Israel's Silicon Wadi:
The forces behind cluster formation

Wadi: canyon or gorge, commonly used in Hebrew and Arabic

Silicon Wadi: Israeli moniker of its technology cluster

By Catherine de Fontenay and Erran Carmel

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Contact:

Catherine de Fontenay is at the Melbourne Business School, University of Melbourne, Australia

C.de.Fontenay@mbs.edu

Erran Carmel is at American University, Washington D.C., USA

carmel@american.edu

I. Introduction : Israel as an ICT cluster

> *"Industry clusters consist of agglomerations of competing and collaborating industries in a region networking into horizontal and vertical relationships, involving strong common buyer-supplier linkages, and relying on a shared foundation of specialized economic institutions."* ("Cluster Based Economic Development: A Key to Regional Competitiveness," Economic Development Administration, U.S. Department of Commerce, October 1997)

By the end of the 1990s Israel was generally acknowledged to have developed a cluster of high-technology industries. For instance, Wired magazine (Hillner, 2000), ranking locations by the strength of cluster effects, gave the Israeli high-tech cluster the same rank as Boston, Helsinki, London, and Kista in Sweden, second only to the Silicon Valley. (As seen in Figure 1, the entire Israeli high-tech industry is close enough together, geographically, to be considered one cluster. Almost all high-technology activity is located in the densely populated areas of metropolitan Tel Aviv, Haifa, and Jerusalem. Some secondary areas with additional activity include the corridor to Beer Sheba, including Kiryat Gat, and the Western Galilee —in all, an area that is no larger than 6000 square kilometers, perhaps half of the extended Silicon Valley's geographical coverage.)

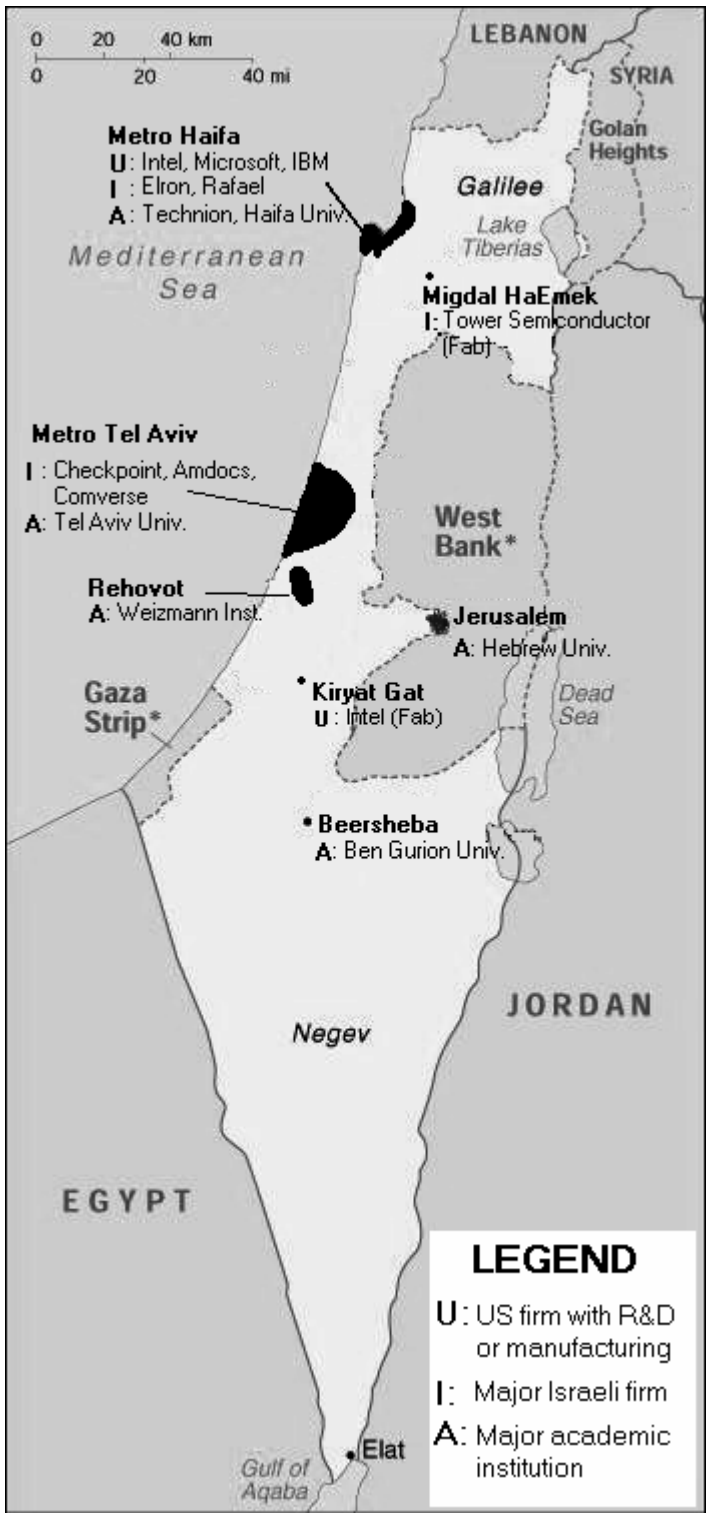

Figure 1: Map of Israel indicating the high tech cluster's significant points.

At the core of the Israeli cluster lies the Information and Communication Technologies (ICT) of software, data communications, electro-optics, hardware design, and internet technologies. Related successful high-technology industries include medical technology, bio-technology, agricultural technology, materials technology, and military technology. Similarly to the recently formed ICT clusters of India and Ireland, much of Israel's ICT output is software. However, the Indian and Irish clusters provide predominantly software services, while most of the output of Israel is in products—software products and telecommunications products. Moreover, its products are destined to the largest world markets, and competing on a par with products from top ICT firms. Primary competitors listed by interviewees were (in order of frequency) American, European, Israeli, Taiwanese or Japanese, and never from developing countries. Israel has more companies listed on the US-based stock exchanges than any other country beside the US and Canada. In 1999 Israel was the largest single foreign destination of US venture capital flows. Leading US technology firms, such as Cisco, Intel and Lucent, acquired Israeli startups for their technologies, just as they acquired startups in the Silicon Valley. In the first 3 quarters of 2000 foreign investors made acquisitions of Israeli high-tech firms totaling $12 billion.

	1990	**1992**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**
ICT manufacturing	1916	2567	3319	3862	5103	5543	6651	10081
ICT services	508	601	1028	1597	1787	2579	2878	4912
Total ICT	2424	3168	4348	5459	6890	8122	9529	14993
ICT as a percent of all Israeli exports	13.8	16.0	16.0	18.9	22.1	24.5	26.1	33.1

Table 1: Israeli ICT exports. In millions of 1995 US dollars.
Source: Israel Central Bureau of Statistics, 2001. Distinction between ICT manufacturing versus ICT services is based on OECD classification, which can be found at www.oecd.org/dsti/sti/it

The economic importance of the Israeli cluster may be illustrated with a few figures: By 2000 the Israeli ICT industry generated $15 billion in year 2000 export revenues (see Table 1), representing about a third of all Israeli exports. The result is striking when one considers that prior to the 1980s the key export sectors were agriculture (Jaffa oranges) and cut diamonds. ICT exports contributed 36% of GDP growth in 2000. In 2000 the industry employed 148,000 people (see Table 2), approximately one third of whom were scientists and engineers. Israel had a higher share of employment in ICT industries than any of the OECD nations (See Table 3). In 2000, near the peak of the high-tech boom, Israel had more than 2000 high-tech firms and new ones were forming at the rate of about 500 start-ups per year.

	1990	1992	1995	1996	1997	1998	1999	2000
ICT manufacturing	36	39	45	46	48	50	52	56
ICT services	20	23	40	49	55	61	72	92
Total ICT	56	62	85	95	103	111	124	148
ICT as a percent of national employment	3.5	3.5	4.0	4.3	4.5	4.7	5.1	6.0

Table 2: Israeli ICT employment. In thousands.
Source: Israel Central Bureau of Statistics, 2001. Distinction between ICT manufacturing versus ICT services is based on OECD classification, which can be found at www.oecd.org/dsti/sti/it

	Percent of R&D in the ICT Sector relative to Business Sector R&D	Percent of Employment in the ICT Sector as a Share of the Business Sector	Percent of Value Added in the ICT Sector as a Share of the Business Sector	Percent of ICT in total exports
Israel	86.1	6.1	13.3	20.1
Finland	51.0	5.6	8.3	19.6
Canada	43.7	4.9	6.5	7.2
Japan	40.4	3.4	5.8	24.0
USA	38.0	3.9	8.7	15.2
OECD average	34.6	3.6	7.4	12.5
Sweden	27.9	6.3	9.3	14.9
Australia	26.8	2.6	4.1	4.4
Italy	26.5	3.5	5.8	4.4
France	26.4	4.0	5.3	9.4
UK	21.8	4.8	8.4	15.0
Germany	20.1	3.1	6.1	8.6
Netherlands	19.6	3.8	5.1	14.6

Table 3: International Comparison: R&D, employment, output, exports. Source: Israel Central Bureau of Statistics, 2001. 1997 data. OECD figures can be found at www.oecd.org/dsti/sti/it

In Section II we explore the underlying forces that give Israel a comparative advantage in the ICT industry. In Section III we focus more specifically on the appearance of strong cluster effects in the Israeli industry, tracing the process of cluster formation from the roots of the industry in the 1960s to the present. Section IV analyzes the present characteristics of the cluster in more detail.

II. Long-term conditions favoring ICT industry growth: Comparative and absolute advantage

The notion of "comparative advantage" in international trade theory rests on a simple idea: In the absence of trade, each country has a limited amount it can produce, and has to give up a certain amount of other goods in order to produce more of good X. If country A has to give up relatively less of other goods to produce X than does country B, country A has a comparative advantage in the production of X. If countries A and B trade, A will specialize in the production of X. Therefore:

(a) country A will specialize in the industries that are more suited to A's factor endowment (labor-intensive products in a country with more labor than capital)

(b) country A will specialize in the industries in which it is more technologically efficient *relative to other industries* than country B. Country A's output per unit of input in those industries *relative* to other industries is higher than B's; in other words, country A has a comparative advantage in those industries. Country A may not necessarily be more technologically efficient in those industries in an absolute sense (i.e. it may not have an "absolute advantage"), but the terms of trade will make country A a more profitable place to undertake those industries.

In this section we review Israel's factor endowments, including its stocks of research knowledge in certain areas, and any other influences on the cost or efficiency of factors. Then we trace the relationship between those factor endowments and comparative advantage in different areas of ICT.

It is appropriate to speak in terms of comparative advantage in the case of Israel, because its factor endowments are different from the OECD countries that are its primary trading partners. Relative to OECD countries it has always been capital- and resource-poor: Israel has "sunshine as its only plentiful natural resource" quips Kaplan (1998). The country's drive to develop heavy industry (including automobiles) in the 1960s was relatively unsuccessful, and thus there are many capital-intensive industries for which the United States and other OECD countries are more technically efficient than Israel, because of longer experience.

It is important to note that, while initially poor, Israel had almost none of the government failures of developing countries—property risk, crime, unreliable infrastructure, corruption, and the possibility of confiscation of profits or assets by the government. — that would undermine its comparative advantage. Infrastructure includes government services such as roads and electrical power and, in the past, telephony. Telecommunications has been privatized and liberalized, generating an abundance of low-cost reliable wireline and wireless providers (Rosenne et al.1997:90). The reliability

of the infrastructure is often cited by large semiconductor firms as a reason for establishing manufacturing in Israel.[1]

What, then, are the comparative advantages and disadvantages of Israel? Israel possesses large endowments in some important production factors for labor-based high-technology: A stock of (initially) underemployed high-skilled labor, a stock of research knowledge in some specific areas within ICT, and organizational skills. In addition, the government has introduced provisions that reduced costs and increased reliability. Finally, given its location, its comparative disadvantage stems from distance to customers—in kilometers as well as in other ways. We expand on each of these points in this section.

General human capital

Israel has a wealth of human capital in math, physics, computer science, and engineering, as well as life sciences and medicine. Most statistical measures point to the high level of general education and, especially, of technical skills, in the Israeli population: Approximately 28% of the population have university degrees, and 1.35% of the population are engineers or scientists, which is significantly more than in other OECD nations (See Figure 2). Israel ranks second behind Switzerland in academic papers per capita and third behind Switzerland and Sweden in citations per capita (May, 1997).

1 Interview with Dr. A.I. Mlavsky, former director of the Israel-US Binational Industrial Research and Development Foundation (BIRD), March, 2001.

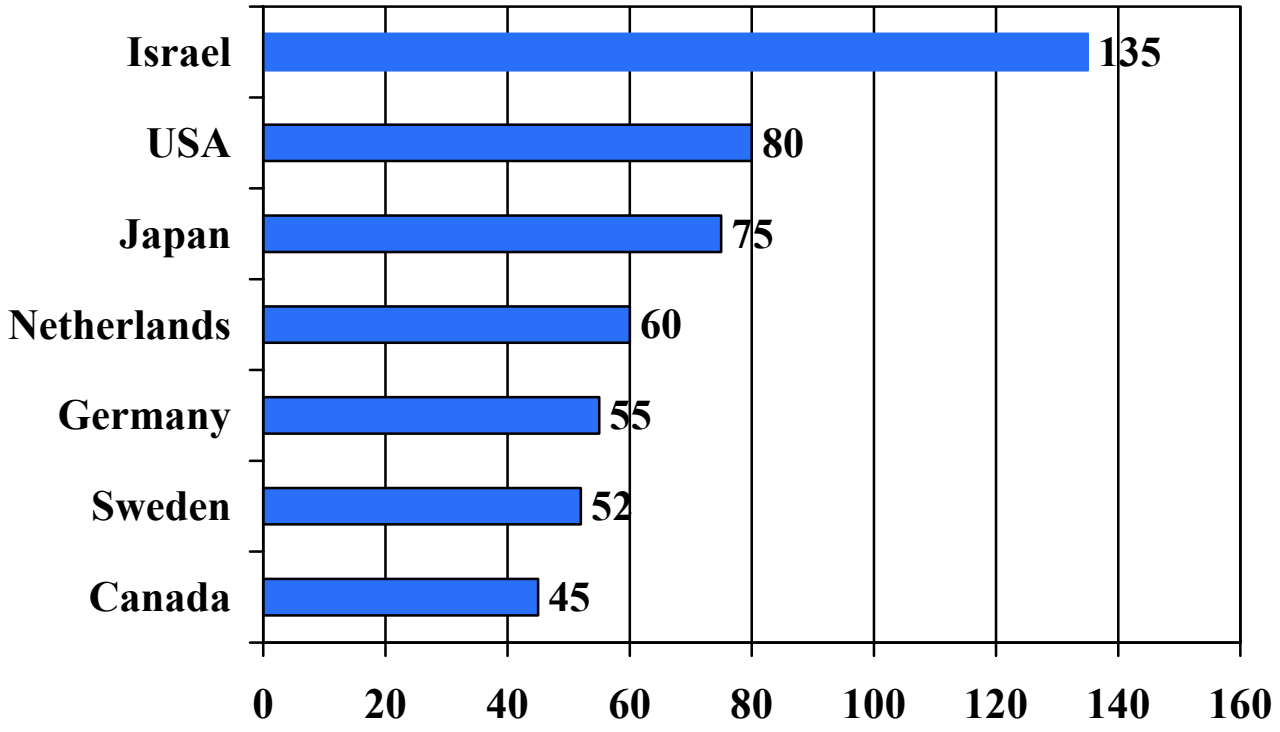

Figure 2: Concentration of Scientists and Engineers, (per 10,000 members of the labor force). Source: Office of the Chief Scientist, Israel Ministry of Industry and Trade, 2001.

Israel's wealth of human capital is partly attributable to its proactive education policy: it has successfully invested in all levels of education and achieved very high literacy rates. Israel has also invested heavily in the English proficiency of the population, which is of particular benefit to the ICT, where English serves as the lingua franca.[2] In terms of subject areas, the state has emphasized science and technology as a national priority, and invested accordingly. Israel's top universities are world-class research institutions, among them the Israel Institute of Technology (called the Technion) and the Weizmann Institute (which focuses on life sciences). The Technion recently planned to expand the number of (undergraduate) computer science majors from 1200 to 1500, rendering it one of the largest computer science departments in the world.

[2] Israelis receive 8 years of English as a second language through the end of high school. There is no other competing second-language program in the schools. Educated Israelis are conversant in English by the time they complete their university degrees. Within Israel's high-tech industry, English abilities are good, though far from faultless. Many younger firms have an English language culture in which e-mail correspondence and voice-mail menus are all in English.

The military is another national institution that plays a key role in directing high-ability youths into computing and engineering. The military serves as a training ground for the technological elite (Perman, 2000). Several key units and programs take the truly brightest high school graduates, train them in intensive science and engineering programs and disperse them in key military areas.[3] Thus the computer and engineering programs in the top universities often have 'doubly selected' graduates. The implication is that Israel has more engineers, and more able engineers, than otherwise might be the case.

Finally, both the amount and level of human capital within Israel was augmented by immigrant human capital. Since its founding Israel has received successive waves of Jewish immigrants. The greatest influx of scientific expertise came with the wave of immigration – totaling one million – from the former Soviet Union in beginning in 1989. Many had scientific and engineering backgrounds. Given the USSR's traditional strength in the theoretical sciences Israel became "a superpower in mathematics" (Stone, 1999). By the end of 1991, 5300 newly emigrated scientists were registered with the Israeli Ministry of Absorption. While many of these scientists had difficulty penetrating the Israeli scientific and academic communities, a significant segment found their way to the ICT industry. Stone (1999) quotes a source about Intel's fab in Kiryat Gat (50 kilometers south of Tel Aviv): "when I visited in 1991, people spoke English. Now they all speak Russian." During our data collection in 2001, we found a small but significant presence of former Soviet Union immigrants in technical and engineering groups at ICT firms. For example, in one small bio-informatics firm, 6 of the 28 technical staff were from this group.

Israel's substantial stock of technological human capital, and the absence of other dominant industries, implies that it has a comparative advantage in high-technology activities that are intensive in the use of very skilled labor, particularly engineering.[4]

Stock of knowledge in specific ICT areas

If Israelis possess a certain stock of knowledge in a subject that is more advanced than the knowledge available elsewhere, they have an absolute advantage in any field relying on that stock, especially in R&D.[5] There are several sources of advanced and economically significant stocks of knowledge within Israeli high tech firms: military R&D, university R&D, and stocks of R&D knowledge brought by Former Soviet Union

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[3] Among these elite units are: 8200 (electronic warfare), MMRM (the Hebrew acronym for the military computer corps), the Signal Corps, and various intelligence units. Among the selective programs that combine university education in science and engineering with extended military service are Talpiot (selects only the top 30 students nationally every year) and Atudah (less selective, but also from the top strata).

4 This is also in some sense a direct process: Israel's best human capital has been funneled to high-technology because there are few other paths to success (as opposed to the US and Europe). There are no large businesses to aspire to enter and the legal profession (until recently) has not siphoned off the best talent. Moreover, the actual process of moving people into ICT activities (via the hiring process for technology firms) is greatly facilitated when people are not locked into existing industries, as is the case for recent immigrants.

5 Absolute advantage is defined as greater technical efficiency: firms in Israel have an absolute advantage in a technology area if they are able to deliver a higher-quality product with the same resources, or the same product with less resources.

immigrants. (As the cluster develops, the stock of R&D within existing local and multinational firms becomes more and more significant, as we shall discuss later.)

The main source of specific ICT knowledge has traditionally been the military, along with government-owned and independent military technology firms (See Table 4). Military research in Israel is acknowledged to be at the forefront in certain areas of communications (especially wireless communications), networks, and data security (especially cryptography). To the extent that these areas are "close" in some technological sense to useful products (existing or potential) in the ICT industry, Israel has an advantage. Commercial products can be developed that are inspired by some of the military technologies. Specific engineering techniques and methodologies learned in those units are directly useful to firms in related commercial areas. And finally, engineers tend to specialize in these specific subject areas, after they have gained several years of (military-related) experience in the area. One CEO we interviewed described military knowledge as "all built around understanding packets and the way they flow, how to capture them and how to manipulate them."

Paradoxically, it may be that the military's R&D is, in some ways, more widely available—thus encouraging greater rates of commercial innovation than patented civilian research would be. Long mandatory periods of service for those in the elite military technology units imply that a body of highly skilled workers had in-depth exposure to state-of-art technologies developed inside the military. Some observers feel that the military protects less of its intellectual property than do commercial firms; this is something of a paradox, as one would expect military intellectual property to be closely guarded.[6] But, with the exception of cryptography, the military does not restrict its former officers and soldiers from working in subject areas that are close to the subject area of their military work. In other words, the military does not implement anything resembling a "non-competition clause" commonly found in firms. Separately, the military itself is not very apt at spinning off commercial/ civilian applications. Thus there are a number of 'low-lying fruit' in terms of commercial applications of its R&D that individuals can reap after their service, encouraging them to move into these areas. Table 4 (reproduced from Dvir and Tishler 1999) provides some examples of the movement of people from the military into related industries.

6 Interview with Dr. David Naveh, March 2001

Firm	Area of expertise
BVR	Simulators, virtual studios
Check Point	Firewalls for Internet data security
Cubital	Fast prototyping machines
DSP	Speech processing devices
Elbit	Defense and medical instrumentation and communication systems
ESC	Laser surgery equipment
Gilat Communications	Very small aperture satellite terminals (VSAT)
Lannet	Data communication equipment
Magic Computers	General database software
Medis EL	Cancer diagnosis equipment
Nexsus	Two-way paging systems
NICE Systems	Computer telephony integration
Optrotech	Printed board inspection systems
Orckit	High-speed modems
RAD Computers	Data communication equipment
Tadiran	Communication and telephone equipment
Tecnomatix	CAD/CAM software for the automobile industry
Teldor Computers	Software development
Telrad	Telephone switching systems

Table 4: High Tech firms managed or launched by personnel previously employed in military or military related industries. Source: Dvir and Tishler, 1999.

For example, Israel has developed a strong position in electro-optics (including such areas as fiber-optics, electro-optic inspection systems for printed circuit boards, and electro-optics-based robotic manufacturing) (Beri, 2001). Electro-optics was an area of military-related R&D as early as the 1960s, and one that began generating civilian applications early (Dvir and Tishler, 1999:22). In 1999 there were 150 Israeli firms in this sector with an estimated $2.5 billion in yearly sales, which represents a significant industrial concentration for a country of Israel's size. There are now electro-optics programs in seven universities and research centers. Among this sector's successful firms were Chromatis (an optical networking systems firm acquired by Lucent for $4.7 billion in 2000, the largest foreign acquisition to date), Trellis Photonics, and Cyoptics. There continues to be a significant electro-optics industry in the military technology sector: firms include Elbit, El-Op (now a part of Elbit), Rafael, and Israel Aircraft Industries.

There has been a wide range of commercial civilian applications of military technologies. Dvir and Tishler (1999) list 10 direct military-to-commercial applications, including defect identification in fabric and fruits, voice logging, wireless paging, and vehicle positioning. But commercial applications have been particularly prevalent in the telecommunications and Internet-related industries, which have been very important in the 1990s. From military R&D came voice compression, DSP chips, streaming

techniques, faster network devices (some of which rely on electro-optical innovations), faster network software, Virtual Private Networks, internet telephony software (an innovation that began in Israel), and network performance products.

Universities are another source of leading technologies, as the government invests $260 million per year in supporting university research (Kaplan 1998). One highly visible area has been applications of algorithms: Adi Shamir of the Weizmann Institute (the "S" of the famous RSA algorithm) helped make a ground-breaking advance in this area by turning asymetric key cryptography into a commercial possibility (Kaplan 1998). There are clear links from algorithmic innovations to the formation of a data security industry (Teubal et al. 2000) and university algorithms have had other useful applications.[7] The Weizmann Institute and other research entities have also proved important for biotechnology. Israel's national emphasis on agriculture and agricultural technology dating back to the nation's early decades helped transition into a healthy bio-tech and life sciences cluster (close to 200 firms were started in the life sciences in 1999 and 2000).

Finally, recent immigration flows endowed Israel with a significant share of the USSR's stock of specific knowledge. Immigrants brought with them both proprietary technologies and very different methodologies than are familiar in the West. They helped fuel the technology boom of the late 1990s, as their innovations and technical skills assisted both startups and established firms (Kaplan, 1998). Much of the implied absolute advantage is in the area of physics and material science, probably as a result of the USSR's traditional emphasis on heavy industry. Some of this body of knowledge has been of use to the measurement, testing and control industry[8] and to the electro-optics industry.

Organizational Human Capital: organizational skills and the work culture

A number of softer factors help explain Israel's advantages. These factors were brought up frequently in interviews we conducted in the Israeli high tech industry and appear as well as in other literature such as Ariav and Goodman (1994). We discuss two of these factors here: organizational skills acquired in the military and the culture of group attachments.

The compulsory military service endows its more capable "graduates" with specific skills that are close to some dimensions of 'business training'.[9] Those selected for positions of military leadership (whether they be in technical or combat areas) are asked to shoulder important responsibilities quickly—and at a very young age. Within the relatively flat organizational structure that is the Israeli military, they are asked to assume complete

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7 Israel's universities are responsible for four famous algorithms (Kaplan 1998:28): "one for data compression, another providing a reliable, highly efficient strategy for finding out whether a large integer is a prime number, yet another providing a firm foundation for an 'electronic wallet,' and a fourth for efficient personal identification."

8 Interview with Dr. David Naveh, March 2001. Naveh cited the case of a Russian immigrant startup that had developed ultra-precise scales. Kaplan (1998: 28) cites the case of a Russian-immigrant led startup that developed a computer numerical control (CNC) system for metal-milling and drilling machines.

9 This exposition benefited from discussions with Prof. Justman of Ben Gurion University in Beersheba, March 2001.

responsibility for their unit/domain, to work long hours, to respond quickly, to be flexible, to improvise, to do whatever it takes to get the job done, to think about the strategic objectives rather than about their specific job description. As a result, they develop a strong sense of responsibility. They are often given very challenging, sometimes impossible, tasks. They learn to work in a hierarchy, but with informal communication, so that they can communicate their opinions to their superiors. They learn to work in teams and form early skills in coordinating and managing within a team. Thus, they learn team leadership skills at an early age.

These organizational skills are very similar to the desired characteristics of an employee in an innovative high-tech startup. Thus, many technically trained workers have "startup-like" experience before joining the workforce. For example, many interviewees asserted that Israeli teams develop products more rapidly: "It's the emphasis placed on getting things to work in the military. It may not be pretty, but it will work."

Although the Israeli military is far from a small organization, many of its units function rather independently. Consequently, the organizational skills developed in the military fit a small-to-medium sized operation better than in a large operation. Indeed, there is some evidence that Israelis prefer smaller organizations and startups. Loyalty to the group, flexibility and lack of hierarchy (all characteristics of the military) are more likely to be preserved in a small firm-- especially a startup.

The second type of organizational human capital is the culture of groups. As Shahar and Kurtz (1995, p.73) write: "…Israel is […] a culture in which individualism exists side by side with strong group attachments. Israelis identify themselves as members of groups, are to loyal to group members, and are concerned with the well-being and collective interests of the group (e.g., work teams, friendship circles, ethnic organizations, and army units)." Israeli group attachments, or *collectivism* as it is more formally labeled, arises from the country's socialist heritage, its sense of shared identity and shared purpose of 'survival'. One of the principal institutions that fosters collectivism is the common military experience. Young soldiers are socialized to develop strong loyalty towards their army companions. We note two implications of this group attachment on the culture of work in technology firms. First, is that Israelis are more comfortable working in teams, helping each other for the good of the group or the firm. This can be posited vis-à-vis the highly individualist Americans—for whom teamwork is a forced, uncomfortable behavior that must be explicitly learned.[10]

Second, collectivist values are manifested in strong loyalty toward the firm. One implication for high tech firms is a low turnover rate. Bernshtock, 1999, found a low, though increasing, turnover of computer and electrical engineers in Israeli high tech organizations.[11] In fact, the low domestic turnover rates have been one of the reasons Israeli firms have been reluctant to move R&D to the Silicon Valley with its infamously high turnover rates.[12] Low turnover is particularly important in the design of elaborate

[10] On Hofstede's well-known inter-cultural measures of individualism, Americans were found to be the most individualist of any nation (Hofstede, 1993).

11 The fact that personal networks are very strong in Israel also tends to reduce quitting and firing.

12 One might be tempted to dismiss Israel's lower turnover rates as a disappearing phenomenon: after all, when the country had a socialist economy with few opportunities, turnover was likely to be lower, and perhaps turnover is simply in the process of adjusting. But, if we compare Israel to India, another country

chips with long development cycles.[13] On the subject of turnover, a partner in an American headhunter firm with a new Israeli office commented that loyalty was historically so high in Israel that before the mid 1990s, his firm could not have operated locally.

Many of these positive work culture characteristics link to related weaknesses. These are Israeli organizational and cultural deficiencies that are frequently pointed to within the high tech community: the inattention to detail, the indifference to quality, the un-scaleable management culture,[14] and the poor service orientation with its disrespect for the customer.

Cost-reducing government programs

The Israeli government offers a number of financial incentives to firms to locate activity in Israel, particularly high-tech research activities, through tax reductions and funding of R&D costs. Given that these funds must come from other sectors in the economy, the funds create an artificial advantage for high-tech relative to other sectors. Our aim is not to determine whether such financial incentives are advisable. Indeed, there have been direct government incentives to multinationals, such as the $608 million contributed to Intel's new fab in Kiryat Gat, that were sharply criticized within Israel.[15] Rather, we seek to determine to what extent these policies contributed to Israel's comparative advantage in R&D, and the resulting decisions to site R&D in Israel.

Government programs have been particularly favorable to R&D. There are substantial incentives to (local and foreign) firms reporting profits in Israel in the form of reductions in corporate tax. Corporate tax in Israel is 36%, relative to 35-40% in the US. However, there is a reduction in corporate tax to 10% for the first seven years, for industries performing substantial R&D or production in Israel, who are then classified as "Approved Enterprises."[16] Locating in a disadvantaged "development area," some of

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with a socialist heritage that has developed a fast-growing ICT cluster, the contrast is striking: whereas Israeli firms reported yearly turnover around 5%, Indian software companies were commonly losing a quarter of their employees a year. (Economist, 2001).

13 Interview, Dr. A.I. Mlavsky, March 2001.

14 Few high tech firms have grown larger than 1000 employees and our interviews revealed that organizations have had difficulty growing: "That's why Israel will never put a man on the moon," meaning that a research organization the size of NASA could never function properly given Israeli organizational culture.

15 Some critics point to out that Intel had established a fab in Israel in 1985 with less government support, as had others, although government incentives did play a role (Autler 2000:55ff).

A "fab" (a semiconductor manufacturing plant) is a costly capital investment. Intel's Kiryat Gat fab was estimated at $1.6 billion. It may seem surprising that such a capital-intensive activity is in Israel. However, the presence of fab production can be explained by the fact that it benefits from the availability of skilled and semi-skilled labor, and of low turnover rates that facilitate on-the-job learning. One interview source explained that low turnover was even more important for their fab than for their R&D center.

16 The 1959 Law for the Encouragement of Capital Investment grants substantial tax benefits to so-called "Approved Enterprises". For an "approved enterprise" only 10% or less of R&D can be performed by a third party (and "third party" includes a subsidiary of the firm outside of Israel), and only 30% or less of production can be performed by a third party. Approved Enterprise status is virtually automatic for Israeli high-tech firms and for many subsidiaries of foreign multinationals. The seven years of reduced taxes begin from the time the firm is profitable, and can be renewed under certain circumstances.

which are quite close to the major metropolitan areas, also lowers taxes. Note also that economic liberalization was occurring during the 1980s and 1990s, reducing tariff barriers and other transactions costs of doing business in Israel.

Since 1975 the Office of the Chief Scientist (OCS, which is part of the Ministry of Industry and Trade) has provided support for specific R&D projects to develop new technologies. The OCS selects projects to fund based on the viability of their proposals, and funds up to 50% of the budget, to be repaid in royalties if the project is successful (Trajtenberg 2000).[17] Thus the OCS sorts projects, similarly to a venture capitalist, and then provides capital. In practice OCS has funded about 70% of proposals received. The subsidy (and possibly the sorting) translates directly into a comparative advantage in R&D.

	1990	1992	1995	1996	1997	1998	1999	2000
ICT manufacturing	30.92	34.30	39.72	44.29	46.84	43.08	47.14	51.01
ICT services	12.24	28.12	34.82	38.04	41.38	40.44	46.78	54.51
All ICT	29.07	32.01	37.40	41.09	43.90	41.64	46.92	53.18

Table 5: Yearly costs of an Israeli ICT employee. In thousands of US dollars.
Source: Israel Central Bureau of Statistics, 2001. Distinction between ICT manufacturing versus ICT services is based on OECD classification, which can be found at www.oecd.org/dsti/sti/it

We stress that government cost-reduction programs are significant because wage differentials alone are, at best, a minor comparative advantage for Israel. During the 1990s boom years high tech wages rose rapidly (also see Table 5). From our interviews with high tech executives, the consensus that emerged was that loaded Israeli wages (including the expensive benefits common in Israel) were roughly on par with those in the US and somewhat lower than the inflated wages of Silicon Valley.[18] Further evidence of the high Israeli ICT labor costs is that dozens of Israeli firms have outsourced some software work to low wage nations such as Russia and India.

Disadvantage: market access

In Israel, similarly to Taiwan or India, local demand is insufficient to support growth, and ICT firms have looked abroad for their markets. The US is the most important ICT market. Israeli firms are, and always have been, at a disadvantage relative to local US firms, because of the distance from the customer.

Distance implies a disadvantage in areas requiring great familiarity and proximity with the final customer: marketing, sales, engineering support and systems integration, and

17 The grant structure includes smaller grants for product and process improvements, and slightly larger grants for projects conducted in less developed areas of Israel (Tratjenberg 2000).

18 Even within Israel significant regional wage differences exist, with the high tech hubs within metropolitan Tel Aviv commanding premiums over other areas.

customer-oriented aspects of engineering such as user interface. It is difficult to familiarize oneself with customers' needs from Israel, 7 to 10 time zones and a full day's travel away. Distance also implies that market access facilitated by social and professional networks is far less likely.

In addition, customer-oriented fields are relatively "underdeveloped" in Israel, given the country's socialist background. Business schools, which train students to understand and respond to customers, were rare until the 1990s.

Partially in response, Israeli firms have focused on areas in which their comparative disadvantage is less marked. In general, Israeli firms have chosen to develop products that are sold to sophisticated business customers, who require relatively little support activities. In these markets, Israelis compete on more equal terms with local firms. For instance, the final customers of the electro-optics segment are other sophisticated high tech firms who are seeking the latest and fastest approach, regardless of other considerations. Certainly market access in this case is easier than in mass consumer markets.

The State also responded to the problem of market access. The Israel-US Binational Industrial Research and Development Foundation (BIRD) was founded in 1977 by both governments. BIRD contributes up to 50% of the cost of a joint research project between a large established American firm and an Israeli firm, generally marketed by the American firm under its label but manufactured in Israel. Cooperative projects helped Israeli firms learn the role of marketing in the product development process.[19] Unfortunately, while many of the joint projects were successful, no studies exist of the impact of BIRD on market access in general. The relatively slow growth of the cluster until the 1990s would suggest that BIRD alone could not have sufficient impact.

III. The process of the Israeli cluster formation

Many of the conditions that form Israel's ICT comparative advantage have been in place for some time. Most of the fundamental factor endowments of the Israeli economy—its endowments of skilled labor, stocks of knowledge, and so on—have not varied dramatically (with the exception of the Russian wave of immigration). A significant nascent ICT industry existed in the 1970s and especially the 1980s. Thus, one might well expect the Israeli ICT industry to continue to grow steadily and to *gradually* exhibit more and more of the characteristics of a cluster. And yet there was a *discrete change* in the cluster characteristics of the Israeli ICT industry in the 1990s, particularly the mid-1990s. There seems to be a disjunction between the factor conditions favorable to a cluster, and the actual formation of the cluster.

Therefore we present and discuss the *process* of cluster formation. It proves insufficient to examine just the underlying factor endowments (presented in the previous section) that

[19] "[Technology transfer] was not what we needed. What we needed was a route to the customer, and what the American companies needed…was the fresh approach of early-stage companies." (Dr. A.I. Mlavsky, cited in Autler 2000:37).

favor cluster formation. In this section we review the history of the Israeli ICT industry, in order to point to the forces that led to a "take-off" in the 1990s.

History leading to the take-off

By most accounts the Israeli high-technology industry dates to the 1960s, when Israeli high-tech firms began to form (see Kaplan, 1998, who maps out the more important events and technologies in Israel from the 1960s onwards). In 1961 ECI Telecom was founded, and in 1962 Tadiran and Elron Electronics. Elron is often seen as the "Fairchild of Israel," akin to the Silicon Valley firm from which arose many of the important firms of the Valley. However, the number of internationally successful firms grew slowly, remaining somewhere around one or two new successful firms per year through the early 1990s.

A defining moment in the formation of the Israeli high-tech cluster was the French arms embargo that began in the aftermath of the 1967 Middle East war. Israel massively increased its support to a domestic military industry, and focused on developing a self-reliant technological edge over its neighbors. The military technology industry has been quite successful and has also been one of the country's leading export sectors (including to the US military).

Gradually, some of these military technology firms began seeking civilian applications of military know-how or military systems. The most promising areas of specialization were those in which the Israeli military R&D had advanced far ahead of any other commercial R&D in the world—in other words, areas in which Israel had an absolute advantage. Many commercial innovations beginning in the 1970s—some of them pathbreaking – were based on military-related R&D: for example, Scitex digital printing systems were based on fast rotation drums learned from fast-rotation electronic warfare systems (Kaplan, 1998).

The military also devoted attention quite early to a new technology field—computing. In 1960 the Israeli military established its centralized computer center (know by its Hebrew acronym MMRM):

> The Center was set up around a Philco Transac 2000 mainframe, one of the earliest transistor-based computers available outside the defense establishments in the USA, USSR and UK. With this platform, modern record keeping became part of military management for personnel and logistics. In the late 1960s MMRM replaced its original engine with an IBM 360/50 mainframe and remained technology current ever since. At the time, and for many years, MMRM was the largest and most sophisticated computing center in the country. (Ariav and Goodman 1994:18)

As the world's computing industry began to shift emphasis from hardware (in which resource-poor Israel had no comparative advantage) to software products (in which human capital plays a larger role), Israel became one of the first nations to compete in global software markets. By the 1980s a diverse set of software firms found niches that were not dominated by American firms. Between 1984 and 1991 "pure" software exports (excluding embedded chips) increased from $5 million to $110 million (Ariav and

Goodman 1994). This was still a small piece of the global trade in software, but significant for the emerging Israeli ICT industry. Then as now, many of the important ideas and firms came from "graduates" of MMRM, the Israeli computer corps.

While the accumulated successes of the emerging Israeli high tech industry were perceptible, firms were struggling with commercialization of innovations. Israel lacked adequate channels to access markets (including market information and market contacts). The case of Elbit is a striking example. Elbit, one of the earliest technology firms, was a military technology firm. The firm developed one of the world's first mini-computers in the 1970s but was unable to commercialize it in any market other than the military. Military technology firms had an easier path to markets, as they could access a local, familiar domestic customer—the Israeli military.

Over the same period, the forces of comparative advantage implied that a steady stream of US firms found Israel a propitious place to invest in R&D. They focused on areas that were intensive in human capital, particularly areas that were relatively close to military areas such as optics and wireless. Motorola was the first US corporation to set up a research unit in Israel, in 1964. The center developed wireless products including remote irrigation systems for agricultural use, and later developed some leading chips such as the 68030. Research units in semiconductor equipment and design followed from 1969 onwards.

The 1990s: the transition to a cluster

The 1990s saw a "takeoff" in the Israeli ICT industry, as it took on more of the characteristics of a cluster. It was during this time that the Israeli cluster began drawing attention from journalistic sources: articles appeared in the American business-technology press with titles such as: e-company's "Start-up Nation," Forbes' "High-Tech Miracle In The Desert", Red Herring's "Birth Of A VC Nation," and Upside's "Beating Swords into Boards." Israeli firms had become visibly successful in previous years, creating a favorable reputation for Israel and its high technology firms. This reputation effect (otherwise known as a *marketing externality*) is itself a characteristic of a cluster.

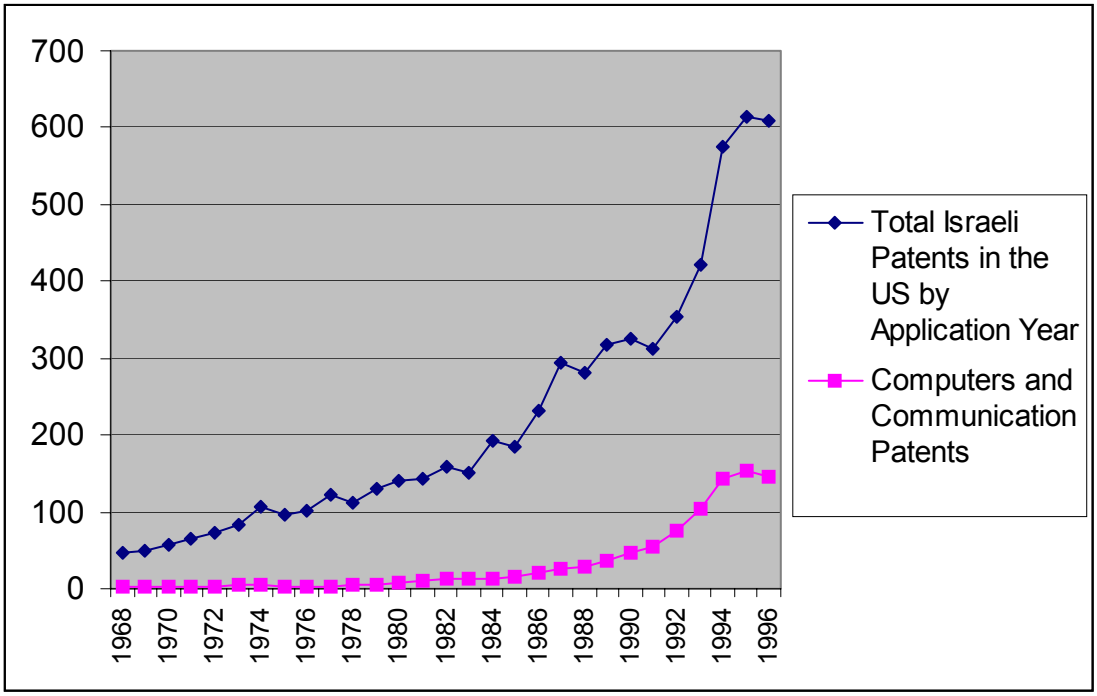

Figure 3: Israeli Patents in the US. Source: Trajtenberg, 1999. Note: The last two years were estimated by Trajtenberg.

Growth rates accelerated during this period, particularly since the mid 1990s[20] (see Table 1). Patent data (Figure 3) also shows an accelerated increase in the 1990s. Furthermore, the rate at which Israel was developing successful ICT firms changed by an order of magnitude over this period, from one or two per year, to roughly 10-20 per year at the end of the decade. In sum, the growth rates suggest that there was an important change in cluster characteristics over the 1990s. Other qualitative indicators (to be discussed in Section IV) suggest that there was indeed a substantive change in the Israeli ICT industry. The industry took on many of the proper characteristics of a cluster over this period.

Catalyst Factors

Qualitatively speaking, there are two types of forces that can explain how Israel accumulated enough firms to become a proper cluster, in which cluster effects conferred real benefits: *cumulative* (endogenous) forces, and *exogenous* forces. Cumulative effects arose from the gradual entry of new waves of Israeli firms, and the gradual establishment of new foreign subsidiaries, that took place beginning in the 1970s. Every firm that is successful creates some cluster effects for other firms, such as information to be passed through networks. Each successful firm also creates demand for certain intermediary services such as legal and accounting services. Greater availability of these services also

20 The exact timing of take-off is not obvious from the data and therefore dating takeoff in more detail than 1992-1996 would be somewhat arbitrary.

facilitates the start-up process for subsequent firms, and higher rates of entry of firms encourage venture capital to enter. Thus, the process of cluster formation could be attributed partially or entirely to cumulative forces.

In conjunction with cumulative forces, however, there were a number of important exogenous forces that encouraged the formation of a cluster. A host of favorable factors came together in the 1990s. Factors specific to Israel included:

- the Soviet immigration[21] (beginning in 1989) and, separately, a strong contraction in the state-dominated military industries, most notably with the dismantling of the Lavi aircraft project[22]—events which, together, created a surplus of engineers, scientists, and technicians, who were then available to the ICT industry (Trajtenberg 1999:7-8).
- the Oslo peace accords (1993), which for a time reduced the stigma and political risk faced by firms in Israel;
- the emergence of an Israeli venture capital infrastructure initially nurtured by the state.

From outside Israel the factors were:

- the Internet boom (beginning in 1995) and telecommunications boom (beginning in the early 1990s);
- the global tightness of labor markets for skilled computer professionals, which was closely related to the Internet boom;
- the financial boom and the related globalization of financial flows including both risk and equity markets.

Some of these factors strongly encouraged the formation of new firms, and the presence of those firms led to cluster effects. Interestingly, other factors encouraged the development of cluster effects more directly: the government's program to encourage venture capital falls into this category. The role of the internet boom and related effects, and of the government programs, is explored in more detail.

Role of the Internet and telecommunications boom

The direct effect of the 1990s global technology boom was to strongly increase demand for Israeli products. We have discussed Israel's absolute advantage in the area of communication technologies and networks due to the high levels of investment in R&D within the military and within academia. However, the potential commercial value of these communication and network innovations exploded with the Internet.

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[21] However, there is some evidence that the immigrants from the former Soviet Union were not catalysts in the sense of becoming entrepreneurs,: Lerner and Hendeles (1996) find low rates of entrepreneurship in that group.

22 The Lavi Aircraft project was a massive defense project aimed at building a world-class jet fighter. More generally, however, the military technology sector underwent a substantial contraction beginning in the mid-1980s, in response to fiscal crises.

One of these key market segments is security. The Internet's rapid diffusion created security concerns about the vulnerability of firms' systems reliability, messaging, and data. Firms were very eager and willing to pay for improved security. Almost no tools existed to address these problems before the mid-1990s. And yet the Israeli military had already addressed a number of these problems in its communications networks-- and developed tools in response. Small wonder that Israel became a leading provider of the tools aimed at resolving these communication problems. "'By sheer luck,' says Professor Shimon Schocken, dean of the school of computer science at the Interdisciplinary Center in Herzeliya: 'Israel already had the solutions to so many of the problems of the Internet'" (Perman 2000).

Within the data security segment Check Point Software is one of the most successful Israeli companies of the period. Its founder, Gil Shwed, created a software product known as a firewall, designed to protect organizational systems connected to an external network. The conceptualization of his product was developed during his time in the military:

> "There, in the late 1980s, Shwed was confronted with the problem that would inspire his life work. The problem was how to connect the military's numerous computers without compromising the security of the most classified among them. … [Check Point developed the civilian version, but] the only drawback was that there were almost no commercial customers whose data networks raised the same security concerns as the military's. That changed, however, with the rise of the Internet after 1993" (Hiltzik, 2000)

Rapidly evolving Internet-related needs multiplied the demand for products in Israel's area of capability, and placed a much higher premium on the speed of development. An Israeli company seeking a commercial application for technologies arising from military expertise now faced a much higher probability of success (and of large success), if that expertise had any applicability to the Internet. Israeli firms were able to develop products that were relevant to network problems, were technically superior to their competitors' and were available sooner, sometimes years sooner. Despite the continued market access difficulties of a distant country, the vacuum in this product area combined with the urgency of demand meant that, when any contacts were made, there was a strong possibility of a sale or a partnership.

The boom also had an impact on competitiveness. First, the high level of demand in most areas of ICT allowed some Israeli firms to venture into and succeed in new areas far afield from traditional Israeli niches.[23] Second, Silicon Valley firms were more widely spread across many ICT areas, particularly in those for which the United States had a comparative advantage, e-commerce and consumer-oriented dot-coms. While the Silicon Valley cluster was devoting a great deal of its energy to this segment, Israeli firms were more likely to succeed in a domain in which they long excelled—technology-driven innovations that needed somewhat less market access.

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[23] An example of a successful mass-market Israeli software product is ICQ (the first Instant Messaging product) from Mirabilis, an product that would alert users when their friends were online and available for electronic conversation. ICQ represented a departure from the more technical innovations that typically have come out of Israel. Mirabalis was sold to America OnLine for $407 million in 1998 (Hiltzik, 2000).

The financial boom in conjunction with the technology boom had two indirect effects on the profitability of high-technology in Israel. The first stemmed from the wave of acquisitions of Israeli firms. Foreign (mostly US) high-technology firms, such as Intel, Cisco, Lucent, Computer Associates, after experiencing huge financial gains, acquired a number of Israeli firms, particularly start-ups. The gains to trade lay in the fact that the acquiring firm was usually in a much better position to market the product, given that its access to markets had already been established (Teubal et al. 2000). A large acquiring multinational is also better able to refine the product in later versions, given its understanding of the subtleties of customer requirements. Thus, the Israeli firms were able to realize large financial rewards from their innovations without having to successfully reach final customers. Teubal et al. (2000) have pointed out that the Mergers & Acquisitions process serves as a shortcut to the market, allowing more Israeli firms to enter and realize profits than would otherwise have been possible.

The financial boom also allowed young Israeli technology firms to go public through a foreign IPO very early. The publicity associated with the IPO process and the subsequent publicity from being listed on a stock exchange became a means for these firms to gain visibility and reputation, thereby gaining even more access to customers and partners. Teubal et al. (2000) argue that this process greatly assisted firms in reaching their final markets. Indeed, for this and other reasons, over 100 Israeli high-tech firms eventually became listed on US and European equity markets, primarily NASDAQ. All in all, Israeli firms found it easier to gain access to customers, partners, and investors as a result of these "reputation effects."

As a result of all these related forces, since the mid-1990s *Israel gained a stock (and flow) of successful firms* that were a source of market contacts and market experience. The increase in the rate of firm formation led to the entry of a full range of suppliers of intermediary services. In particular, the successes-- and the prospect of further successes -- attracted venture capital flows into a growing number of venture capital firms. All of these consequences can be termed "cluster effects."

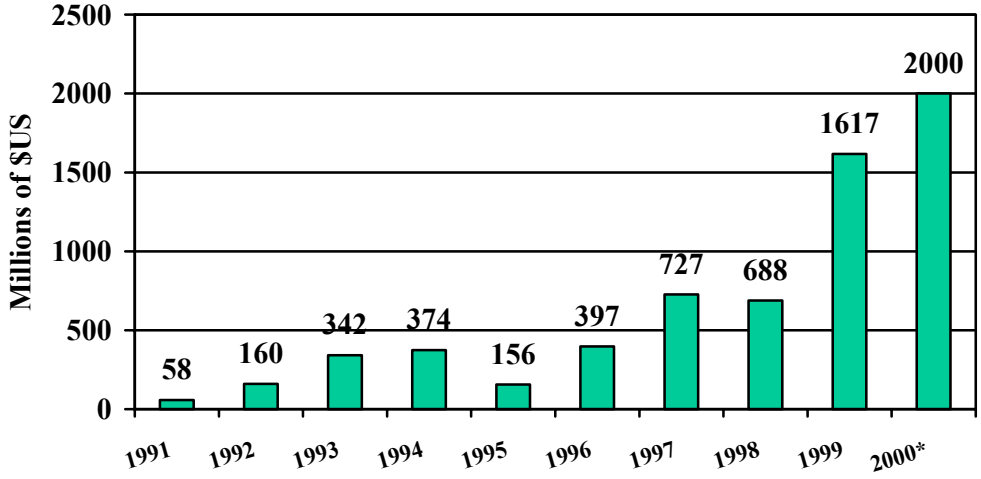

Figure 4: Capital raised by venture capital funds and other investors in Israel, 1991-2000. Y2000 is estimated. Source: Israel Office of the Chief Scientist, Zinook Research and Data Center

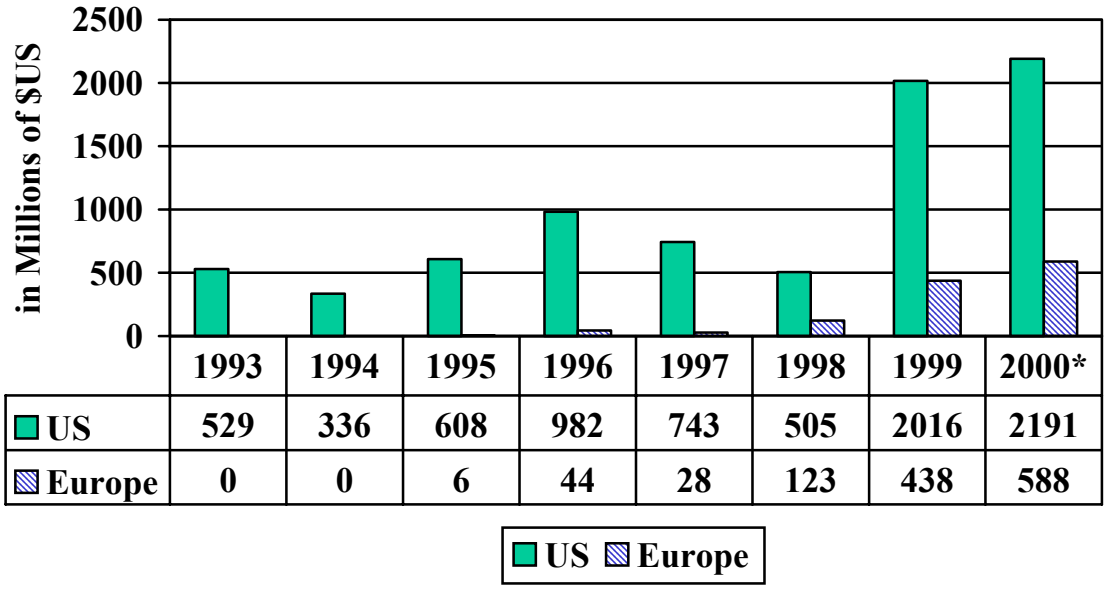

Figure 5: Capital Raising via IPO's of Israeli companies in the USA and Europe, 1993-2000. Note: 2000 includes first 3 quarters only. Source: Source: Israel Office of the Chief Scientist ; Giza, Zinook Research and Data Center

Emergence of a venture capital infrastructure

Until 1985 there was no institutional risk capital in Israel. Then in 1985 three well-known technology entrepreneurs set up Israel's first venture capital fund, Athena, with $29 million. The next entry was a state-backed fund called Yozma (the Hebrew word for initiative) which started operations in 1993, and seeded 10 venture capital funds, including some of the most successful in Israel. The government provided 40% of funding with easy purchase clauses for investors, whether domestic or foreign.

Dr. A.I. Mlavsky, who led part of the government effort to encourage investment, joked that before 1995 the Israeli venture community could all meet in a café (Hiltzik, 2000). But by 1996 there were 35 venture capital funds managing investments of roughly half a billion dollars, and by 2000 there were more than 100 funds managing $7.3 billion dollars of investment (See Figures 4 and 5). In 2000 Israel ranked on par with Silicon Valley in venture capital per capita (Gordon, 2000). The surge in venture capital was primarily a result of the global technology and finance booms, but the state's Yozma initiative may have substantially accelerated the formation of the venture capital industry in Israel and flow-on growth.

Another government program that contributed to seed venture capital was the "incubator" program, founded in the early 1990s to assist fledgling entrepreneurs, especially immigrants from the former Soviet Union.[24] By some measures the program has been successful, in that half of the projects continued with private funding after they completed their two years, but its economic impact is not yet clear.[25]

IV. Characteristics of the cluster

An industrial cluster is defined not only by geographic proximity, but by the magnitude of *cluster effects*. These cluster effects are of great interest because they confer a positive benefit on an individual firm in the cluster, independently of other characteristics of the location (Porter 1990 and 1998). As suggested by the paper's opening quote, cluster effects arise from professional and personal networks, that diffuse information; networks of suppliers of specialized goods and services, that are unavailable or more expensive outside a cluster; and specialized economic institutions that reduce inefficiencies and improve information flows.

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24 The purpose of the incubator program is to fund fledgling entrepreneurs and to assist them in developing their ideas into businesses that can be funded by seed venture capitalists. Entrepreneurs whose ideas are approved by the Government's Office of the Chief Scientist receive two years of funding and guidance; the second year of funding is conditional on attracting some outside funding. In this program the OCS is explicitly playing the guiding role of a venture capitalist (Trajtenberg 2000, and interview with Dr. David Naveh, March 2001.)

25 Another new program was the Magnet program, established in 1993, but it is more of a complement to existing OCS funding. Under Magnet the OCS sought to fund more collaborative "pre-competitive" research, rather than single-firm research projects. As with the incubator program, there are no measures yet of the impact of Magnet.

The characteristics of the cluster are determined by the **cumulative** impact of the firms, institutions and individuals that have established presence or connections in Israel. These links form the basis for the cluster's relationships and enhanced productivity.

Cumulative Effects: Networks, Knowledge, and Institutions

Networks

We begin with the web of professional person-to-person networks, or "horizontal relationships." Saxenian (1994) emphasized the important role of these professional networks in the rise of the Silicon Valley. Professional networks facilitated information spillovers between firms, thereby promoting the diffusion of the most successful techniques and technologies, successful organizational structures, and rapid movement of talented labor. Similarly, *Israeli firms can draw on their connections for high-skill potential employees, for market and technical information, and for entrée with potential customers or partners in US markets.*

The peculiarity of Israel is that universal military service serves as a foundation for domestic professional high-tech networks. Connections with army friends function much as do university connections in the United States, with the added benefit that they are more close-knit, and are based on more information about each others' performance under stressful conditions.[26] Thus it is common for high-tech startup founders to recruit a core team quickly from old army friends, or persons that they "knew about" when they were in the army—thus military networks stretch across time as well, as Autler (2000) points out.[27] The value of these connections is clearly enhanced, as more and more individuals from technology units enter the ICT industry.

The small size of the Israeli population (6 million citizens) implies that personal connections from universities and other social settings fill most gaps left by the military professional network.[28] After the military, the other source of professional networks is the Technion (the Israeli Institute of Technology), which for many years produced the country's scientific and engineering elite (and until the 1990s, only five universities produced scientists and engineers).

While the cluster's domestic professional networks are critical, so too are professional ties with other world clusters, in particular to Israelis overseas. There are 500,000 Israelis in the United States. For decades a significant number of Israelis have been going to the US for technology-related MSc and PhD degrees. Many remained to work at US

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26 Army background helps employers and investors make selection decisions: information on a person's unit and performance in the army is easily available, and these provide a great deal of information as to a person's ability and work habits. For example, someone from an elite intelligence unit may be offered a job, merely on that basis. Finally, it has been suggested that Israelis easily recognize in each other the leadership qualities developed inside the military, facilitating the hiring of an effective team. (This exposition benefited from discussions with Prof. Justman of Ben Gurion University in Beersheba, March 2001.)

27 Autler (2000:46-47) echoes this analysis of the function of military networks.

28 However, the everyone- knows-everyone networking is changing as the high tech industry grows. For instance, the entrance of a major US headhunting agency in 1998 suggests that the informal network is just recently being encroached on by a more systematic, professional approach.

technology multinationals, at academic institutions, or at smaller high-tech firms they helped found. This "brain drain" has costs, but it also fosters a web of relationships.

Multinational presence in Israel has been another important source of networks to the US. Israelis in the local office often develop strong connections with people from the firm's US office. They may also spend time in the US as part of their career in the firm.

The success of Israeli high-tech has generated new links with overseas. Israeli firms now have hundreds of sales offices in the US, most with at least some Israeli representation, and each of these offices establish connections in their region. These successful Israeli firms have thus developed an active network in US clusters, reinforcing the links between the US and Israel.

Knowledge

Over their history, Israeli high-tech firms (both locally-founded firms and subsidiaries of foreign firms) have amassed a substantial stock of technological knowledge, that builds on the stock from military and university research, and immigration. As a consequence, Israel is now considered a center of expertise in areas grown out of this knowledge base, and the people with this knowledge a desirable commodity. For example, all major communication chip firms (firms engaged in Digital Signal Processing) establish large R&D centers in Israel, according to one CEO in this field. More generally, the availability of a pool of workers with accumulated knowledge will improve the productivity of local or international firms that settle in the region, as Porter (1998) noted.

The value of accumulated knowledge is not restricted to technical areas. The marketing and management knowledge accumulated by Israelis within these firms has also been extremely valuable, particularly to local startups. Broader categories of knowledge were also important: New waves of Israeli firms relied on advice from familiars with information about US markets grown out of direct experience. A seasoned R&D executive from one of Israel's most successful software firms told us that "small companies come to us about once a week for advice," and successful investors such as Yossi Vardi have similar influence (Hiltzik, 2000). The collective knowledge of firms diffuses rapidly through the network. For instance, by the late 1990s it was widely understood that there are tax advantages to incorporating the firm in Delaware, USA, rather than in Israel, and that it might be profitable to move the firm's headquarters to the United States early on.

Autler (2000) chronicles how networks and knowledge have coalesced to raise the productivity of the Israeli cluster. New firms in Israel have been able to draw on their extensive local networks to hire connections with the requisite technical, marketing and management skills into new firms. Firms hire from military connections, from universities, and from earlier generations of Israeli firms and MNCs. Firms also transmit information to each other through professional interactions.

For example, he traces the links between firms in the semiconductor equipment industry (Autler 2000: 57-66). In 1969 Kulicke & Soffa, a US equipment manufacturer, established a design center in Israel. Intel and National Semiconductor followed, establishing design centers in the 1970s and manufacturing plants ("fabs") in the 1980s.

Many of their researchers started important spinoffs in the area of equipment, notably a subsdiary of KLA in the 1980s, and a number of other subsidiaries and local firms. Moreover, the fabs cooperated to provide a local source of information about manufacturing concerns, that was critical to the success of equipment manufacturers. At the same time, El-Op, a military manufacturer, gave rise to a number of spinoffs in the area of semiconductor inspection and testing, and university research led to yet another group of firms in the area of inspection systems. By the third and fourth generation of semiconductor equipment in Israel, firms such as Nanonics and Nova were drawing on several of these sources, as well as the earlier generation of firms. Autler shows that a similar confluence of expertise is at work in other industries, such as semiconductor design, networking (software- and Internet-based network management tools) and network security.[29]

International networks have also facilitated hiring overseas, when the knowledge needed is not locally available. Broadly speaking, this is a more recent phenomenon within the cluster: earlier, only the MNCs were able to send Israelis to their US offices for training and, to a lesser extent, to send US personnel out to Israel for brief stints (as Autler describes for Intel, p.54). The fact that many firms are now spread across two countries has also greatly eased hiring constraints, as the necessary personnel can be hired in the US office if the skills are not found in Israel.

Intermediaries and Institutions

By the mid-to-late 1990s the Israeli cluster had also developed a network of specialized suppliers and intermediaries, that was all but absent prior to the 1990s. In some industries, the main concern is the supply chain of physical goods, but in much of ICT the most important suppliers are suppliers of specialized services. Israel developed personnel services, executive headhunting, specialized accounting, legal and tax counsel, strategy consulting, research, training, conferences, exhibitions, and so on. For example, service providers specialized in assisting Israeli firms in hiring US-based management teams for US headquarters or a US sales office. A robust venture capital industry has emerged, as described earlier. These intermediaries were also important in that they had their own professional networks to the US and other major markets.

The cluster also developed a range of specialized economic institutions. The government established programs that are relevant to high-technology startups, such as the Incubator program for training new entrepreneurs. The Magnet Program and BIRD foster contacts and cooperative research between firms. The state reduced bureaucracy and simplified tax issues (somewhat) to remove impediments to common high-technology transactions, such as mergers[30]. Within academic institutions, business and technology programs have grown significantly (for example, the number of institutes offering an MBA grew fivefold during the 1990s).

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[29] The influence of the military is predominant in the latter two industries, however.

30 Presentation by Jonathan Feuchtwanger of Naschitz, Brandes and Company at the High Technology Management Forum, Recanati School of Business, Tel Aviv University, February, 2001.

What activities are favored (or disadvantaged) in the cluster?

This section takes a more systematic look at the impact of comparative advantage and cluster effects on the structure of the Israeli ICT industry. If these forces are indeed shaping the Israeli cluster, then they should be reflected in the makeup of the industry and in the decisions of individual firms regarding which activities to undertake in Israel. By implication, those forces will also be shaping the future prospects of the cluster.

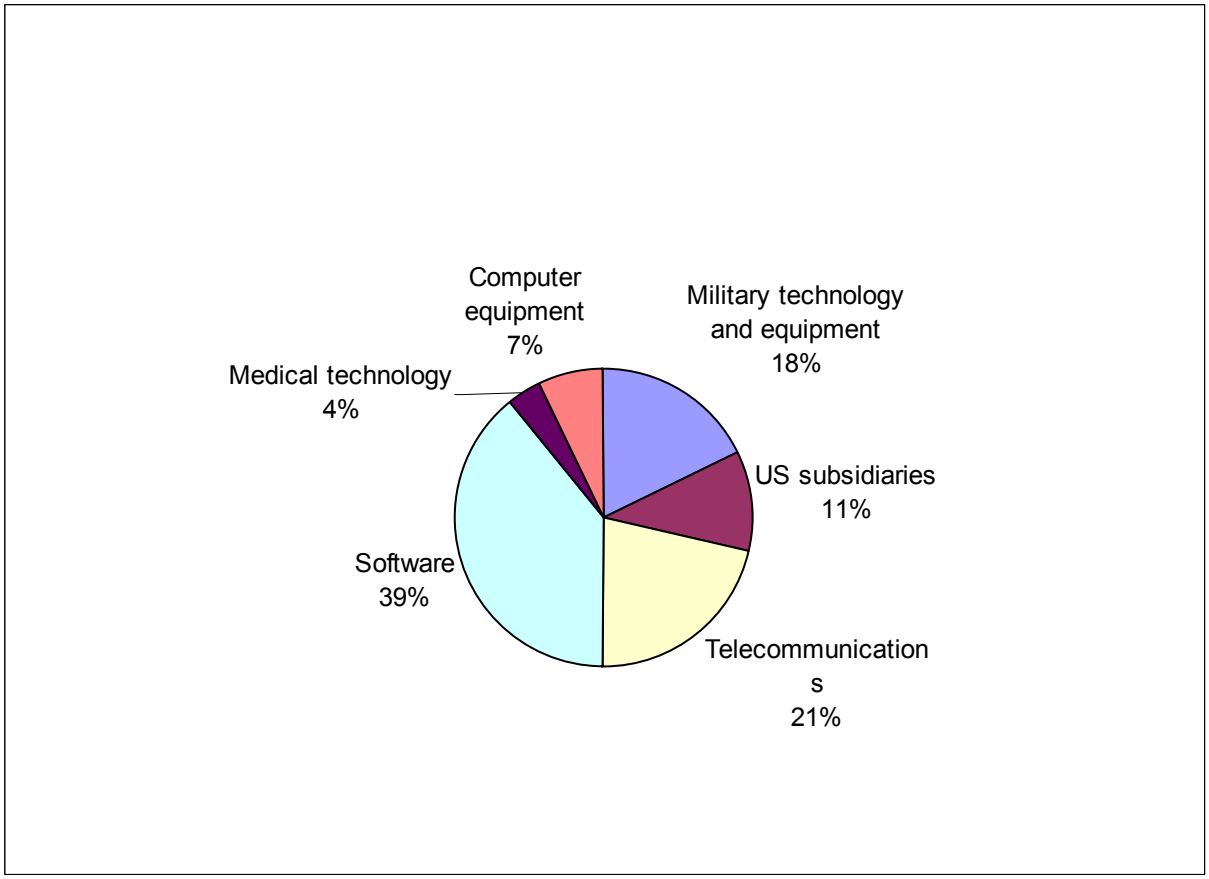

Figure 6a: Largest Israeli High Technology firms: Distribution of firms by type.
Source: Dun and Bradstreet Top 100 Israeli firms by 1999 sales. All high-technology firms (28 in all) from among the 100. Categories and classification defined by authors.

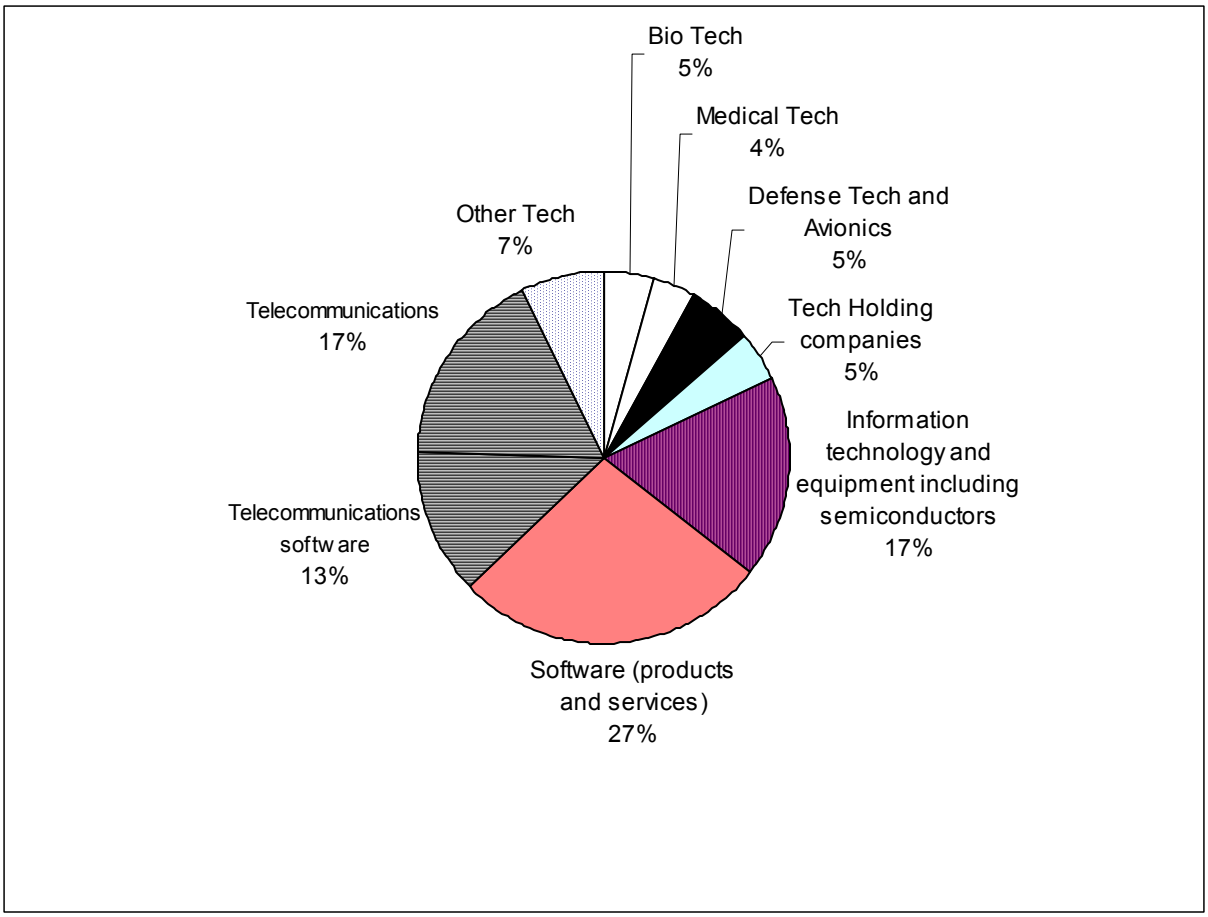

Figure 6b: Distribution of all 110 Israeli technology-related stocks trading on Wall Street. June 2001. Categories and classification by authors.

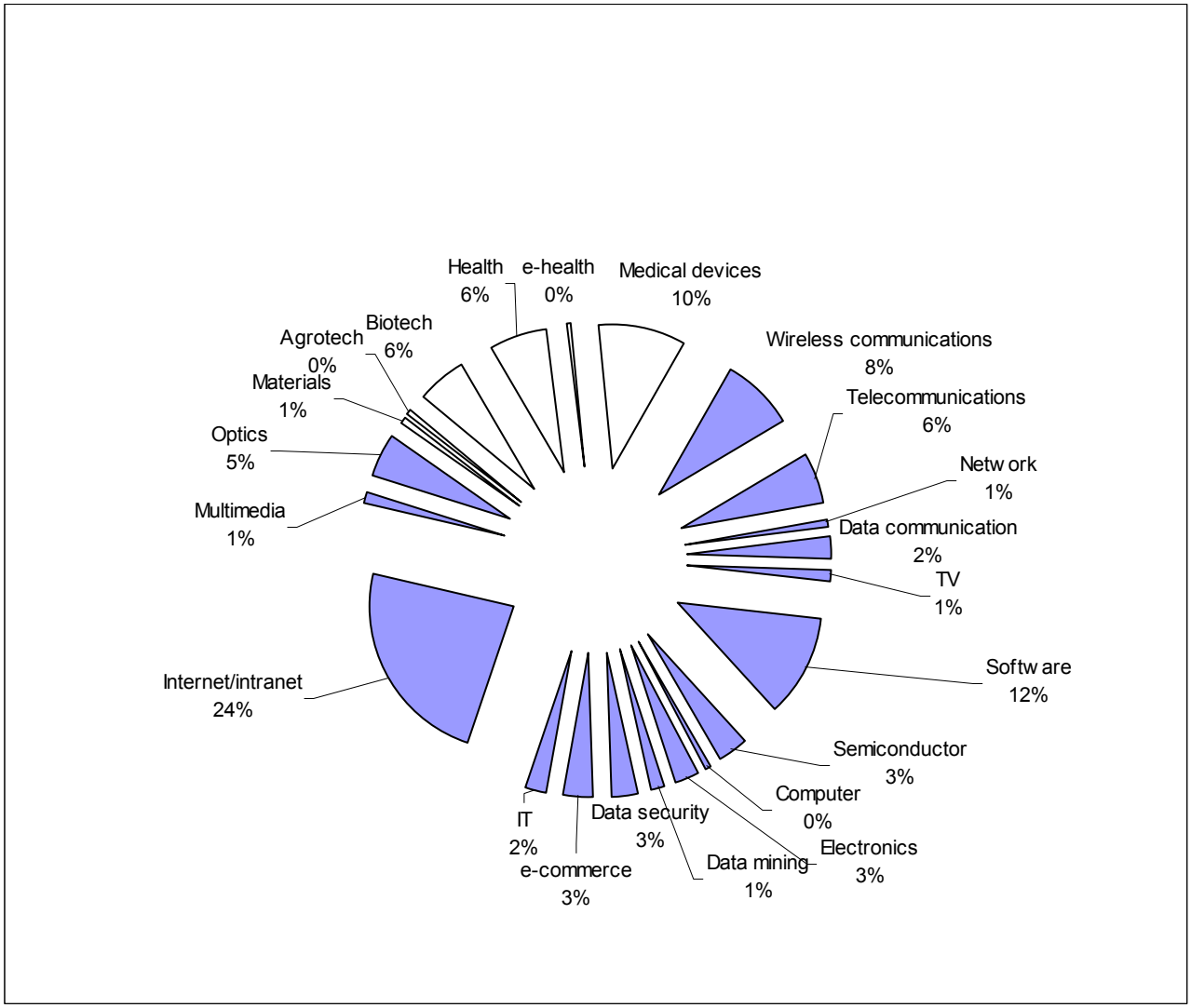

Figure 6c: Young Israeli High-Tech firms: Distribution of 249 Firms by Type.
Source: Israel Venture Capital Online (IVC) www.ivc-online.com, March, 2001.
Note: These are young firms with products in R&D or Beta testing.

Industry composition

The distribution of Israeli high-tech firms by area is displayed in Figures 6a,6b,6c, detailing the breakdown by area of respectively, the largest firms, the set of firms on Wall Street (young and old), and very young firms. While the concentrations are somewhat different, together they paint a picture of Israel's areas of specialization in high tech. The pre-eminence of software and telecommunications is evident in all three. Historical areas of strength and comparative advantage, such as military equipment and bio-medical equipment, also continue to be significant.[31] Medical and bio-tech industries are currently

[31] Israel has a biomedical electronics industry dating back to the 1960s. Teubal, et al (1976:362) wrote in 1976 that there is recognition that "…Israel should enjoy a comparative advantage in science-based

growing in importance, and thus are more prominent in the list of young firms (Figure 6c). Because military technology and equipment firms are older, larger and more established, they do not appear in the chart of young firms.

The impact of specific comparative advantage and of the 1990s boom is also visible. The more detailed chart of young firms (Figure 6c) includes many of the areas derived from the military and university R&D, and particularly those which exploded in the 1990s: optics, data security, wireless communications, data communications, networks, and presumably some of the areas labeled "internet/intranet." The areas of specialization derived from the immigration from the former Soviet Union are not so evident, perhaps because their impact is diffused in different categories.

To some degree, the figures also indicate a bent towards labor-intensive areas, which reflects Israel's broad comparative advantage in skilled labor activities (over capital-intensive activities). Software firms, which tend to be highly labor intensive,[32] are strongly represented (39%, 40%, and over 55%, respectively in Figures 6a-6c).

Finally, Israel's comparative disadvantage in market access is somewhat evident in industry composition. For example, the focus away from segments requiring high customer-proximity can be seen by the relatively small number of firms in the e-commerce segment (Figure 6c). Only a relatively few Israeli firms were active in this segment even at the time when in the USA it was considered the most promising.

Location decisions

Location decisions—where firms choose to establish and expand R&D—are a telling indicator of national advantages. We discuss here two such sets of decisions: decisions by Israeli firms to set up or maintain an R&D unit in the US and decisions by US firms to set up or expand an R&D unit in Israel. We interviewed executives from 29 high-technology firms as well as other industry sources (see Appendix 1: Data Sources), eliciting information as to which functions of the company were located in which site, and why.

While many Israeli firms moved their customer support, sales and marketing functions to the US and sometimes even their CFO and CEO, core R&D functions remained in Israel.[33] Numerous industry sources in Israel were insistent that this was the norm and could not think of even one firm that moved their R&D functions to the US. We made every effort to locate Israeli firms with primary R&D locations in the US for our sample. We finally did locate one firm that had relocated entirely to the US. This firm moved R&D to the US when it had about 20 engineers, in order to reduce the communication

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industries because of the advanced state of research in Israeli academic institutions and the relative abundance of scientific and technological manpower."

[32] Overall, based on recent data from the Central Bureau of Statistics, we estimated ICT labor costs at 60% of firm revenue on average, implying that labor is necessarily a larger part of costs than capital equipment and other overhead.

33 A very different set of managerial decisions vis-à-vis Israeli advantages are made with regards to technical support functions (also known as customer support or engineering support) staffed by applications engineers. These technical units are typically set up in proximity to customers in the US, Europe, and Asia. Some of the Israeli firms perform a considerable amount of custom development —meaning modifying the product for the needs of one customer. Israeli firms vary as to how many of these customer support functions they maintain in Israel and how many they establish in the US, partly because there are costs to reducing interaction between technical support functions and R&D.

costs between R&D and the functions of the firm that were in the US. This firm 's product required significant interactions with customers, thus Israel's disadvantage in market access may have been particularly costly.

While maintaining core R&D in Israel, several Israeli firms established a small US R&D unit (greenfields) to hire engineers with a very specific form of expertise (such as mixed-signal / analog front-end engineering, or communications hardware in large systems) that was relatively unavailable in Israel. In addition, two other important Israeli firms had established a small R&D unit in the Silicon Valley, to "test the waters," assessing the benefits of performing R&D near US headquarters and US customers, and in an area with experienced high-quality labor. But in both cases the Israeli firms closed their Silicon Valley units during the boom period, concluding that the labor costs (exacerbated by high turnover) were too high. This is significant, because if no Israeli firms are observed to establish an R&D site in the US, one might conclude that they are deterred by the fixed costs of setting up a new site. But if firms open a site and then close it, it suggests that the benefits of the Silicon Valley and of proximity to US headquarters and customers are not high enough to outweigh the higher costs of labor and of communication to the rest of R&D back in Israel.

Some large Israeli firms acquired American companies and retained their R&D operations. However, in one such case of inheriting an R&D unit as a result of acquisition, the Israeli firm closed the unit and moved all its functions back to R&D in Israel.[34] If a firm closes an acquired American unit, it is giving up the product-specific skills of the American researchers and the site's better market access for the sake of lower communication costs and/or Israel's advantage in R&D.

Choices made by high-mobility Israeli founders are particularly revealing in terms of R&D location decisions. In a number of the firms we interviewed the founders were living in the US at the time the company was formed, or moved to the US to form their company. Most of these firms placed their headquarters in the US but R&D in Israel. Clearly, they did not choose Israel for R&D because they were there, but because of its advantage in their area of R&D.[35]

American multinational corporations have been establishing R&D centers in Israel for several decades (cf. Felsenstein, 1997).[36] The centers' output tends to be destined to world markets, implying that they were not established to access Israeli markets, but for reasons of cost or productivity. In general, these American firms saw the benefits of

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34 Israel's firms may be compared with those of another small nation with high levels of exports of technology products: Sweden. In Swedish MNCS the foreign ratio of R&D rose to 23% in 1991 (Granstrand, 1999). It is unlikely that Israeli high-tech firms are even close to this measure. Based on our interviews in the industry we estimate that the foreign component of R&D is no higher than 10% (including acquisitions) and likely less. The high concentration of R&D in Israel is also noted in Ein-Dor, et al, 1997.

35 This location decision might be influenced by patriotism, or by the fact that it was easier to recruit good engineers though their military connections. But overall it speaks strongly of Israel's comparative advantage in R&D, which is large enough to outweigh the cost of spreading the firm across locations.

36 Motorola now has 4000 employees in Israel, half of which are engineers. IBM's Haifa Research Lab is the largest of IBM's labs outside the US, working on a variety of projects including medical imaging, image and character recognition (such as systems for postal services), and multimedia. National Semiconductor established a design center in Herzeliya in1978 and later, production facilities in Migdal HaEmek. Digital also opened a design center in Jerusalem which it later sold to Intel.

undertaking R&D in Israel relative to the US as important enough to outweigh the cost of distance (coordination costs). These benefits included the quality of human capital, low cost of labor (in some cases), government incentives (such as OCS grants, tax holidays, or matching funds in some cases), low turnover rates (that justified intense on-the-job training), as well as offset requirements (which require some US firms to purchase a quota amount from Israeli firms). Finally, the role of the internal Israeli champion who pressured the firm to open an Israeli site so he could return to Israel for personal reasons was important in the cases such as Intel and Microsoft. Significantly, most of these units founded by 'champions' continued to expand.[37]

For many years the multinationals established primarily greenfields centers, but during the 1990s more R&D centers came about as a result of acquisitions. Often Israeli firms were acquired for their innovative products—which reflects Israel's advantage in its areas of strength in R&D. For example, Computer Associates acquired one of Israel's leading data security firms, Memco, and made the acquisition the worldwide center of its data security products development.[38]

Prospects for the future

The world boom in finance and technology in the 1990s ended by 2001, and the Israeli ICT industry, which was so closely tied to the US market, began suffering from a fall in US demand. By late 2001, Israeli high tech firms laid off more than 11000 employees and 500 technology firms closed, including more than 100 start-ups. The effects of the recession in Israel were compounded by the ever-worsening conflict with the Palestinians that began in September 2000. The state of near-war drastically heightened security concerns and other barriers to doing business with Israel, such as stigma. By 2002 the Israeli economy and its ICT sector had plunged into a strong recession.

There is a risk that the country could find itself specialized in areas that have very low growth potential, particularly in the wake of the recession. However, among the world's emerging ICT clusters, such as Ireland, India or Taiwan, Israel is fairly diversified, as is clear from the broad industrial composition of Figure 6. The figure suggests that the Israeli cluster has expanded beyond the bounds of its strongest expertise, into fields such as biotechnology. Indeed, of the few Israeli firms to go public in late 2001, two were biotechnology firms. The composition of startups in Israel was clearly evolving. However, the recession and political-security problems in Israel have obscured most evidence about the cluster's evolution and prospects.

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[37] Intel's largest R&D center outside the USA is in Haifa's Matam technology park. Intel has more than 5000 employees in Israel, including production facilities in Jerusalem and Kiryat Gat (which opened in 1996 to manufacture 0.18 micron chips) and acquisitions. Intel's Israeli design center was instrumental in designing key chips such as the MMX and the Pentium II. Microsoft opened an R&D center in Haifa in 1991 that focuses on product development for Windows and networks, and now has about 100 engineers.

[38] GE Medical Systems' first partnered and then acquired ElGems as part of GE medical systems division (El-Gems has 100 engineers working on nuclear medicine products); BMC bought New Dimension, which made data center systems software, and now has 400 employees in Israel. Sun, Cisco, Applied Materials and others also have R&D in Israel through acquisitions (smaller firms such as VerticalNet and non-US firms such as SAP have also made acquisitions: German-based SAP bought the Israeli firm TopTier in 2001 to complement its enterprise management software).

V. Appendix: Data Sources

This study relied on both primary and secondary sources for data. Interviews were conducted both in Israel and in the US by the two authors. During the first half of 2001, we interviewed executives from 29 high tech firms with operations in Israel. Many of these firms had operations in both the United States and Israel. The majority of firms (26 of 29) were in the ICT area, while the remainder (3) were in bio-informatics, medical technology, and material science. The majority of the firms were founded in Israel, and the minority were American firms with an Israeli R&D center. Among the interviewees were some of the most prominent figures in Israeli high technology. In addition, in Israel, we interviewed partners and executives from venture capital, executive recruiting, personnel, legal, and accounting firms. All of these firms specialized in high technology. We had fertile discussions with five Israeli academics from major universities who study Israeli high technology. Finally, we interviewed one Israeli government official, the former head of the Office of the Chief Scientist, and two former heads of the BIRD foundation, a quasi-governmental organization.

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