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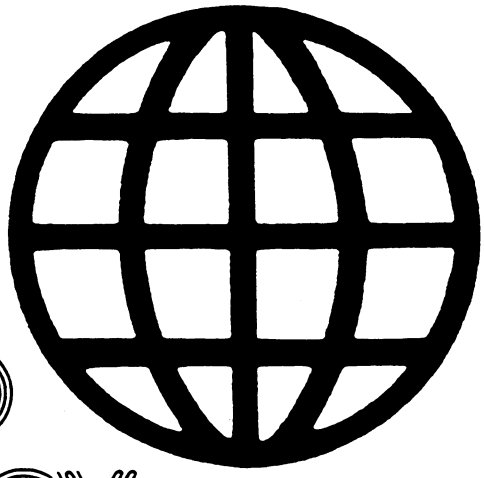

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Korea's Foreign Exchange Crisis and Its Implications for U.S.-Korean Trade

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After nearly three decades of extraordinary growth and development, the Korean economy was derailed in November 1997 by a serious foreign exchange crisis. In response, the Republic of Korea (Korea) signed an emergency arrangement with the International Monetary Fund (IMF) on December 4, 1997. Facing the high interest rates, sharp currency depreciation, a falling stock index, and a crippling shortage of liquidity, Korea had to initiate a series of reforms to stabilize its volatile financial market and help its transition from a state-directed economic system to one that is freer.[2] *In response to the currency depreciation, there was a significant decline in the dollar value of U.S. exports to Korea and a modest increase in the dollar value of U.S. imports from Korea. This article will examine the crisis, Korea's stabilization efforts, and changes in U.S.-Korea bilateral merchandise trade.*

Korea was the world's 11th-largest economy in 1997 and, after Japan, the most advanced economy in Asia. Korea had evolved into the world's largest producer of DRAM chips, the third-largest producer of automobiles, and a leading producer of consumer electronic products, steel, and ships. Korea was also the fifth-largest market for U.S. exports and the eighth-largest source of U.S. imports.

Nonetheless, 35 years of extraordinary economic growth came to an abrupt halt in November 1997. A U.S. Government official noted four general conditions that severely limited competition and market access: pervasive government intervention in the economy, the lack of transparency between the government and Korea's leading conglomerates, a poorly supervised and arcane banking system, and "crony capitalism." These four general conditions contributed significantly to Korea's worst economic crisis since the end of the Korean Conflict.[3] An official of the International Monetary Fund (IMF) has asserted that two other, more immediate factors specifically precipitated the crisis of 1997: shortage of foreign exchange reserves, and the loss of confidence in Korea by foreign creditors. As a result, in

[1] The views expressed in this article are those of the author. They are not the views of the International Trade Commission or any of the Commissioners.

[2] U.S. Department of Commerce, *Korea*, National Trade Estimates Reports, Asia/Pacific, 1998, found at Internet address http://www.infoserv2,ita.doc.gov, retrieved July 15, 1998.

[3] David L. Aaron, Under Secretary of Commerce, "Dealing with the crisis in Asia," *Business America*, Feb. 1998, retrieved Apr. 23, 1998.

November 1997, the Korean economy entered into a harsh recession, with a currency depreciation, spiraling interest rates, liquidity shortfalls, foreign exchange losses, and labor unrest.[4]

The adverse affects of the foreign-exchange crisis have been dramatic. After average annual growth of 7.5 percent during 1990-96, Korea's real GDP growth dropped to 5.8 percent in 1997. The full force of the crisis hit in the first quarter of 1998, with a projected 3.8-percent contraction in GDP for the full year 1998 (table 1).[5] Korea experienced a collapse in domestic demand, escalating unemployment, and an overall slump in economic activity. The Bank of Korea reported that the first quarter of 1998 represented the country's worst economic performance in 18 years. Korea's unemployment rate soared to an 11-year high at 6.7 percent (1.5 million) in April 1998. Korea's nominal per capita income had grown from $82 in 1962 to $8,350 in 1995 and $10,000 in 1996. But it slipped back below $10,000 in 1997; usable gross reserves declined by 68 percent; and benchmark 3-year bond rates rose from 14 percent to almost 30 percent in 1997.[6] In the 10-month period ending April 1998, the Korean won was devalued by more than 40 percent against the U.S. dollar, 26 percent against the Japanese yen, 37 percent against the Chinese yuan, and 26 percent against the Taiwan dollar.[7]

Factors Contributing to Korea's Foreign Exchange Crisis

In the years following the Korean Conflict, successive Korean administrations, in conjunction with large family-owned conglomerates (chaebols), adopted an activist state-led industrialization program that was designed to produce high annual growth rates in a short period of time.[8] With government encouragement, the chaebols grew and diversified into a variety of unrelated capital-intensive industries as part of a plan to shift production to high-technology products.

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[4] Stanley Fisher, "The IMF and the Asian Crisis," speech, Los Angeles CA, Mar. 20, 1998, found at the *The International Monetary Fund* Internet address http://www.imf.org/external/np/speeches, retrieved May 13, 1998.

[5] International Monetary Fund, *IMF Concludes Article IV Consultations with Korea*, press release No. 98/39, June 19, 1998, found at Internet address http://www.imf.org, retrieved June 19, 1998.

[6] "South Korea Faces Crisis After Leaving Developing World," *Journal of the Group of 77*, Sept./Nov. 1997, found at Internet address http://www.g77.org, retrieved Apr. 23, 1998.

[7] Kang Yeoun-sun, "Economy Grows 5.5 Percent in 1997, Lowest in Five Years," *Korea Herald*, Mar. 18, 1998; Lee Kap-soo, "Korea Marks Negative GDP Growth for First Time in 18 Years," *Korea Herald*, May 22, 1998; Chun Sung-woo, "Exports Supported by Price Competitiveness, Ministry Says," *Korea Herald*, May 25, 1998; found at Internet address http://www.koreaherald.co.kr, retrieved June 15, 1998.

[8] "A Land of Overachievers," *Korea Herald*, May 1, 1998, retrieved Jan.4, 1999.

Table 1
Korea at a glance

Population, 1997(*Million*)	46
GDP, 1997 (*Million dollars*)	487.5
GDP per capita, 1997(*Dollars*)	10,598
Real GDP growth rate:	*Percent*
1995	8.9
1996	7.1
1997	5.8
1998	[1] -3.8
External debt:	*Billion dollars*
1995	119.7
1996	157.6
1997	154.4
Usable gross reserves:	
1995	28.5
1996	29.4
1997	9.1
Debt service ratio:	*Percent*
1997	9.0
Exchange rate:	*Won per dollar*
1995	774.7
1996	842.2
1997	1,960.0
May 1998	1,394.6
Inflation rate:	*Percent*
1995	4.5
1996	5.0
1997	4.7
Consumer price inflation:	
1995	4.7
1996	4.9
1997	6.6
Unemployment:	
1995	2.0
1996	2.0
1997	2.7

[1] Official projection by the Government of Korea.

Source: U.S. Department of State, U.S. Department of Commerce, Embassy of South Korea-Washington, DC, IMF.

This expansion was bankrolled principally through short-term debt-financed investment.[9] The need for bank loans to cover expansion plans grew immensely as the chaebols globalized. To meet the growing demand for capital, Korea's banks borrowed heavily from foreign creditors, including Japan (40 percent), Western Europe (45 percent), and the United States (15 percent).[10] Korean businesses also amassed more than $12 billion in short-term debt to Japanese banks.[11] Reportedly, government policies towards "favored industries" not only protected them from international competition, but also granted them special financial and tax benefits.[12] Government officials had sufficient control over the nation's banking system to direct capital to favored industries. According to Korea's finance minister, "the government-led development strategy of the last 30 years was effective in mobilizing production factors for rapid industrialization, enabling Korea to achieve remarkably high economic growth of over 8 percent per annum."[13] In the end, Korea's emphasis on high growth rates created unforeseen structural problems in its economy. Observers note that some delays in Korea's adoption of a democratic, free-market economy compounded these problems by perpetuating collusive links between the government and the private sector, and reinforcing powerful proclivity on part of government to intervene in the market.[14]

With greater economic globalization, Korea's major corporations reportedly became less competitive in world markets, effectively making debt-financed growth increasingly perilous. By the beginning of 1990, Korea's current account had slipped into the red and its gross foreign debt had more than tripled by 1996.[15] According to the IMF, "Korean conglomerates undertook an aggressive investment drive financed by large increases in borrowing from domestic banks, which, in turn, sharply increased short-term external borrowing. During 1997, an unprecedented number of highly leveraged conglomerates went into bankruptcy as the buildup in capacity proved unviable, owing to the depreciation of the won, a sharp decline in demand for Korean exports in Asia, and the slowing of domestic demand in 1996."[16] Often, Government officials reportedly directed the borrowed capital to favored industries without regard to the borrower's ability to repay. Access to these funds accelerated Korea's

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[9] Ibid.

[10] Thomas S. Mulligan, "IMF Disburses $2 Billion Payment to South Korea," the *Los Angeles Times*, Dec. 31, 1997, NEWSEDGE, retrieved Jan. 12, 1998.

[11] Kang Yeoun-sun, "Yen's Fall Feared to Deal Double Blow to Economy; Exports to Lag, Shaky Won-Dollar Rates to Delay Recovery," *Korea Herald*, Apr. 6, 1998, found at Internet address http://www.koreaherald.co, retrieved Aug. 31, 1998.

[12] Anthony Spaeth, "Biting the bullet," *Time*, Dec. 5, 1997, found at Internet address http://pathfinder.com/ time, retrieved Aug. 20, 1998.

[13] Finance Minister Lee Kyu-Sung, *Korea's Economic Restructuring: Progress Report and Future Plans*, May 20, 1998, The Republic of Korea Embassy-USA, found at Internet address http://korea.emb.washington.dc.us/
new/policy/speech/sppeck.wcgi?92v, retrieved Aug. 20, 1998.

[14] "South Korea's New Start," *The Economist*, Jan. 3, 1998, retrieved Apr. 23, 1998.

[15] Dr. Duck-woo Nam, *The Financial Crisis in Korea*, 11th Conference of the Korea-U.S. Business Council in Hawaii, Jan. 9, 1998, found at Internet address http://www.keia.com, retrieved Aug. 20, 1998.

[16] *IMF Concludes Article IV Consultations with Korea*, IMF, press release No. 98/39, June 9, 1998, found at Internet address http://www.imf.org, retrieved June 19, 1998.

globalization efforts, allowing the chaebols with extremely high debt-to-capital ratios to use billions of dollars in short-term funds to finance long-term investment.[17] Korea's chaebols were allowed to operate on narrow profit margins with an almost inexhaustible line of credit.[18] This almost risk-free expansion eventually put many of Korea's chaebols in danger of bankruptcy as they "over-extended and over-borrowed during Korea's decades of growth."[19] By the end of the first quarter of 1998, the average debt to equity for Korea's largest 30 chaebols had grown to nearly 519 percent, up from over 386 percent in 1996, and Korea's total external debt accounted for approximately 32 percent of its GDP.[20]

A series of major bankruptcies, high interest rates, and a drop in Korea's exports combined to leave Korea's banks with billions of dollars in bad debts. As of January 1998, eight prominent and highly leveraged chaebols, including those controlling Hanbo Iron & Steel and Kia Motors, and nearly 15,000 small and medium-size firms filed for bankruptcy after finding themselves no longer able to service their excessive debts.[21] The IMF reported that these bankruptcies "resulted in a severe deterioration in the balance sheets of Korean financial institutions."[22] The Korean Government struggled with the choice of declaring a debt moratorium or allowing Korea's banks to default on more than $154.4 billion in nonperforming loans from foreign banks, 44 percent of which were in the form of short-term debt.[23]

These conditions reportedly undermined foreign creditors' confidence in Korean banks. The cost of borrowing abroad began to rise and it became increasingly difficult for Korean banks to find new sources of capital. By November 1997, confidence had declined to the point where foreign banks would no longer roll over maturing debts. According to informed sources this, in turn, precipitated a massive outflow of capital as wealthy Koreans and foreign investors began to withdraw their investments from Korean stocks and bonds and converted their holdings into dollars.[24] At the same time, a number of banks, mostly merchant banks, reportedly faced serious liquidity problems, as well as possible insolvency.

The capital outflow placed severe strains on the Korean central bank's foreign exchange reserves as stock prices plummeted and as the value of the won depreciated to record levels

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[17] Kevin Sullivan, S. Korea Bows to IMF on Reforms," *Washington Post*, Dec. 30, 1997, NEWSEDGE, retrieved Jan. 12, 1998.

[18] *IMF Concludes Article IV Consultations with Korea.*

[19] Sandra Sugawara, "Big Korean Firms Set for Fight," *Washington Post*, June 19, 1998, pp. C13.

[20] *Korea's Economy Reinvented: Strategy Details and Progress (June 1998)*, Ministry of Finance and Economy, Press Release, June 12, 1998, found at Internet address http://kiep.gov.kr, retrieved Sept. 25, 1998.

[21] Kevin Sullivan, "S. Korea Bows to IMF on Reforms," *Washington Post*. "Editorial: Reforms and Market Economy," *Korea Herald*, June 16, 1998.

[22] *IMF Concludes Article IV Consultations with Korea.*

[23] *Address by Republic of Korea President Kim Young Sam*, Nov. 22, 1997, found at Internet address http://www.foreignaffairs.org, retrieved Aug. 20, 1998.

[24] "Credit Crunch Endures Despite Liquidity," *Business Korea*, Oct. 1998, retrieved Nov. 13, 1998.

against the U.S. dollar. The evolving financial crises in Thailand and Indonesia, Hong Kong's declining stock market, and the banking crisis in Japan exacerbated foreign creditors trepidations as they reduced credit lines.[25] As the volume of nonpreforming loans grew larger, international credit rating agencies downgraded Korean corporate debt issues to speculative grade and the Bank of Korea was forced to provide the nation's private banks with emergency foreign exchange to prevent them from defaulting.[26]

In late August, IMF officials indicated that the Korean Government introduced a series of financial stabilization measures and reforms designed to inject liquidity, assist failing corporations, and boost confidence in its financial system. These measures, however, proved to be largely ineffective in restoring confidence and slowing the outflow of capital.[27] Korea was forced to request emergency assistance from the IMF in late November 1997 because its usable foreign exchange reserves were nearly exhausted. An IMF-led bailout was intended to restore confidence and stem the outflow of foreign capital. However, because these initial measures did not prove to be adequate, the Korean Government was forced to seek additional assistance from the IMF.

Economic Stabilization Efforts

On December 4, 1997, Korea and the IMF reached an agreement on a "Mexican-style" economic financial aid and reform package totaling more than $58.2 billion.[28] The package included monies from the World Bank, the Asian Development Bank (ADB), and the Group of 7 countries, including the United States and Japan (figure 1). The IMF alone pledged to provide $20.9 billion in the form of a 3-year credit line. The IMF adjustment program included a variety of restructuring measures designed to raise the confidence of the international business community in Korean financial institutions, end the massive outflow of capital from Korea, promote the regeneration of domestic demand, reinforce Korea's social safety net, and restructure Korea's financial and corporate sectors.[29] The program was conceived to pare Korea's current account deficit to less than 1 percent of GDP in 1998-99, contain inflation at or below 5 percent in 1998, and restrict Korea's GDP growth to no more than 3 percent in 1998.[30]

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[25] U.S. Department of Commerce, *Korea: Economic Trends and Outlook*, National Trade Data Bank, Country Commercial Guide, Stat-USA Database, found at Internet address http://www.stat-usa.gov, retrieved Jan. 5, 1999.

[26] *IMF Concludes Article IV Consultations with Korea.*

[27] *Korea's Economic Adjustments Under the IMF-supported Program*, Presentation by Kunio Saito, Director, Regional Office for Asia and Pacific, IMF, at the Sogan University/Korea Economic Daily Conference, Jan. 21, 1998, found at Internet address http://www.imf.org, retrieved Sept. 16, 1998.

[28] *IMF Concludes Article IV Consultations with Korea.*

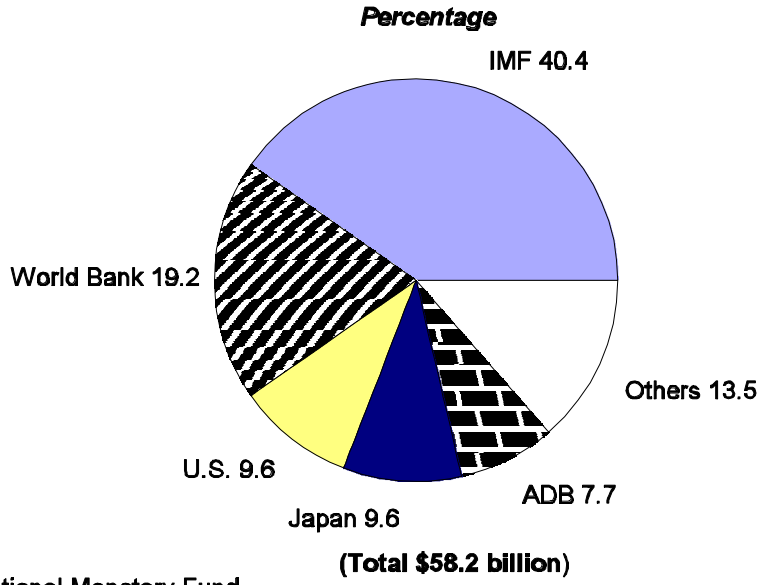
[29] Chol-Hwan Chan, Governor Bank of Korea, *Letter of Intent of the Government of Korea*, IMF, July 24, 1998, found at Internet address http://www. Imf.org, retrieved Sept. 16, 1998.

[30] *Summary of the IMF Agreement*, The Republic of Korea Embassy-USA, Apr. 4, 1998,

(continued...)

In conjunction with the IMF program, the Korean Government reportedly has pledged to intensify and accelerate additional macroeconomic policy adjustments and structural reforms long sought by its principal trading partners.[31] For example, the Korean media notes that the Korean Government has proposed reforms to its economy that would have been considered "unthinkable" before the crisis; these include the closure of insolvent banks that fail to satisfy the standard capital adequacy ratio of 8 percent set by the Bank for International Settlement (BIS), the adoption of policies allowing strategic alliances with foreign firms, creating more transparency between the private sector and government, and the implementation of new rules governing Korea's chaebols (table 2).[32]

Figure 1
Sourcing of emergency funds for Korea based on IMF Agreement



Source: International Monetary Fund.

[30] (...continued)
found at Internet address:http://korea.emb.washington.dc.us, retrieved Sept. 25, 1998.

[31] Deputy Prime Minister Kang, *Economic Turn-Around*, The Republic of Korea Embassy-USA, official speeches, Sept. 22, 1997, retrieved Jan. 5, 1999.

[32] "Reforms and Market Economy," *Korea Herald*, June 16, 1998.

Table 2
Specific reforms proposed by the Korean Government

Financial Sector:

- Implemented a new purchasing method to enable the Korean Asset Management Corp. (KAMC) to absorb additional bad loans held by failing banks. The government intends to write off 50 percent of all bad loans by the end of 1997 and eliminate all bad loans by the end of 1999.
- Steps have been taken to develop a stronger, more transparent and globally competitive financial industry, including voluntary and enforced restructuring through merger and acquisitions. The result of these bank mergers will be greater capitalization for the remaining banks and increased activity in areas, such as securities, that are not traditionally a part of bank business. Fourteen insolvent merchant banks have been closed and 1 suspended; 2 commercial banks were recapitalized and were placed under supervision.
- Announced the privatization of 5 state-owned enterprises and their 21 subsidiaries, and the gradual privatization of 6 other state-owned enterprises.
- The trading band in which the won is allowed to float will be increased from 2.25 percent to 10 percent, in order to better reflect depreciation expectations in the market once the foreign exchange markets are stabilized. Capital market will also undergo substantial liberalization.
- Limits on swap facilities with the central bank will be increased for foreign bank branches in Korea to improve capital inflow. Overseas borrowing by major public enterprises will be encouraged. Other government measures to attract new foreign capital include facilitating crude oil imports, granting permission to airlines to apply a "sale and lease-back" method for aircraft purchases, and considering the issue of treasury bills in the international financial market. The capital account was substantially opened to foreign investment.
- Will require merchant banks to have a minimum capital ratio of 8 percent by June 30, 1999.
- The government will release relevant financial data concerning the size and terms of foreign debt and current size of non-performing assets of domestic financial institutions. Also released will be data on the size of bad loans held by individual commercial banks.
- The short-term interest rate (call rate) was raised from 12.5 percent to 25 percent.
- A revised Bank of Korea Act providing for central bank independence was submitted to the National Assembly. The bill would consolidate supervision of all the banks, including specialized banks, merchant banks, and other financial institutions, in an agency with operational and financial autonomy needed to deal with the financial institutions now in distress.
- Up to $3.3 billion in trade finance will be provided on commercial terms to small and medium-sized companies.
- Institute labor market reform to facilitate the redeployment of labor.

Chaebol (family owned conglomerates):

- Improve their capital structure; require chaebol to appoint outside directors.
- Chaebol are required to produce combined financial statements beginning January 1998.
- Strengthen the rights of share holders, particularly those with minority holdings.

Table 2—*Continued*
Specific reforms proposed by the Korean Government

Trade liberalization:
• Set a timetable to eliminate trade-related subsidies and phase out the import diversification program, as well as streamline and improve the transparency of import certification procedures.
• Reduce the number of items subject to adjustment tariffs from 62 to 38.
• Fully liberalized foreign investment and foreign exchange transactions. Opened an additional 30 industries to foreign direct investment; leaving only 31 of 1,148 industries restricted from foreign participation. Allowed foreigners to own land.

Source: *Recent Korean Economic Trends & Status of Structural Reform*, speech by Mr. Hoon Shin, Deputy Governor, Bank of Korea, June 26, 1998, found at Internet address http://www. bok.or.kr, retrieved Nov. 2, 1998. Republic of Korea Ministry of Foreign Affairs, Ministry of Finance and Economy.

On March 27, 1998, the Korean Government announced that it would use $300 million provided by the World Bank to help Korean manufacturers aggressively finance and promote exports. Korea has also received loans from its principal trading partners tied to its import of raw materials, capital goods, and intermediate goods needed by its export industries. The U.S. Export-Import Bank agreed to provide Korea with $2 billion in loans tied to the purchase of U.S. inputs to help maintain Korean imports of U.S. capital goods. It also raised its short-term export insurance limit to $750 million, increased the number of eligible Korean banks from 6 to 10, and extended the Credit Guarantee Program for $3 billion ($1 billion in short-term credit and $2 billion in medium-term credit).[33] The U.S. Department of Agriculture's Commodity Credit Corporation Export Credit Guarantee Program (GMS-102) is supporting $1.5 billion in U.S. agricultural exports to Korea in 1998 and an additional $50 million in 1999.[34] The Japanese Export-Import Bank recently granted $1 billion in import letters of credit to assist Korean importers purchase imports of raw materials and equipment from Japan.[35] Germany pledged to provide Korea with $200 million in export credits and its Bayerische Vereins bank agreed to invest about $260 million to several Korean commercial banks.[36] Likewise, Australia provided a $200 million credit to fund the purchase of Australian agricultural products.[37]

[33] "Washington Stepping Up Export Drive to Korea," *Korea Herald*, Feb. 4, 1998.

[34] U.S. Department of Agriculture, *USDA Extends Fiscal 1998 GMS-102 Credit Guarantees to South Korea*, Sept. 29, 1998. *USDA Extends Supplier Credit Guarantees to South Korea*, Oct. 9, 1998, found at Internet address http://www.fas,usda.gov, retrieved Jan. 20, 1999.

[35] "Japan to Lend $1 billion to Korea for Import Financing," *Korea Herald*, May 25, 1998.

[36] Kang Yeoun-sun, "U.S. Extends $2 Billion Loan to Korea," *Korea Herald*, June 12, 1998.

[37] "Australia to Extend $200 million Credit to Korea," *Korea Herald*, Mar. 14, 1997.

Bilateral U.S. -Korean trade

Korea reported that the United States accounted for 15 percent of its total exports and for 22 percent of its total imports during 1997. Total merchandise trade between the United States and Korea increased by 54 percent between 1992 and 1997, rising from $30.7 billion to $47.2 billion (table 3). The bilateral trade surplus held by the United States during 1995-97 appears to be shifting back to Korea's favor in view of developments in 1998, as Korea experienced a trade surplus of $4.8 billion through July 1998.

Table 3
U.S.-Korean trade, 1992-97

(*Million dollars*)

Trade	1992	1993	1994	1995	1996	1997	Jan.-July 1997	Jan.-July 1998
U.S. exports	14,220	14,359	17,499	24,483	24,433	24,287	15,882	8,578
U.S. imports	16,523	16,986	19,547	24,026	22,532	22,939	13,011	13,396
Trade balance	-2,303	-2,627	-2,048	547	1,901	1,348	2,871	-4,818

Source: Complied from official statistics of the U.S. Department of Commerce.

U.S. Exports

After increasing by 72 percent during 1992-95, U.S. exports to Korea declined by an average annual rate of 0.4 percent during 1995-97 and plummeted by 46 percent during the first 7 months of 1998 compared with January-July 1997 (figure 2). During this period, Korea reported a jump in import prices by 50 percent, consumer price inflation of 99 percent, and a decline in household income by between 10 to 15 percent.[38] Consequently, by the end of July 1998, Korea had dropped from the fifth- to the 11th-largest market for U.S. exports. Despite Korea's rank, U.S. exports to Korea accounted for only 3.8 percent of U.S. global exports during 1997. Traditionally, U.S. exports to Korea consisted primarily of capital goods and equipment, electronic components, aircraft, computers, and raw materials important to Korea's export industries (table 4). In 1997, the 10 leading U.S. export categories accounted collectively for 40 percent of total U.S. exports to Korea.

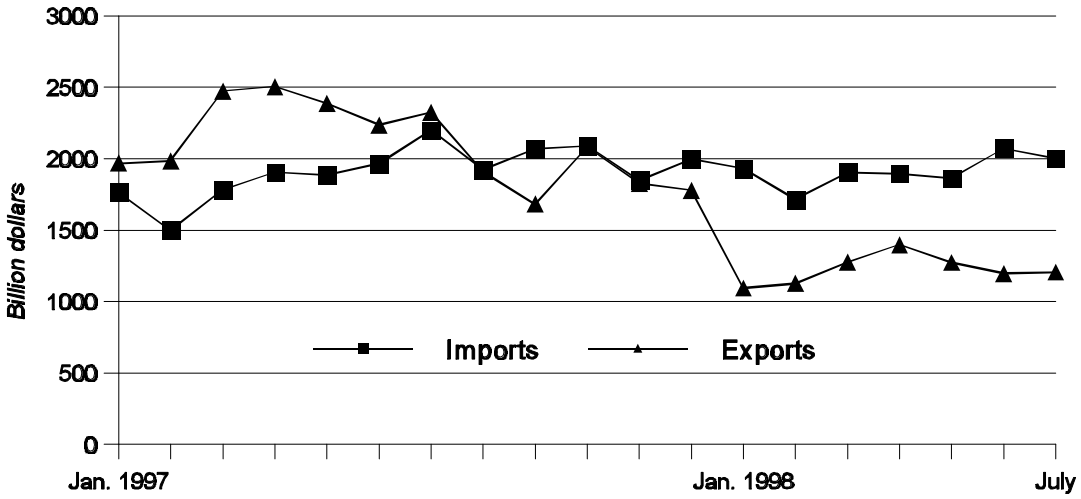
Korea's demand for U.S. products was adversely affected by a 50-percent devaluation of the won against the dollar by the end of 1997, declining domestic consumption, a record decline in investment in new plant and equipment, and the reluctance on the part of local banks to buy export bills of exchange.[39] As of August 1998, letters of credit opened for imports were more than 43 percent below the November 1997 level.[40] The Korean press reported that

[38] U.S. Department of State telegram No. 003943, "OECD: ERDC Annual Review of Korea," prepared by U.S. Embassy, Seoul, July 10, 1998.

[39] U.S. Department of State telegram No. 007539, "Korea's Economic Crisis: What Does It Mean for U.S. Business?," prepared by U.S. Embassy, Seoul, Dec. 24, 1997.

[40] U.S. Department of State telegram No. 005270, "ROK Exports Decline Again in August," Prepared by U.S. Embassy, Seoul, Sept. 9, 1998.

Figure 2
U.S.-Korean bilateral trade, Jan. 1997-July 1998



Source: Compiled from official statistics of the U.S. Department of Commerce.

Table 4
Leading U.S. exports to Korea, by product, 1992-97

(*Million dollars*)

Product	1992	1993	1994	1995	1996	1997
Electric integrated circuits	730	876	1,186	1,541	1,559	2,680
Aircraft, spacecraft, parts	1,481	1,490	1,674	2,182	2,107	2,161
Computers, office machinery, and parts	481	548	726	991	1,198	1,297
Medical and scientific equipment	486	538	733	827	1,117	1,086
Raw hides and skins of bovine or equine animals	539	496	560	648	567	553
Ferros waste and scrap	167	180	231	302	388	499
Corn (maize)	206	53	253	1,114	1,262	452
Soybeans	247	247	228	336	439	372
Television, radio transmission and reception apparatus	157	207	458	504	578	371
Turbojets, turboprops, other gas turbines	324	94	196	419	242	335
Top 10 total	4,818	4,729	6,245	8,837	9,457	9,806
Percent of total U.S. exports	34	33	36	36	37	40

Source: Complied from official statistics of the U.S. Department of Commerce.

the IMF program was also contributing to the decline in the demand for U.S. exports as it created a severe cash crunch, high unemployment, wage cuts, and high inflation.[41] The demand for imports was also unfavorably affected by grass roots "Buy Korean" campaigns aimed at conserving scarce foreign exchange and by a reduction in industrial production and expansion plans by most of Korea's industries. Korea reported that its imports of consumer goods declined by 72 percent during the first half of 1998, capital goods by 34 percent, machinery by 62 percent, and raw materials by 34 percent.[42]

U.S. Imports

U.S. imports from Korea increased by more than 39 percent, to $22.9 billion, during 1992-97, but still only accounted for 2.7 percent of total U.S. imports during 1997. U.S. imports from Korea increased by 1.8 percent in 1997 and 3.0 percent during the first 7 months of 1998 compared to the corresponding periods of 1996 and 1997 (table 5). The leading U.S. imports from Korea consisted of DRAM chips and electronic equipment, computers and office machinery, steel, and apparel. The 10 leading U.S. import categories accounted for 62 percent of total U.S. imports from Korea during 1997.

Table 5
Leading U.S. imports from Korea, by product, 1992-97

(*Million dollars*)

Product	1992	1993	1994	1995	1996	1997
Electric integrated circuits	1,890	2,423	3,851	6,929	6,112	5,860
Computers, office machinery, parts	1,379	2,173	2,495	3,866	3,878	4,167
Motor vehicles and parts	877	866	1,638	1,816	2,205	2,102
Televisions, radio transmission and reception apparatus	206	287	401	515	287	410
Electric water heaters	269	304	414	451	416	387
Sweaters, pullovers, sweatshirts, waistcoats	402	383	410	334	281	351
Flat-rolled iron or nonalloy steel products	252	125	235	253	239	238
Women's or girl's suits, ensembles, suit-type, jackets dresses, skirts, divided skirts, trousers	289	284	276	279	245	237
Woven fabrics of synthetic filament yarn	121	170	144	179	190	213
Men's or boy's overcoats, raincoats, cloaks, anoraks	209	250	266	215	190	210
Top 10 total	5,894	7,265	10,130	14,837	14,043	14,175
Percent of total U.S. imports	36	43	52	62	62	62

Source: Complied from official data provided by the U.S. Department of Commerce.

Korea and Japan compete intensely in the United States and other global markets for products such as semiconductors, consumer electronics, automobiles, steel, ships, and petrochemical products.[43] Contrary to expectations, the sharp devaluation of the Korean won did not lead to

[41] Chun Sung-woo, "Economy Seen Contracting Under IMF Program; Private Institute Predict Zero or Negative Growth Due to Tight Monetary Policy," *Korea Herald*, Jan. 1, 1998.

[42] "Imported Luxury Consumer Goods Down 72 percent," *Korea Herald*, Apr. 2, 1998.

[43] Ibid.

a massive influx of Korean products into the U.S. market in the first 7 months of 1998.[44] Although the strong dollar was expected to help Korean exporters increase their share of the U.S. market, many of the benefits Korea may have derived from the depreciation of the won were offset by the continued weakness of the Japanese yen against the U.S. dollar. Since a large portion of Korea's exports compete with Japanese products in the U.S. market, declines in the value of the yen helped Japanese products maintain their price competitiveness.[45] Further, in advanced economies like the United States, domestic consumption patterns for these goods are influenced much more by product quality than solely by a sudden drop in price.[46] Since Japanese products are often perceived to be superior in quality to competing Korean products, a decline in the price of Korean exports alone was not sufficient to offset the demand for quality goods in the U.S. markets. Due in part to the lower price strategies of Southeast Asian nations, particularly Thailand, Indonesia, and Malaysia, Korea was not able to export itself out of its financial and economic difficulties.[47] According to a Bank of Korea economist, "as opposed to the theory, the country has failed to recoup the benefits of the so-called 'J-curve'[48] effects" of the devaluation. During the first 5 months of 1998, Korea's total exports increased by 35 percent in won terms, but only modestly in dollar terms (8 percent).[49]

Outlook

In the near term, Korean demand for U.S. exports is expected to remain sluggish as Korea continues to undergo major structural adjustments and belt-tightening measures mandated by the IMF recovery program. Further, Korean businesses reportedly are scaling back their investment spending in response to the exceptionally high cost of borrowing, excess capacity, and severe balance sheet problems.[50] Employment and household disposable income are also expected to decline in response to company downsizing and increasing consumer prices despite some forecasts of increases in Korea's real GDP growth rate. By the middle of 1998, Korea's exchange market and stock price index had begun to stabilize, and Korea's current account

[44] "Expanding Focus," *Business Korea*, Mar. 1998, p. 57. Sohn Tae-soo, "Export Prospects Gloomy for Second Quarter," *Korea Herald*, May 21, 1998, retrieved June 15, 1998.

[45] Koo Hee-jin, "Exporters in Emergency on Yen's Tumble," *Korea Herald*, May 27, 1998.

[46] Ibid.

[47] Ibid.

[48] The effect of exchange rates on trade flows are usually experienced gradually, over a period of approximately 6 months to 2 years after the initial shift in the real exchange rate. The lag takes place because it takes time to adjust export prices, as expressed in foreign currencies, to account for exchange rate changes. This phenomenon is known as the *J-curve* effect because a graph of the path of the trade balance after an exchange rate depreciation resembles the letter "J". U.S. International Trade Commission, *Shifts in U.S. Merchandise Trade in 1997*, publication 3120, July 1998, p. D-4.

[49] *Korea's Economy Reinvented: Strategy Details and Progress (June 1998)*, Ministry of Finance and Economy, press release, June 12, 1998.

[50] "1st Quarter Machinery Imports Drop 50 Percent," *Korea Herald*, Apr. 20, 1998.

balance is projected to rebound to a $35 million surplus by the end of 1999.[51] High interest rates should also attract foreign investors to the Korean bond market. Exchange and inflation rates reportedly are expected to remain high and the number of bankruptcies and unemployment are likely to grow.[52] However, there have been some early signs of economic rebound.

The Korean Government believes it has taken many of the steps necessary to restore its economic competitiveness and boost the confidence of international markets in its financial system.[53] In 1998, President Kim pledged that Korea's economy would eventually emerge as a truly open market as Korea dismantled existing trade barriers, opened most industrial sectors to international competition, and shifted the government's role from one of "market leader" to one of market "supporter."[54] However, President Kim acknowledged that even with the implementation of these reforms it will likely take several years before positive results are observed.

Although there has been some skepticism about the Korean Government's willingness to deregulate the economy, some steps have already been taken. During 1998, Korea also revised foreign direct investment (FDI) rules to attract much needed foreign investment. "Hostile" and "unfriendly" mergers and acquisitions by foreign investors will now be permitted. Foreign equity limits were raised from 33 percent in 1996 to 55 percent in 1997, and in May 1998, all barriers were removed to foreign equity ownership in approximately 97 percent of Korea's industries.[55] Foreign investors, once effectively barred from investing in domestic manufacturing, are now being courted as redeemers by debt-ridden companies. There are presently a large number of distressed, but operationally sound, small and medium-sized companies that are now available to foreign investors at highly competitive prices.[56] Foreign direct investment in Korea has steadily grown during 1998 as Korea successfully implemented liberalizing measures and achieved stability in its foreign exchange market. These reforms have drawn a number of foreign companies to Korea. For example, Hewlett Packard announced that it would invest $200 million to expand its Korean production base and to acquire additional property for its Korean operations; Gillette announced that it would purchase the rights to a Korean battery manufacturer for $60 million.[57] Also, the Ssangyong

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[51] *Prospects for the Korean Economy*, Republic of Korea Embassy-USA, found at Internet address http://korea.emb.washington.dc.us, retrieved Aug. 20, 1998.

[52] "International Economy: Asia," *Barclays Economic Review*, first quarter 1998, pp. 27-29, retrieved Apr. 23, 1998.

[53] Park Kun Woo, Trade, ambassador of Republic of Korea, Embassy-USA, Official speeches, Oct. 17, 1998, found at Internet address http://korea.emb.washington.dc.us, retrieved Jan. 5, 1999.

[54] *A Way Out for the Korean Economy*, Republic of Korea Embassy-USA, press release, June 10, 1998, found at Internet address http://korea.emb.washington.dc.us, retrieved Aug. 20, 1998.

[55] Kang Yeoun-sun, "Slow Reforms Blamed for Latest Economic Ills; Korea's Financial System Faces High Risk Among 8 Asian Economies, J.P. Morgan Says," *Korean Herald*, May 27, 1998, found at Internet address http://www.koreaherald.co, retrieved June 15, 1998.

[56] Hur Nami-Il, "Korean Companies 'on sale'," *Business Korea*, Feb. 1998, retrieved Nov. 3, 1998.

[57] *Korea News Briefs*, Republic of Korea Embassy-USA, Apr. 1998, found at Internet address

(continued...)

Group sold Ssangyong Paper to Procter & Gamble in order to raise much needed cash.[58] Other foreign firms investing in Korea include BASF, Rothschild, Volvo, Coca-Cola, Motorola, and Commerz Bank of Germany.

Demand for U.S. raw materials and capital goods should begin to grow in the medium term. Korean firms generally rely on imported manufacturing inputs and intermediate goods to produce goods for export. Eventually, Korea will begin to run a shortage of materials for its manufacturing sector and will have to import or face additional economic difficulties. Government sources indicated that the projected current account surplus indicates that Korea is not importing the inputs necessary to revive its economy.[59] Hence, demand for U.S. machinery, equipment, and consumer durables should grow as Korea's economy emerges from its current recession.**#**

[57] (...continued)
http://korea.emb.washington.dc.us, retrieved June 15, 1998. U.S. Department of Commerce, *The Asian Commercial Overview*, Sept. 18, 1998, NTDB database, found at Internet address http://www.stat-usa.gov., retrieved Nov. 3, 1998.

[58] *Acquisition Opportunities in Korea*, Fry Consultants, Inc., found at Internet address http://www.fryconsultants.com. Retrieved Aug. 20, 1998.

[59] Cho Yoon-jung, "Korea Marks Record Trade Surplus of $3.7 Billion in March," *Korea Herald*, Apr. 2, 1998, found at Internet address http://www.koreaherald.co.kr, retrieved June 15, 1998.

Advanced Structural Ceramics: Vast Potential Has Yet to be Realized

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A great deal of initial promise had been expected of advanced structural ceramics (ASC)[2] by virtue of their high strength-to-mass ratio, relative resistance in extreme chemical environments, high hardness and wear resistance, and their ability to withstand significantly higher temperatures than metals or polymers. However, global markets for these materials are far below projections made at the beginning of the decade. Although the use of ASC in cutting tools and wear applications continues to show sustained growth due to their demonstrated superiority in particular applications, industry's goal of significant use penetration into the huge automotive and aerospace engine components markets and the power generation industry is yet to be realized. During the next decade, ASC producers, assisted by U.S. Government initiatives, will work to make these materials more competitive by reducing product cost, speeding product development cycles, and gaining acceptance among end-users. This article examines (1) current end-use applications of ASC, (2) obstacles to commercialization of these materials, (3) efforts by industry and domestic and foreign governments to overcome these obstacles, and (4) the use of these ceramics in major global markets.

ASCs have found acceptance in key markets due to unique advantages related to their high hardness, mechanical wear resistance, and resistance to thermal and chemical breakdown (table 1). Applications requiring all or a combination of these attributes have caused ASCs to be rated often as superior to metal alternatives. Major uses for ASCs include wear parts, cutting tools, seals and bearings, and engine components (see text box). Japanese manufacturers pioneered the use of ASCs in engine applications in the late 1980s, and Japan still maintains a competitive advantage in this application.

[1] The views expressed in this article are those of the author. They are not the views of the International Trade Commission or any of the Commissioners.

[2] Advanced structural ceramics, in this context, refer to the silicon carbide and silicon nitride family of materials offering outstanding wear resistance in such applications as cutting tools, seals and bearings, and wear parts for components largely destined for the automotive, aerospace, defense, and papermaking industries.

Table 1:
Advanced structural ceramics: End-use industry, application, material properties, global and U.S. market size (1997, estimated)

Item	End-use industry	Application	Material properties	Global market size	U.S. market size
				Million dollars	
Wear parts . . .	Chemical Military Paper-making Power-generation	Spray nozzles, resistant bearings, military armor, turbine blades, turbine spray nozzles	Chemical and thermal resistance, high hardness	300	100-120
Cutting tools . .	Automotive Aerospace	Tooling for turning and milling operations	Chemical and thermal resistance, high fracture toughness, chipping resistance	150	40-50
Seals and bearings	Automotive Aerospace Dental	Pump seals, ball and shaft bearings	Chemical resistance, sliding wear resistance, high compression strength	(1)	(1)
Engine components . . .	Automotive Aerospace	Turbocharger rotors, water pump seals, nozzles, spacer rings	Wear resistance, strength and toughness, mechanical fatigue resistance	2 52	(1)

[1] Not available.
[2] Includes only silicon nitride engine components.

Source: R. Nathan Katz, “Wear Application of Silicon Carbide and Nitride Ceramics.”

Current Markets for Advanced Structural Ceramics

Wear parts

Major industrial wear applications for ASCs include use as paper foils in the paper industry and applications in the chemical and minerals industries, where desulfurization systems require spray nozzles that resist both sulfuric acid and a lime slurry. Silicon nitride hybrid bearings are well suited to the chemical and atmospheric conditions present in semiconductor processing while silicon carbide has proven its value as an armor material in uses ranging from aircraft protection to individual soldier protection.

Cutting tools

The most sustained use for ASCs has been in the market for cutting tools, particularly for use in manufacturing automotive and aircraft components, which requires significant hardness of materials at elevated temperatures, high fracture toughness, high thermal shock resistance, chipping resistance, and chemical inertness. ASCs are increasingly becoming materials of choice for the cutting tool industry; they present serious alternatives to traditional metal tools, including tool steels and cermets (ceramic/metallic composites), as well as superabrasive tools such as diamond and cubic boron nitride, because they offer dramatic advantages in cutting speed, precision, maintenance minimization, and longevity. The market for advanced ceramics cutting tools is dominated by silicon nitride (Si_3N_4)-based materials. Silicon nitride is the single most commonly used ceramic material for turning, milling, and other cutting operations performed on gray cast iron and nickel-based superalloys used by the automotive and aircraft engine industries. The percentage of advanced ceramics cutting tools has grown from less than 3 percent of the total cutting tool market a decade ago to 6 to 10 percent today.

Seals and bearings

Silicon carbide seals are used in pumps operating in environments where the fluid being pumped is highly corrosive, and in slide bearings of certain "leak-proof" chemical pumps using a slurry of hydrochloric acid and abrasive solids. On average, a silicon carbide slide bearing used in such a magnetic pump drive lasts 18 months between replacements, compared to a life of 2 to 3 weeks for a similar metallic component. Silicon nitride roller bearings are used in machine tool spindles, turbomolecular pumps (low-volume evacuation pumps used in semiconductor manufacturing and scientific and technical laboratories), mainshafts, and shafts for dental drills; advantages include high strength, fracture toughness, resistance to mechanical fatigue and crack growth, and an ability to operate in low-lubrication environments. Such bearings have been used most recently in the space shuttle main engine fuel pump, where it is anticipated that they will outlast steel bearings by a factor of 10.

Engine components

Silicon nitride and silicon carbide are increasingly used in automotive engines and components such as turbochargers and water pumps. Silicon nitride was chosen as the material of choice for turbocharger rotors and rocker arm wear pads in 1985 by Japanese manufacturers to increase the horsepower of 4-cylinder Japanese cars due to its combination of wear resistance, toughness, strength, and mechanical fatigue resistance. The reliability of the ceramic turbocharger has been such that Japanese automakers issue the same warranty (70,000 miles) for ceramic units as for metal units. The silicon carbide water pump seal was introduced in Japan during the late 1980s to eliminate primary failure caused by leakage through the seal.

Source: R. Nathan Katz, "Wear Application of Silicon Carbide and Silicon Nitride," June 1998.

The commercial U.S. introduction of silicon nitride components[3] into engines occurred during the early 1990s, and has been largely confined to heavy-duty diesel engines, principally manufactured by Detroit Diesel Corp. and Cummins Engine.[4] Manufacturers have begun to adopt the use of ceramic components, particularly in diesel applications, because they are reliable and despite the cost disadvantage of these ceramic components, as compared to the cost of similar metal components. Ceramic components resist harsh fuel delivery environments created by diesel fuels better than metal components do, thus making it easier keep the system operating within the warranty period issued by the manufacturer.[5] The introduction of silicon nitride into U.S. commercial aircraft turbines by AlliedSignal Inc. has occurred only in recent years and only in nozzles, auxiliary power unit oil spacer rings, and seal runners; the latter is used to better control oil leakage occurring in certain aircraft. The use of silicon nitride has also resulted in a tenfold increase in seal life.[6]

Near Term Potential Applications

A major breakthrough for advanced ceramics applications beyond current markets is not anticipated by industry sources during the next 3 to 5 years because of the current high cost of the components. Instead, the application of these materials within current markets is likely to broaden. Reportedly, the silicon nitride automotive valve retains the greatest potential for any single ASC product. Mercedes Benz Gmbh is currently evaluating the costs and benefits of using ceramic valves in a test fleet of its vehicles.[7] Positive results could enormously promote the use of ceramics as a valve material--a breakthrough that has been widely anticipated for the last decade. In another automotive-related development, Ceradyne, Inc. (Costa Mesa, CA) has announced that it expects to ship 1 million dollars worth of silicon nitride engine components, including cam and fuel pump roller followers, annually, beginning in 1999. The company anticipates significantly higher sales volumes in the year 2000 and thereafter.[8]

After automotive and aerospace, the largest potential market for ceramics appears to be industrial gas turbines for electric power generation. Positive results from thermal and stress analyses tests, conducted by the U.S. Department of Energy, may prepare the way for the use of advanced ceramics in applications such as silicon nitride gas turbine blades and nozzles

[3] Components include fuel injector links, cam roller followers, fuel injection check balls, and fuel pump cam roller followers.

[4] R. Nathan Katz, “Silicon Nitride: Applications and Markets,” Mar. 1998, p. 10.

[5] USITC staff telephone interview with R. Nathan Katz, Worcester Polytechnic Institute, Washington, DC, Oct. 2, 1998.

[6] Ibid.

[7] Ibid.

[8] "Ceradyne, Inc. Receives Diesel Engine Ceramic Components Award,” Ceradyne, Inc. press release, Nov. 10, 1998.

in industrial gas turbines for power generation.[9] However, the first commercial application in electrical power generation is likely to be in the form of ceramic composite combustor liners for gas turbines due to their unique high-strength properties at the elevated temperatures reached by such turbines.[10]

The worldwide market for ASCs is currently growing at an estimated annual rate of 7 to 8 percent, and, according to one market forecast, is estimated to reach approximately $1.5 billion in sales worldwide by the year 2000.[11] U.S. consumption of ASCs reached approximately $365 million in 1996, and is forecast to reach $542 million by 2001.[12] Although this projected 9-percent annual increase remains a respectable rate of industry growth, it is below the 10- to 20-percent growth rates projected for this industry at the beginning of the decade.

Obstacles to Further Commercialization

To gain acceptance for its products, the ASC industry has had to eliminate many technical barriers that have retarded use in the past. Ceramic brittleness has been largely contained by creating stronger and denser materials that resist the propagation of surface cracks that develop on the surface of the material. This has been partly achieved through the use of higher purity powders and engineering advances made in the knowledge of product microstructure that permit more precise prediction of product performance. Most of the remaining hurdles faced by the advanced ceramics industry essentially stem from the lack of a standardized product data base, the lack of vertical integration among the various processing steps, relatively long lead times in bringing ceramic products to market, and high product cost related to the expense involved in machining these extremely hard materials. These factors place ASCs at a competitive disadvantage for many applications, relative to steel, aluminum, and plastics.

Lack of Shared Data Base and Product Standards

Years of design, testing, and performance experience have yielded a vast technical data set for the materials with which ASCs compete. Such a comprehensive data base, along with universally recognized product standards and a full listing of materials and grades

[9] USITC staff telephone interview with Merrill Smith, U.S. Department of Energy, Washington, DC, Mar. 4, 1999.

[10] USITC staff telephone interview with Deborah Haught, U.S. Department of Energy, Washington, D, Jan. 20, 1999.

[11] Laurel M. Sheppard, "Advanced Ceramics for the New Millennium," *Ceramic Industry*, June 1998, p. 46.

[12] "Market Push from Advanced Ceramics," *High Tech Ceramics News*, July 1997, p. 1. The data provided in this article does not include separate figures for major ASC end-uses. Estimates for these end-uses were gathered from various industry sources and are included in table 1.

commercially available, would improve the ability of ASCs to compete with traditional materials. The development of product standards would (1) establish a uniform product nomenclature regarding material constituents and testing procedures and (2) begin to address the following areas often raised by potential users:

- Elimination of variable component performance from different suppliers;
- Elimination of variable component production from a single supplier;
- Verifiable reliability of components; and
- Consistency in product quality.[13]

Industry sources believe that achievement of such goals would inspire confidence in design engineers regarding the behavior of ceramic materials over time, and encourage engineers to take advantage of unique ASC properties by recommending them in their design process.[14] A shared data base would contain information on such variables as fracture toughness, hardness, elasticity and high temperature strength, and would lead to the development of models predicting the likely behavior of ceramic components over time and under various load and thermal conditions. In the case of metals and plastics, a data base has evolved over a period of many years, yielding highly accurate predictive models of material behavior over time. In turn, these models have been used to develop product standards that design engineers use when recommending a particular part[15] in their design. Engineers can be confident of the quality and safety of metal and plastic components in their designs because of the development of such a data base and product standards, and because of the long period of practical experience with these materials. Ceramics manufacturers are said to be reluctant to contribute to organizing a shared data base because of short-term competitive disadvantages that may result from allowing a competitor to produce a particular ceramic product that another manufacturer has developed and promoted as its own.[16]

Where such a data base and predictive modeling exist for ceramics, they are often considered the property of a single part manufacturer who typically does not make the information publicly available. Often, the mechanical property data that are available to engineers are not verifiable because manufacturers use different measurement techniques to obtain these data and measurements are often not consistent among manufacturers.[17] For example, an automotive or aerospace parts fabricator who buys material from a ceramics vendor cannot compare the material properties of the purchased part with the properties of a similar part from another vendor in the same industry. As a result, customers often have to rely on a single vendor for replacement parts with the disadvantages associated with a lack of product competition and the potential instability of a vendor eventually leaving the industry or

[13] USITC staff telephone interview with James McCauley, Army Materials Branch, U.S. Department of Defense, Oct. 1998.

[14] Staff interview, McCauley.

[15] Within industry, the term "part" and the term "component" are generally used interchangeably. In this paper, the term "part" refers to the final product manufactured by the ceramics manufacturer which is incorporated by the end-user into a final design "component" in an application such as a bearing, seal, cam follower, valve, etc.

[16] Staff interviews, McCauley and Ballard.

[17] Ronald H. Chand, "Why Are Advanced Ceramics Not Materials of Choice," Mar. 1998.

discontinuing the product.[18] The problem is especially acute when designing components for defense-related applications because the U.S. Department of Defense requires that components conform to "detailed specifications and verification procedures" and "standardized characteristics and properties," to assure the quality of material purchased.. This policy effectively excludes the use of those ceramic components for which no, or few, such standards exist.[19]

Problems of Vertical Integration of Advanced Ceramics Processing

A second obstacle to commercialization of advanced ceramics concerns the unique way in which the advanced ceramics industry has evolved. In the metals and plastics industries, a number of producers manufacture a basic feed stock material, such as ingot or resin, having a widely available chemical formulation. This feedstock is then converted by independent fabricators into a part. However, the advanced ceramics industry lacks both the generic formulation of feedstock and the independent fabricator who can convert such a feedstock into a finished part. Each advanced ceramics manufacturer generally has its own proprietary products whose formulas are carefully guarded from other manufacturers. Moreover, the industry is vertically integrated in that ceramics manufacturers also fabricate finished components.[20] A customer wishing to specify a certain ASC in the design can not solicit price quotes from a group of parts fabricators, as a steel customer can from various steel fabricators, to compare prices for the manufacture of the part. The customer is committed to having the part manufactured by a single ceramic vendor. This necessarily discourages design engineers from incorporating advanced ceramics components for which the availability of replacement components depends on the survival of a single manufacturer.

Long Product Development Cycles Limit New Applications

Another major factor limiting the commercialization of advanced ceramics is the difficulty in forming rapid prototypes for ceramic products.[21] Rapid prototyping (RP) involves the forming of product prototypes or production molds through the use of Computer-Aided Design (CAD) three-dimensional computer models linked to numerically controlled or rapid prototype tooling. The process typically uses laser-assisted machining to melt and layer powder metal or liquid plastic resin into the finished prototype or mold, according to the designs of the computer model. RP is an increasingly important method to quickly translate a manufacturing design into a prototype--reducing conventional prototype design methods from a period of weeks to a matter of hours or days. The prototype can also be rigorously tested before production tooling is ordered and final production of the part begins. RP is now widely used in plastics and powder metals formation. So far, it has been difficult to adapt to ceramics because of the high melting points of ceramic materials. Rapid creation of a

[18] USITC staff telephone interview with Clifford Ballard, AlliedSignal Inc., Aug. 17, 1998.

[19] USITC staff telephone interview with James McCauley, Army Materials Branch, U.S. Department of Defense, Oct. 1998.

[20] Staff interview, McCauley.

[21] Clifford Ballard, "Targeting Ceramic Technology for Business Growth," Mar. 1998.

prototype is an essential element in the manufacture of commercial components because prototypes must be subjected to a host of qualifications testing for hardness, toughness, and thermal reaction before a finished part can be fabricated according to its design. The existing inability to adapt RP to ceramics has meant longer development cycles and more expensive qualifications testing systems for ceramic prototypes than for metal and plastic components.

High Product Cost

The difficulty in machining extremely hard ceramic materials constitutes a major cost factor in the manufacture of ASC components, often accounting for 50 percent of the selling price.[22] In addition, the machining process itself often is inherently damaging to the ceramic part because the diamond wheel grinding process used may produce micro cracks and residual stress on the surface of the material.[23] Other processes that minimize machining costs, such as near-net-shape processing[24] applied to metals and plastics, have been difficult to adapt to ceramics. For example, sintered[25] ceramics typically shrink between 15 to 20 percent, which makes it difficult to use near-net shape processes to produce components to the strict tolerances required for advanced applications. Machining costs can be lowered by machining parts in their "green"or softer state, but the shrinkage problem still arises when the green ceramic is subsequently sintered. Pressure-assisted hot consolidation methods for forming ceramics have been developed to create simple near-net shapes of extremely high densities, thus limiting shrinkage.[26] However, the ability to form complex near-net shapes is still elusive, and the industry has preferred to deal with the problem of complex shaping by designing less complex components that do not need expensive forming and machining operations.[27]

Although the cost of many ceramic components has fallen in recent years, the costs still generally exceed the cost of comparable metal components. For example, the cost of a ceramic automotive cam roller follower remains 3 to 4 times the cost of such a steel component, although down from a premium of 5 to 10 times the cost nearly 5 years ago.[28] Ceramic cam followers are used commercially in certain applications, despite this apparent cost disadvantage, because of superior wear characteristics and lighter weight. Continued

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[22] Ronald H. Chand, "Why Are Advanced Ceramics Not Materials of Choice," Mar. 1998.

[23] Ibid.

[24] Any of a variety of material forming methods which are used to produce a semimanufactured part that is close to the final manufactured part. Near-net-shape forming methods eliminate the need for extensive grinding or finishing operations.

[25] During the sintering phase, ceramic compacts are heated over a carefully controlled time/temperature profile, causing the ceramic to fuse and to reach designed density.

[26] W.M. Goldberger and Peter Booth, "Using Silicon Carbide in Advanced Ceramics," *Ceramic Industry*, June 1998, pp. 64-70.

[27] For example, an internal thread on a part is considered to be a complex shape and difficult to form or machine on a ceramic part. Ceramics processors often seek to substitute a different fastening system on complex ceramic components (USITC staff telephone interview with Joel P. Moskowitz, Ceradyne, Inc., Nov. 6, 1998).

[28] USITC staff telephone interview with John Mangels, Ceradyne Inc., Jan. 5, 1999.

success in narrowing cost differentials will likely contribute to the further commercialization of ceramic components.

Current Efforts to Make Advanced Ceramics Competitive

Efforts are underway to resolve many of the existing barriers to the commercialization of ASCs. Many of these efforts have been in the form of partnerships between ceramics producers and the U.S. Government. A few of the more significant research programs are detailed below.

Development of a Database for Structural Ceramics

A major effort to develop a standardized database for the structural ceramics industry has been led by the National Institute of Science and Technology (NIST).[29] In an effort to ensure reliable manufacturing of ceramics, NIST established the Ceramic Processing Characterization Consortium (CPCC) to work with industry to develop practical, standard measurement methods to assess certain critical properties of raw materials and green and sintered shapes.[30] The consortium consist of nearly 60 companies representing ceramic manufacturers, raw material suppliers and instrument makers, as well as 5 government agencies and 11 universities. CPCC has identified a number of target areas for the development of measurement standards.[31] NIST is also assembling and publishing its Structural Ceramics Database (SCD), which provides industry with data on strength, thermal and mechanical stability, and corrosion resistance for a wide range of ASC.[32] The goal of the SCD is to consolidate numerical data from an ever-increasing number of publications worldwide in order to facilitate the rapid comparison of material properties for product design and process development.[33] However, while industry sources believe the development of such a comprehensive data base for structural ceramics should prove extremely helpful in

[29] U.S. Department of Commerce.

[30] *Ceramic Processing Characterization Consortium*, Dec. 17, 1998, at Internet http://www.ceramics. nist.gov/programs/cpcc, and USITC staff telephone interview with Sandy Dapkunas, NIST, Dec. 16, 1998.

[31] These standards include Physical and Chemical Features of Powders; Powders in Liquid Media; Distribution and Removal of Temporary Additives; Green Bodies, Dry; Sintered Bodies; and Porous Ceramics.

[32] *User's Manual for WebSCD*, National Institute of Science and Technology (NIST), Dec. 17, 1998, found at Internet http://www.ceramics.nist.gov/srd/scd/ and USITC staff telephone interview with E.F. Begley, NIST, Dec. 17, 1998.

[33] *Evaluated Materials Data*, NIST, Jan. 5, 1999, found at Internet http://www.ceramics.nist.gov/pubs/annual/.

promoting the use of such materials, the industry reportedly remains far from developing a uniform set of product standards to aid design engineers in their choice of a ceramic part.[34]

Powder Injection Molding

A promising new technology, pioneered by AlliedSignal Inc., uses a new water-based binder as part of a ceramic powder injection molding process. This new process permits the fully automated, one-step forming of parts of alumina and silicon nitride with complex geometries. The use of injection molding in the manufacture of ceramics has traditionally been limited to the small-volume manufacture of complex specialty parts; this is because molds used to form the ceramic have been expensive, and the binders used to make the ceramic powders moldable have been difficult to use and remove after the completion of the shape-forming process and prior to sintering.[35] The substitution of a water-based binder for traditional polymer or wax binding materials allows the ceramic to be molded at lower temperatures and requires no separate time-consuming and costly debinding step, thus resulting in manufacturing cost reductions of up to 30 to 40 percent.[36] In other respects, including the processing of the ceramic raw materials used and the sintering of the molded part, AlliedSignal's process differs little from traditional ceramic-forming processes.

Worldwide annual sales of all ceramics products produced using powder injection molding technology reached nearly $100 million in 1997. According to one industry source, sales are projected to reach $1 billion within the next 5 years at annual growth rates of 25 to 40 percent.[37] In developing its powder injection molding technology, AlliedSignal was aided by a U.S. Department of Commerce, Advanced Technology Program (ATP) grant of nearly $2 million during 1993-96.

[34] U.S. staff telephone interview with Sandy Dapkunas, NIST, Jan. 5, 1999.

[35] Clifford Ballard, "Ceramic Injection Molding Meets the Demand for Manufacturing Complex Shapes," *Ceramic Industry*, Mar. 1997, p. 44.

[36] Ibid.

[37] Ibid.

Solid Freeform Fabrication

Solid freeform fabrication (SFF) is a rapid prototyping process that has, until now, been used for the commercial fabrication of polymer and plastic parts.[38] SFF forms three-dimensional parts directly from CAD files, without the use of hard tooling, dies or molds. Much research effort is presently being expended to apply the same process to the fabrication of structural metal and ceramic parts. Direct fabrication of ceramic parts and molds using SFF techniques (see text box) would allow parts to be produced in hours or days, compared to weeks or months using conventional ceramic processes. Thus, this development would significantly reduce the lead times and costs of developing new products.

In the near term, commercial production of ASCs using SFF technology is expected to be largely limited to prototype and tooling production, as well as production of highly specialized finished parts in smaller production runs. [39] However, with anticipated advances in SFF technology permitting the more rapid production of larger parts, many in the industry anticipate producing finished products, such as wear parts and seals, in larger production runs of 30 to 40 units.[40]

Rapid prototyping is unlikely to replace more conventional manufacturing techniques, particularly in applications where mass production results in lower unit costs. However, in the shorter production runs that characterize much of the ceramics industry, rapid prototyping will likely prove to be economical because it does not require tooling.[41] Efforts by U.S. manufacturers to incorporate rapid prototyping technology in the manufacture of ceramics are currently ahead of European and Japanese efforts in this area and, based on the current plans of firms developing the technology, will likely lead to initial U.S. commercial introduction of these products.

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[38] Mukesh K. Agarwala, Amit Bandyopadhyay, Remco van Weeren, Ahmad Safari, Stephen C. Danforth, Noshir A. Langrana, Vikram R. Jamalabad, and Philip J. Whalen, "FDC, Rapid Fabrication of Structural Components," *American Ceramic Society Bulletin*, Nov. 1996, p. 60.

[39] USITC staff telephone interview with Charles Gasdaskas, Powderflo Technologies, Dec. 1998.

[40] USITC staff telephone interview with Stephen Danforth, Rutgers University, Feb. 2, 1999.

[41] "Rapid Prototyping Primer," found at Internet address http://www.me.psu.edu/rapidpro/primer.

Newly-emerging SFF Processes Presently Being Used to Produce Ceramic Items Such as Prototypes, Tooling, and Finished Parts

Fused Deposition of Ceramics (FDC)

In the FDC process, a physical part may be constructed by a rapid prototyping machine, in a layer-by-layer fashion, according to three-dimensional data. The first layer of the part is bonded to a platform; the platform then retracts a preset distance, where new material is extruded over the surface of the first layer and bonded to form the second layer. The process is repeated until the part is completed. The use of a ceramic-polymer feedstock,[1] with a melting point lower than that of ceramic alone, overcomes a principal obstacle associated with the rapid prototyping of ceramics, that is, the high melting point of ceramics. Two firms presently using FDC technology include AlliedSignal Inc. (Morristown, NJ) and Lone Peak Engineering (Draper, UT).

Laminated Object Manufacturing (LOM)

LOM is a solid freeform process, developed by Lone Peak Engineering,[2] in which three-dimensional data is sliced into cross-sectional planes. The laser cuts a cross-sectional outline in the top layer of the plane. A new layer is bonded to the previously cut layer and a new cross section is created and cut as before. Once all layers have been laminated and cut, excess material is removed to expose the finished part.

Three Dimensional Printing (TDP)

Developed at the Massachusetts Institute of Technology (MIT) and used commercially by Soligen Inc. (Northridge, CA),[3] TDP begins with a thin distribution of powder spread over the surface of a powder bed. A slicing algorithm generated from a computer model of the desired part computes information for the layer. A binding material joins particles where the object is to be formed. The process is repeated as a piston lowers to spread and selectively join each succeeding powder layer until the part is completed.

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[1] Alair Griffin, Lone Peak Engineering, Inc., "Rapid Prototyping with Engineered Ceramic," *Ceramic Industry*, Apr. 1997, p. 87.

[2] "Laminated Object Manufacturing," found at Internet address http://aros.net/~lonepeak/lpe/swift.html.

[3] "Three Dimensional Printing," found at Internet address http://web.mit.edu/afs/athena/org/t/tdp/www/home.html.

Source: Company information and articles as noted.

The Role of the U.S. Government in ASC Research

Total spending by the U.S. Government on ASC research and development, including ceramic-matrix composites, is estimated at $127 million in fiscal year 1998, compared with $117 million for fiscal year 1997.[42] Key agencies currently involved in ASC funding include the Department of Energy and the Defense Advanced Research Projects Agency (DARPA) of the U.S. Department of Defense. The National Institute of Science and Technology (NIST), although instrumental in the past in providing funding for projects involving commercialization of advanced ceramics, is now concentrating on its materials data base and the development of uniform testing methods. Some of the major research programs currently funded are highlighted below:

U.S. Department of Energy

The **Advanced Turbine Systems Program** seeks to complete the development and demonstration of ultra-high efficiency natural gas turbine systems for electric utilities, independent power producers, and industrial end users over the next 5 years. Objectives include(1) development of gas turbines capable of thermal efficiency improvements of 15 percent over present levels in a given power class,(2) reduction in the cost of electricity costs by 10 percent, as compared to conventional systems,(3) ability to alternate between the use of competing fuels, and (4) reductions in nitrogen oxide emissions.[43] The program has already resulted in the first industrial test of ceramic blades in a gas turbine engine and has demonstrated the feasibility and benefits of using continuous fiber ceramic composite material in a gas turbine combustor liner.[44]

The Advanced Research Program of the Department of Defense (DARPA)

The **Freeform Manufacturing Program**, begun in 1994, seeks to find solutions to the problem of expensive ceramic prototypes that have resulted in long lead times to test and manufacture ceramic parts. All SFF technologies for the rapid prototyping of ceramics have been partially funded by DARPA. The objective of the program is to develop machine capability to convert virtual objects, in the form of CAD files, to functional advanced ceramic and ceramic composites parts, without part-specific tooling or operator intervention.[45]

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[42] Figures provided by Sandy Dapkunas, NIST.

[43] *Advanced Turbine Systems Program Overview*, Office of Industrial Technologies, U.S. Department of Energy, Dec. 7, 1998, found at Internet http://www.oit.doe.gov/.

[44] Ibid.

[45] *Research and Development Areas*, Defense Sciences Office, Defense Advanced Research

(continued...)

Technology is being developed through the formation of teams composed of parts manufacturers. Commercial results of this program include the manufacture of rapid ceramic prototypes by Lone Peak Inc. (Draper, UT) and the licensing to Soligen Inc. (Northridge, CA) of a three-dimensional rapid prototyping printing process to create structural ceramics and tooling capability for the manufacture of slip casting molds.[46]

The High Temperature Ceramics Program is designed to develop ceramic materials for high-temperature structural applications in gas turbines for power generation and to develop low-cost methods for the manufacture of these ceramics. These high-temperature ceramics are intended to compete with established materials for use in hot section components, such as turbine blades and nozzles, in acquisition and life cycle costs, and in terms of performance. Using funds provided by the program, the University of Michigan is managing an effort with two industrial subcontractors, Williams Intl. (Walled Lake, MI) and ACR Inc. (Macomb, MI), to develop and demonstrate the performance of low-cost ceramic components in turbine engines.[47]

The Advanced Materials Partnership Program seeks the establishment of economically viable manufacturing capability for advanced materials through partnerships between government and industry. According to program officials, the formation of such partnerships are expected to accelerate the commercialization of advanced materials technology.[48] Partnerships negotiated in 1998 include those with ACR Inc. for the creation of low-cost, damage tolerant, co-fired structural ceramic engine components; with Pratt & Whitney (East Hartford, CT) for low-cost ceramic bearing manufacturing; with Allied Signal Inc. for turbomachinery components; and with Sundstrand Corp. (Rockford, IL) for cruise missile turbine engine components.[49]

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[45] (...continued)
Projects Agency (DARPA), Dec. 7, 1998, found at Internet http://www.darpa.mil/DSO/rd.

[46] Slip casting is a process used to form complex shapes from a broad range of ceramic materials. In the process, a "slip", a suspension of powder and liquid, is pumped or poured into a permeable mold. Capillary suction of the mold causes the liquid to be filtered and deposited into a densely packed layer of particles of desired thickness against the mold wall.

[47] *Research and Development Areas*, Defense Sciences Office, Defense Advanced Research Projects Agency (DARPA), Dec. 7, 1998, at Internet http://www.darpa.mil/DSO/rd.

[48] USITC staff telephone interview with William Coblenz, DARPA, Jan. 20, 1999.

[49] *Research and Development Areas*, Defense Sciences Office, Defense Advanced Research Projects Agency (DARPA), Dec. 7, 1998, at Internet http://www.darpa.mil/DSO/rd.

Foreign Markets for Advanced Structural Ceramics

Western Europe[50]

ASC demand in Western Europe has been growing in similar end-use segments but at a slightly slower rate than that in the United States. Major markets include cutting tools and pump seals. The total market for advanced ceramics mechanical components[51] in 1996 totaled $430 million with a reported average annual growth rate estimated at just under 6 percent to the year 2000, when the market is projected to reach $538 million.[52] Germany is the largest consumer of engineering ceramics, accounting for 37 percent of Western Europe's engineering ceramics demand in 1996, compared to 15 percent for France and 14 percent for the United Kingdom.

The Western European market for advanced ceramic cutting tools now appear to be established on an equal footing with traditional nonceramic cutting tools made of tool steels and cermets, as well as superabrasive tools, such as industrial diamond and cubic boron nitride tools.[53] Because of their combination of toughness and hardness, which permits high cutting speeds and high material feed rates, silicon nitride ceramics have gained a dominant position in Western Europe in applications that call for cutting tools to operate under conditions of high temperatures, corrosive environments, and at very high speeds and pressures. In addition, nearly 10 million silicon carbide water pump seals are produced annually for the European market.[54]

Western European research and development in advanced materials is typically organized by national governments or on a continent-wide basis through the European Community in Brussels. Most ceramic-related projects fall under the BRITE-EURAM (European Research on Advanced Materials) project, which has operated since the 1980s. Presently, there is financing for approximately 40 to 50 projects with a significant ceramics focus. The average budget per project is in excess of $4 million spread over a 5-year period.[55] Approximately one-half of BRITE-EURAM funding is provided by industry participants in the individual

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[50] The definition of Western Europe for the purposes of this section include the 15 member nations of the European Union, along with Switzerland and Norway. This entire section is based on J. Briggs, "West European Markets for Advanced Ceramics," Mar. 1998.

[51] The study in which these figures appear classifies ASC as *mechanical components,* which are part of a broader category known as *engineering ceramics*. *Mechanical components* are comprised of cutting tools, pump seals, armor, and other wear components and mechanical components. *Engineering ceramics* also includes catalysts and filters, thermal ceramics, and bioceramics, items that are not included as structural ceramics in this paper.

[52] J. Briggs, "West European Markets for Advanced Ceramics," Mar. 1998, p. 2.

[53] Ibid., p. 9.

[54] Ibid.

[55] Ibid., p. 13.

projects. Research areas include developing advanced ceramics for use in gas turbine engines, membranes and filters, biomaterials, and superconductor systems.[56]

Thus far, in Western Europe there has been little activity comparable to the broader-based efforts in the United States in the application of rapid prototyping systems to ceramic manufacture.[57] Current rapid prototyping research efforts appear to be largely concentrated on the creation of metal castings and have not, as yet, progressed to the stage of commercial production of ceramic items. Researchers at the Fraunhofer Institute for Applied Materials Research in Germany have produced silicon carbide parts using rapid solidification and expect future rapid prototype developments using these materials.[58]

Japan

According to the Japan Fine Ceramics Association, structural applications for Japanese advanced ceramics are classified as mechanical applications. Growth in mechanical[59] applications advanced marginally during 1993-1997, increasing from 238 billion yen ($2.1 billion) in 1993 to 271 billion yen ($2.2 billion) in 1997.[60] The Japan Fine Ceramics Association forecasts an average annual growth rate of 5-8 percent for mechanical applications of advanced ceramics between now and the year 2005, reaching a range of 524-741 billion yen ($4.5-6.4 billion).[61]

Japanese applications of ASCs are similar to those discussed for ASCs in the United States and Western Europe. Much Japanese production of ASCs is also directed to the automotive market. Silicon nitride has been used in automotive engines in Japan since 1985 in the form of turbine blades for turbochargers, as rocker arm wear pads, and as glow plugs for diesel engines, while silicon carbide is widely used in water pump seals.[62] Japanese manufacturers currently supply many of the ASC components used in automotive applications in the United States, with Kyocera supplying Detroit Diesel with diesel fuel line components such as fuel injection check balls and fuel injector links while Toshiba is supplying Cummins Engine with similar components under a joint agreement with Enceratec Inc. (Columbus, IN).[63]

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[56] Ibid.

[57] Allan J. Lightman, Ch. 7: "Materials--Ceramics," in *Rapid Prototyping in Europe and Japan*, Mar. 1997, found at Internet http://itri.loyola.edu/rp.

[58] Ibid.

[59] Conversations with industry analysts suggest that the definition for "mechanical" applications published by the Japan Fine Ceramics Association is broader than is the U.S. industry definition of "structural" ceramics and may also include thermal/refractory products.

[60] "Growth for Japan's Fine Ceramics," *High Tech Ceramics News,* Aug. 1998, p. 1-2.

[61] Ibid. Yen value to dollar value conversions are based on an average exchange rate of $1 = 113 yen for 1993 and an average rate of $1 = 123 yen for 1997. Estimates for the year 2005 are based on the approximate current exchange rate of $1 = 116 yen.

[62] "Wear Applications of SiC and Si_3N_4," *High Tech Ceramics News*, July 1998, p. 1.

[63] USITC staff telephone interview with William Mandler, Enceratec Inc., Mar. 17, 1999.

As in Western Europe, little activity has taken place in Japan in the application of rapid prototyping for ceramics manufacturing. Most Japanese rapid prototyping activity is dedicated to the creation of polymers.[64]

Outlook

The objective of the U.S. ceramics industry to further commercialize ASC and to expand beyond the current narrow applications base will depend on the success of efforts to continue to lower costs, to accelerate the introduction of new products to the market, to produce near-net shapes in complex geometrical designs, and to establish a uniform data base. Other objectives, such as development of uniform set of product standards to assure product reliability and quality, to help ensure uniform performance and production of ASC components, and to free customers from dependance on a single vendor, appear longer-term in nature as industry participants seem to be less inclined, at the moment, to move in this direction. Both Western European and Japanese manufacturers are continuing plans for the expanded use of ASC in cutting tools, wear parts, and seals and bearings. However, it appears that the U.S. industry is closer to commercial realization of such key ceramic technologies as rapid prototyping. Progress toward achieving these objectives should assure for the U.S. industry an important share of what, despite past disappointments, is still likely to develop into an important global market.

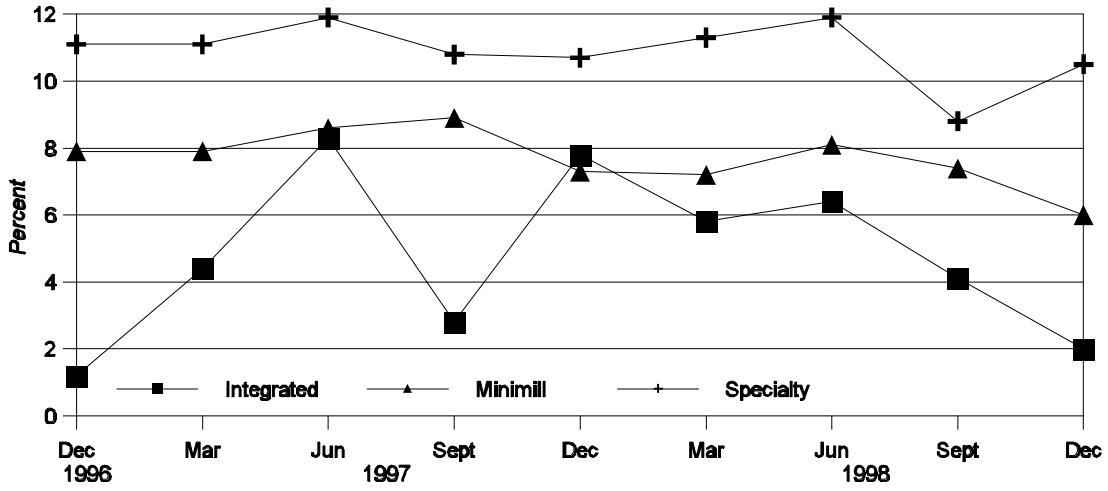
[64] Lightman.

APPENDIX A
KEY PERFORMANCE INDICATORS OF SELECTED INDUSTRIES

- **STEEL** (Tracy Quilter, 202-205-3437/tquilter@usitc.gov)
- **AUTOMOBILES** (Laura A. Polly, 202-205-3408/polly@usitc.gov)
- **ALUMINUM** (Harpreet Kaur, 202-205-3120/hkaur@usitc.gov)
- **FLAT GLASS** (James Lukes, 202-205-3426/lukes@usitc.gov)
- **SERVICES** (Tsedale Assefa, 202-205-2374/assefa@usitc.gov)

STEEL

Figure A-1
Steel industry: Profitability by strategic group[1]



[1]Operating profit as a percent of sales. Integrated group contains 7 firms. Minimill group contains 8 firms. Specialty group contains 4 firms. Usinor purchased all outstanding shares of J&L Specialty Steel; therefore, J&L's financial data is no longer available. Profitability in prior quarters has been recalculated for this sector excluding J&L's results.

Source: Individual company financial statements.

- Net sales and operating income declined for all three sectors for the quarter ending December 1998 as compared to the same period for 1997. Integrated producers experienced the most significant drop in profitability as fewer orders translated into decreased operating levels. However, a few steelmakers in other sectors reported increased shipments, but indicated that results were offset by lower average selling prices throughout the quarter. Additional factors contributing to the decline include lower oil prices which led to reduced demand for pipe and tube products.

- Steelmakers have attempted price increases during the first few months of 1999 as Steel Dynamics and Bethlehem Steel, followed by others, announced price increases for products such as hot-rolled sheet and coated sheet.

- Geneva Steel of Utah filed for bankruptcy protection under Chapter 11 in February 1999. The company faced liquidity problems and could not meet a January interest payment. Geneva is the third U.S. steelmaker to recently file for bankruptcy protection (Acme, Laclede).

Table A-1
Steel mill products, all grades

Item	Q4 1998	Percentage change, Q4 1998 from Q4 1997	YTD 1998	Percentage change, YTD 1998 from YTD 1997
Producers' shipments *(1,000 short tons)*	22,999	-13.3	102,427	-2.4
Imports *(1,000 short tons)*	11,002	55.4	41,520	33.3
Exports *(1,000 short tons)*	1,225	-22.6	5,520	-8.5
Apparent supply *(1,000 short tons)*	32,776	2.3	138,427	6.4
Ratio of imports to apparent supply *(percent)*	33.6	[2]11.5	30.0	[2]6.0

[1]Based on unrounded numbers.
[2]Percentage point change.

Note.–Because of rounding, figures may not add to the totals shown.
Source: American Iron and Steel Institute.

STEEL

Table A-2
Steel service centers

Item	Dec. 1998	Percentage change, Dec. 1998 from Sept. 1998[1]	Q4 1998	Q4 1997
Shipments *(1,000 net tons)*	2,143	-15.0	7,053	7,104
Ending inventories *(1,000 net tons)*	8,544	0.9	8,544	7,271
Inventories on hand *(months)*	4.0	([2])	4.0	3.2

[1]Based on unrounded numbers.
[2]Not applicable.

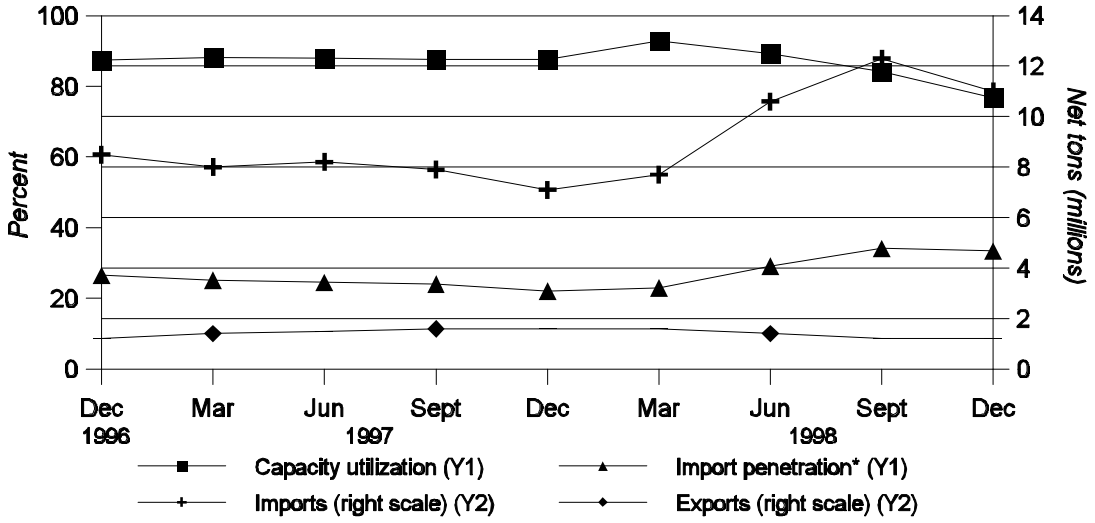
Note.–Because of rounding, figures may not add to the totals shown.
Source: Steel Service Center Institute.

- The Steel Service Center Institute (SSCI) reported a decrease in shipments and an increase in inventories for Q4 1998 compared with Q4 1997. Inventories at the end of 1998 were 8.5 million tons, an increase of 18 percent from the same time last year. December's inventories on hand reached 4.0 months for the first time since February 1991. The SSCI product groups with the most significant decreases in average daily shipments for Q4 1998 from Q4 1997 include alloy products, carbon bars, and carbon plate. However, shipments of stainless products rose 8 percent.

- Imports in Q4 1998 reached 11 million short tons, a 55 percent increase over Q4 1997. However, this is a slight decrease from Q3 1998 when imports reached 12.3 million tons. Semifinished products accounted for 18 percent of the total imported for the quarter.

- Capacity utilization averaged 76.7 percent for Q4 1998, which is a substantial decline from Q4 1997 when the average was 87.6 percent.

Figure A-2
Steel mill products, all grades: Selected industry conditions



*Import share of apparent open market supply.
Source: American Iron and Steel Institute.

AUTOMOBILES

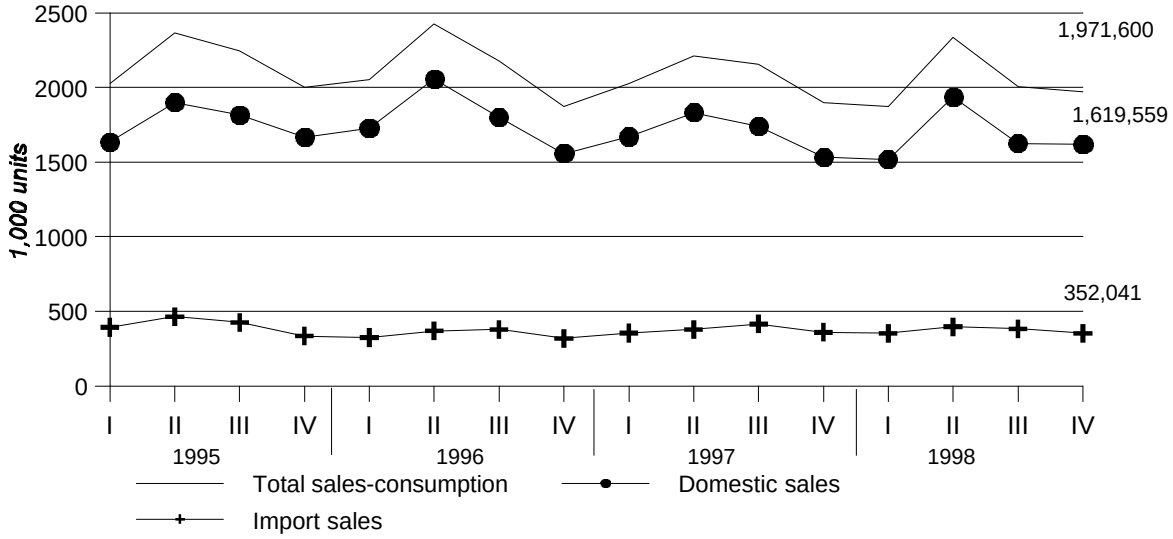
Table A-3
U.S. sales of new automobiles, domestic and imported, and share of U.S. market accounted for by sales of total imports and Japanese imports, by specified periods, January 1997-December 1998

Item	Oct.-Dec. 1998	Jan-Dec. 1998	Percentage change: Oct.-Dec. 1998 from Jul.-Sep. 1998	Percentage change: Jan.-Dec. 1998 from Jan.-Dec. 1997
U.S. sales of domestic autos (*1,000 units*)[1]	1,620	6,699	-0.3	-2.4
U.S. sales of imported autos (*1,000 units*)[2]	352	1,485	-7.9	4.1
Total U.S. sales (*1,000 units*)[1, 2]	1,972	8,184	-1.8	-1.3
Ratio of U.S. sales of imported autos to total U.S. sales (*percent*)[1, 2]	17.9	18.1	-6.2	5.5
U.S. sales of Japanese imports as a share of the total U.S. market (*percent*)[1, 2]	9.2	8.8	-12.4	-3.2

[1] Domestic automobile sales include U.S.-, Canadian-, and Mexican-built automobiles sold in the United States.
[2] Does not include automobiles imported from Canada and Mexico.

Source: Compiled from data obtained from *Automotive News*.

Figure A-3
U.S. sales of new passenger automobiles, by quarter

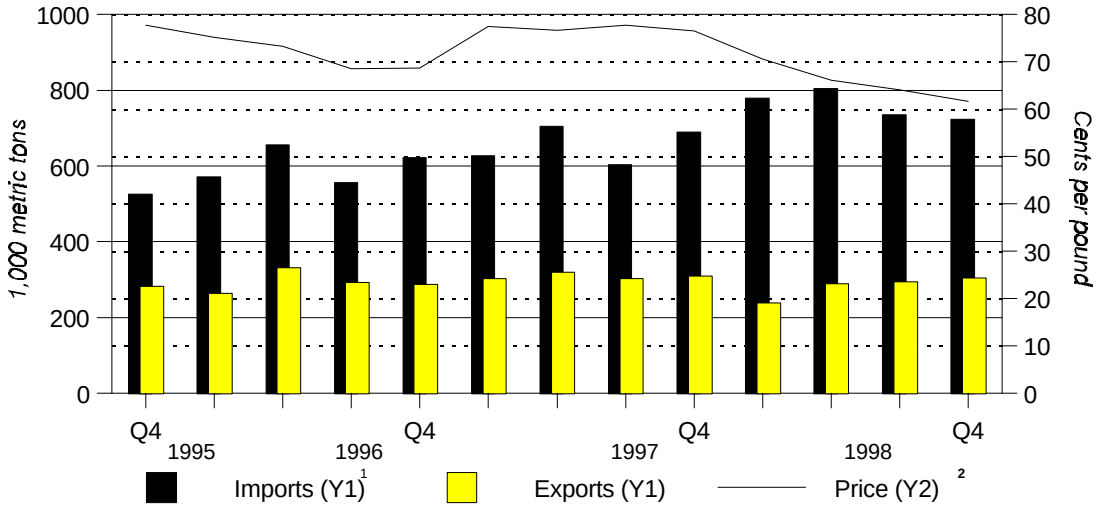


Note.--Domestic sales include all automobiles assembled in Canada and imported into the United States under the United States-Canadian automobile agreement; these same units are not included in import sales.

Source: *Automotive News*; prepared by the Office of Industries.

ALUMINUM

Figure A-4
Aluminum: U.S. imports, exports, and price



[1] Crude forms (metals and alloys) and mill products (e.g., plates, sheets, and bars) for consumption.
[2] Quarterly average of the monthly U.S. market price of primary aluminum ingots.

Sources: U.S. Geological Survey, World Bureau of Metal Statistics.

- Despite the increased demand for aluminum mill products in the United States and Europe, particularly in the automotive and aerospace industry, the decline in overall global production attributed to the decline in consumption in Asia (reportedly a 10 percent decrease compared to 1997) contributed to lower fourth quarter prices in 1998 (a 19.5 percent decrease compared to 1997).
- In the United States, increased production helped offset a 1.6 percent decrease in U.S. imports and enabled a 3.4 percent increase in U.S. exports in the fourth quarter of 1998, as compared to the preceding quarter. Import penetration remained at 32 percent as in the previous quarter.
- U.S. aluminum producers are optimistic about 1999 due to the increased use of aluminum in automobiles (an anticipated 5 percent increase in consumption). In 1999, the major U.S. car producers will be producing truck-specific engines with aluminum cylinder heads for the first time.

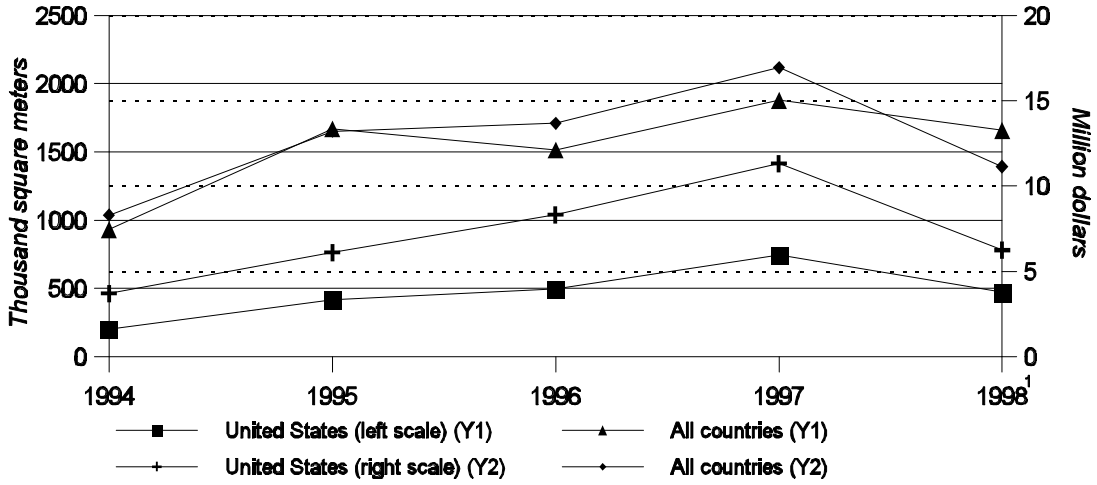
Table A-4
U.S. production, secondary recovery, imports, import penetration, exports, average nominal price, and inventory level of aluminum, by specified periods, October 1997-December 1997 and October 1998-December 1998

			Percentage change	
Item	Q4 1997	Q4 1998	Q4 1998 from Q3 1998	Q4 1998 from Q4 1997
Primary production (*1,000 metric tons*)	915	939	1.0	3.0
Secondary recovery (*1,000 metric tons*)	872	928	4.0	6.4
Imports (*1,000 metric tons*)	689	724	-1.6	5.0
Import Penetration (*percent*)	32	32	[1]0.0	[1]0.0
Exports (*1,000 metric tons*)	309	305	3.4	-1.3
Average Nominal Price (¢/lb)	76.5	61.6	-3.9	-19.5
LME Inventory Level (*1,000 metric tons*)	622	513	-0.0	-17.5

[1]Percentage point change
Source: Compiled from data obtained from U.S. Geological Survey & World Bureau of Metal Statistics.

FLAT GLASS

Figure A-5
Average monthly Japanese imports of flat glass, by quantity and value, from the United States and all countries, 1994-98[1]



[1] Data for 1998 include Jan.-Oct.
Source: Compiled from official statistics of the Ministry of Trade and Industry, Japan.

Background

- The U.S.-Japanese agreement on Japanese market access for imports of flat glass[1] seeks to increase access and sales of foreign flat glass in Japan through such means as increased adoption of nondiscriminatory standards and expanded promotion of safety and insulating glass.[2] The agreement covers the 1995-99 period.

- Japanese demand for imported glass began weakening in the second half of 1997. The Asian financial crisis and an increase in the Japanese consumption tax from 3 to 5 percent likely were contributing factors.[3]

Current

- Japanese demand for imported glass weakened in September and October, and figures for the year moved further below 1997 averages. The average monthly quantity and value of Japanese imports from all countries decreased by 12 and 34 percent for the first ten months of 1998 to below 1.7 million square meters ($11.1 million), respectively. Imports from the United States declined 37 and 45 percent to 473,000 square meters ($6.3 million), respectively. The above-average decline in imports from the United States occurred as the U.S. dollar appreciated against the Japanese yen and was largely offset by increased Japanese imports of flat glass from China.

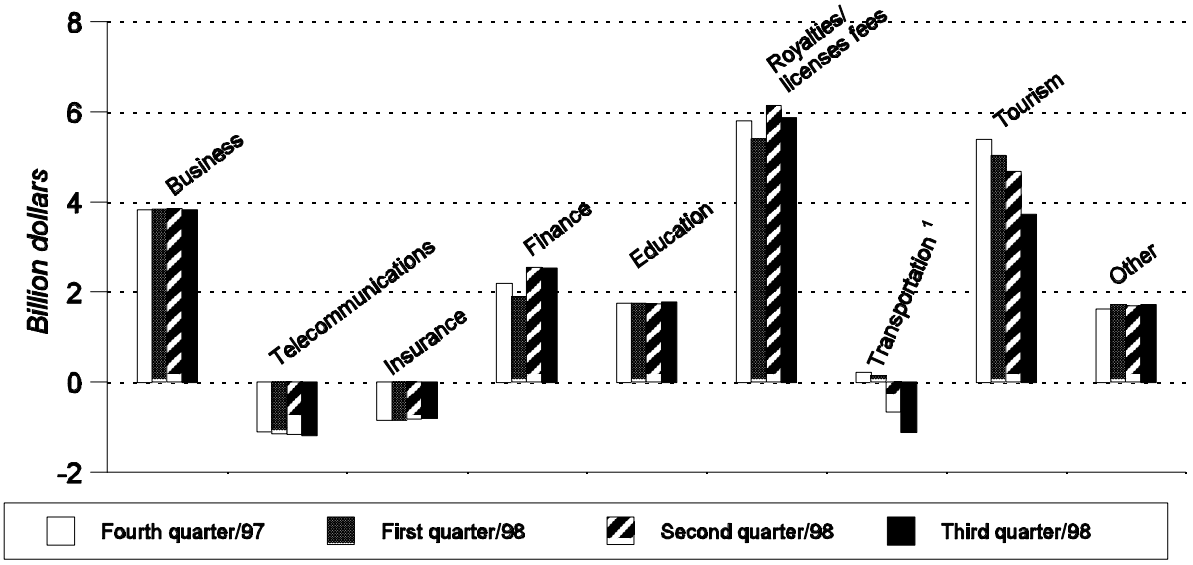
[1] Flat glass is largely unworked; safety glass (tempered or laminated) and insulating glass are also covered under the U.S.-Japanese agreement on flat glass.

[2] USITC, "Flat glass," *Industry, Trade, and Technology Review*, Oct. 1997, p. 42.

[3] USITC, "Flat glass," *Industry, Trade, and Technology Review*, June 1998, p. 37.

SERVICES

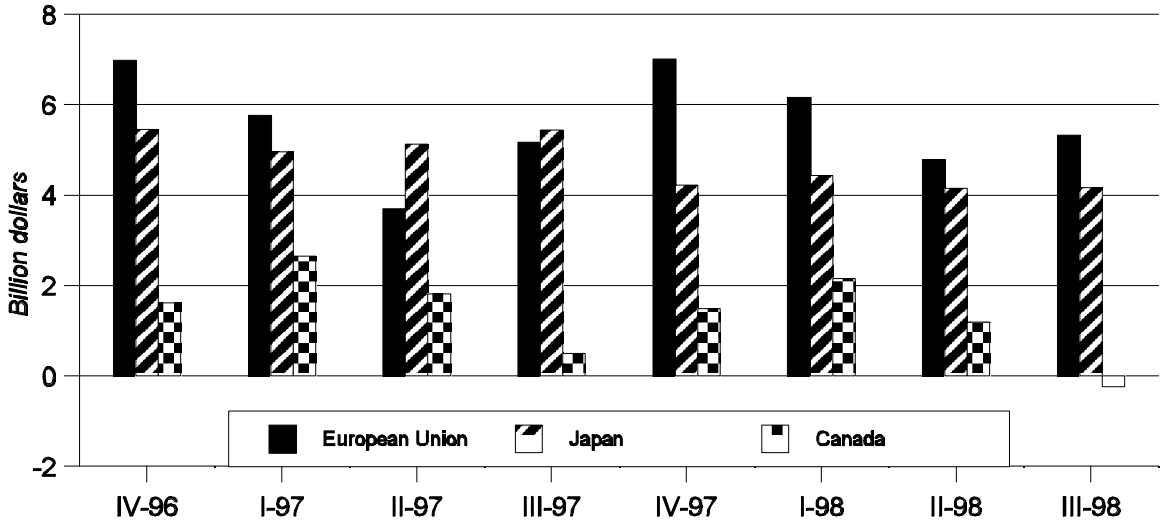
Figure A-6
Balance on U.S. service trade accounts, fourth quarter 1997 through third quarter 1998



[1] Includes port fees.

Source: Bureau of Economic Analysis, *Survey of Current Business*, Jan. 1999, p. 26.

Figure A-7
Surpluses on cross-border U.S. service transactions with selected trading partners, by selected quarters, 1996-98[1]



[1] Figures reflect private-sector transactions only; military shipments and other public-sector transactions have been excluded.
Source: Bureau of Economic Analysis, *Survey of Current Business,* Jan. 1999, pp. 34-37.