosal and Barlett [1991], which departs from the conventional parent-centered perspective and instead adopts a 'network conceptualization' of the MNC where '. . . the subsidiary can be modeled as a semiautonomous entity whose development is analogous to that of an independent firm.'[80] Consistent with this view, we also found evidence of the important role of affiliate independence and initiative in our case studies. For example, Jim Barton, head of coatings at DuPont Canada, whom we interviewed in 1995, described the process whereby the Ajax, Ontario plant was assigned the role of supplying coatings for Ford as follows:

> There was a big intra-firm competitive process for which plant would get the new business. Each operation had to put together a position with respect to its productivity. There was a series of negotiations which were carried out within the global sphere . . . The decision was made by a global business team. . . . Now, since 1985, the company has added a company equivalent in size to the whole company on 1985. This is because of greater participation in North America. We are involved in ongoing sessions with senior management at other companies in Canada. Every company has its own similar stories.

Evidence that MNC affiliates actively take the initiative to seek mandates (by inventing new products and/or touting their own production efficiency within the MNC), as opposed to having their fate determined by the parent, also appeared in several other cases we described earlier, such as the Canadian affiliates of IBM, DEC, HP, Ford, GE, Pratt & Whitney and Westinghouse.

Based on our case studies, it is clear that pressure on Canadian affiliates stemming from competitive pressures on the parent (i.e., over-capacity, Japanese competition) was often key in affiliate development. Canadian affiliates often responded to such pressures with product or process innovations, including adoption of the JIT system, which made them more valuable to parents. This often led to transformation of affiliates from low value added assembly activities to high value added intermediate production.

[80] Dunning [1994] p. 78 notes that the R&D/sales ratio of U.S. MNC affiliates roughly doubled between 1977 and 1989, from 0.41% to 0.79%.

IX. CONCLUSION

Using confidential firm level data on U.S. MNCs and Canadian affiliates, Feinberg and Keane [2006] document that intra-firm trade in the U.S.-Canada context roughly doubled from 1984 to 1995. A massive reorganization of Canadian manufacturing affiliates also occurred. In 1984 most affiliate output was final goods for sale in Canada but, by 1995, affiliate output was mostly intermediates for sale to U.S. parents. This pattern recurs across many industries. Tariff reductions cannot explain the phenomenon, as there is little correlation at the industry level between tariff reductions and increased intra-firm trade. In this paper, we have used statistical analysis and case study evidence to delve into the root causes of increased intra-firm trade.

Our key empirical finding is a strong positive relationship (at the industry and firm level) between growth in intra-firm trade and success in reducing inventories. The dramatic growth of intra-firm trade began in 1984 – precisely the time when many U.S. MNCs and Canadian affiliates began to adopt advanced logistics management practices, such as the 'just-in-time' (JIT) system pioneered by Toyota in the 50s and 60s. Thus, we argue that improved logistics in general, and JIT in particular, is a key reason for increased intra-firm trade.

Our review of the OR and industrial engineering literatures shows that this conclusion is theoretically plausible. Improved logistics enables MNCs to better organize 'convergent' production processes involving frequent intra-firm transfers of goods (see Strader *et al.* [1999], McGrath and Hoole [1992]), and reduces the inventory-carrying cost of intra-firm trade. Indeed, the industrial engineering studies of HP (Lee *et al.* [1993]) and DEC (Arntzen *et al.* [1993]) concluded that inventory-carrying costs were a substantial part Q9
of the cost of intra-firm trade. This realization led DEC and HP to adopt JIT to lower trade costs. In the low tariff environment existing between the U.S. and Canada in 1984, inventory-carrying costs were often a more important component of trade costs than tariffs. Indeed, Lee *et al.* [1993] note that including tariffs in their model made only a small difference in their solutions for how to organize HP's worldwide supply chain. Reducing inventory costs played a much more significant role.

Our conclusion that improved logistics led to increased intra-firm trade is not based just on correlating two trending variables (i.e., inventories and intra-firm trade) in the aggregate. The timing and success of JIT adoption (and hence, inventory reduction) varied considerably across industries and firms, creating the leverage to identify the relationship between inventories and intra-firm trade at the industry/firm level. Furthermore, tariffs also exhibit a strong trend over the sample period, but they nevertheless fail to correlate with intra-firm trade at the industry level.

Our conclusion is bolstered by case studies of most of the largest U.S. MNCs with affiliates in Canada, relying both on interviews with affiliate executives and secondary sources. We found very few instances where any of these sources mentioned tariff reductions as a key reason for increased intra-firm trade in the 80s and 90s. Instead, they consistently stress factors like foreign competition leading to over-capacity, which in turn led to reorganization of worldwide production facilities. This reorganization generally involved adoption of JIT logistics, global standardization of parts and processes, use of globally-standardized common components across varieties of differentiated products, systems for global tracking of parts and components, and global sourcing. All these factors increased intra-firm trade in intermediates.

Another key facet of U.S. manufacturers' efforts to improve their logistics/supply chain management was outsourcing of many activities previously performed in house to 'best in class' suppliers on a global basis. In response, many successful Canadian affiliates, acting as semi-autonomous agents within the MNC, took the initiative to transform themselves from inefficient final goods producers into efficient JIT suppliers of key intermediates.[81] In this role, they sometimes became globally competitive suppliers (not just internal suppliers to the MNC itself).

In the JIT framework, outsourcing key intermediates is not an 'arms length' transaction, but requires tremendous proprietary information sharing between the buyer and supplier. Thus, consistent with the theoretical framework in Quinn and Hilmer [1994], the relationship with a supplier tends to be tighter the closer is an activity to the core competence of the corporation. For example, Ford decided to source engines from an affiliate (i.e., keep it internalized since it is in the core). They outsourced painting to ABB, with whom they have very close ties (i.e., a long term contract, and shared information, personnel, assets, etc.), as paint is in the defensive ring that surrounds the core. Yet activities peripheral to the core, like payroll, cleaning, etc., may be outsourced to third parties on an arms-length, short-term basis.

Our work may have implications beyond the U.S.-Canada context. The magnitude of the increase in world trade in the past few decades is generally considered an important "mystery" (see Burgeoning and Kehoe [2001], Yi [2003]). It is hard to explain on the basis of tariff and transport costs, because the growth of trade was so massive while the declines in tariffs and transport costs were so modest. The mystery has become particularly severe since the mid-80s, when the growth of trade accelerated noticeably, even though tariffs were already quite low by the early 80s.[82] Q11

[81] Recently, Helpman [2005] and Grossman, Helpman and Szeidl [2003] have emphasized the importance of better understanding MNC sourcing decisions if we are to explain the growth of intra-firm trade in intermediates.

[82] Yi [2003] is the most successful attempt to explain growth of trade using tariff reductions in a general equilibrium model, but, as he notes, his model still explains only half of the growth of U.S. exports in the post-1962 period, and 'falls short of capturing the nonlinear export surge beginning in the late 1980s' (p. 85). As Yi notes, in the 1989–99 period, U.S. exports grew 80%

The fact that improved I/S ratios at the industry level are closely associated with the growth of trade provides an important clue about what may be going on. In the 80s, many manufacturers in the U.S. and Western Europe began in earnest to adopt advanced logistics methods like JIT. As JIT lowers the inventory carrying cost of intra-firm trade, it may account for a decline in trade costs well beyond that due to declining tariffs and transport costs. Prior empirical work on trade has focused on tariffs and physical transport costs (see Yi [2003] p.91 for a good review), but has paid little attention to inventory carrying costs. Our work suggests that these may be crucial, especially for explaining the post-1983 acceleration in trade growth.

APPENDICES

Available on the Journal of Industrial Economics Web Site:

A. The Emerging Awareness of Japanese Manufacturing Superiority in the Early 80s.

B. Increased Intra-firm Flows of Intermediates in the Chemical Industry

C. More on Westinghouse, United Technologies and GE

D. The Case of Whirlpool

E. JIT and U.S. Auto Firms' Investments in Mexico

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in the data while his model generates only a 27% increase (p. 88). In his conclusion, Yi speculates that one reason for the remaining growth of trade may be 'technology induced increases in the . . . possibilities for vertical specialization.' We argue that the JIT system is a source of such technical change.

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