The technopoles of Southern California

A J Scott
Department of Geography, University of California–Los Angeles, 405 Hilgard Ave, Los Angeles, CA 90024, USA
Received 18 August 1989

Abstract. The paper opens with a brief identification of California's pathway (via flexible-production organization) to industrialization and regional growth. The emergence of the aircraft industry in the region during the 1920s and 1930s is described. The formation of the postwar aerospace-electronics industry is then discussed in detail. The geography of Southern California's contemporary technopoles (high-technology industrial districts) is outlined, with a particular emphasis on the aircraft, electronics, biotechnology, and medical-device industries. The functional role of interfirm linkages and local labor markets in the high-technology industrial development of Southern California is analyzed. The paper ends with a few brief allusions to the strengths and vulnerabilities of high-technology industry in the region.

Introduction
Southern California is one of the world's great urban-industrial regions. Its functional core is made up of an immense megalopolis, stretching some 250 miles from Santa Barbara in the north-west to San Diego in the south, and reaching its highest density of development in the pivotal area of Los Angeles. In administrative terms, this area comprises 188 individual municipalities organized within the seven counties of Los Angeles, Orange, Riverside, San Bernardino, San Diego, Santa Barbara, and Ventura (see figure 1). In 1988, the aggregate population of these counties was estimated at close to 16.3 million and the total labor force in manufacturing at some 1.4 million workers (Employment Development Department, 1988). Of the

Figure 1. The seven principal counties of Southern California. The main built-up area is represented by shading.
latter workers, approximately one-third were engaged in high-technology industry (as defined below).

Southern California, then, is a major hub of population and of manufacturing activity; more specifically, it is also a primary center of high-technology industry. Indeed, despite the evident and inexplicable neglect in the scholarly literature of Southern California as a high-technology industrial region, it is probably the most densely-developed such region of comparable areal extent anywhere in the world, and over the last couple of decades, while older industrial regions have experienced stubborn economic crises, it has grown at an extremely rapid pace. The work presented in this paper is an attempt to document the origins and character of this growth and to sketch out its changing geographical expression within the region. An attempt is also made to articulate a number of theoretical challenges that the peculiar pattern of high-technology industrial development in Southern California raises for economic and urban geography. Some of these challenges find a provisional response in the study set forth below, but all of them demand much further research before definitive answers can be proposed with any degree of confidence. What now follows is for the most part a review and synthesis of the preliminary results of a continuing research program on high-technology industry in Southern California. As such, the discussion passes in broad strokes over an extremely complex set of issues. A fuller set of arguments and a more detailed discussion of data sources and methods of analysis may be found in the original research reports upon which the present paper is based (Scott, 1988a; 1988b; Scott and Drayse, 1990; Scott and Kwok, 1989; Scott and Mattingly, 1989; Scott and Paul, 1989).

An overview of high-technology industrial development in Southern California

The industrialization process

Southern California’s road to industrialization contrasts in many important respects with the classical Fordist model pioneered after the 1920s and 1930s in the mass-production sectors of the Manufacturing Belt of the USA. In fact, mass production in its narrowest sense has never been particularly significant in the economy of Southern California. It is true, of course, that in the early days of the aircraft industry, and especially during World War Two, a form of proto-mass production came into being—as embodied in the great assembly plants, each with large numbers of semifinished aircraft moving intermittently past a series of work stations. In its subsequent evolution, however, most of the aircraft industry (especially on the military side) deviated markedly from the typical model of mass production, with its moving assembly line, its standardized outputs, and its deskilled workers, and shifted towards the production of smaller and smaller batches of ever more R&D-intensive outputs. In addition, massive industrialization occurred in the region rather later than it did in the Manufacturing Belt, and, as in the specific case of the aircraft industry, it has tended to become increasingly focused on flexible batch-production methods. The growth of industry in the region has continued vigorously on into the present day even at a time when industrial employment in the Manufacturing Belt has been in a long-term downswing.

The traditional mass-production (and related) sectors in Southern California have always been dominated by cars, tires, and machinery. To these sectors we might add such large-scale process industries as petroleum products and steel. Even in their heyday in the 1950s, these sectors employed only some 7%–8% of all manufacturing workers in the region. Over the last couple of decades they have declined significantly—like their counterparts in the Northeast of the country—and today they account for little more than 2% of total manufacturing employment (Scott and
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Paul, 1989). The dominant industries in the region consist of two major ensembles involving low-technology craft-specialty sectors (clothing, furniture, printing and publishing, motion pictures, etc) on the one hand, and high-technology sectors (computers, electronics, and aerospace products for the most part) on the other hand. Both ensembles are growing rapidly at the present time, and notwithstanding their markedly contrasting production processes and outputs, they have in common an insistent search for diverse forms of flexibility in technologies, organizational structures, and the use of labor. Since the 1950s, Southern California has been in the vanguard of this particular pattern of industrialization, and the region can be seen as one of the paradigmatic cases of local economic development under this new (or resurgent) form of industrial activity.

The claim that advanced capitalist production systems are now to a significant degree evolving in the direction of post-Fordist flexible forms of economic activity is currently a hotly debated issue (see Gertler, 1988; Harvey and Scott, 1989; Piore and Sabel, 1984; Pollert, 1988; Sayer, 1989; Williams et al, 1987). In the present context I shall not attempt to deal directly with the many ramifications of this debate. I shall, however, describe some of the main lineaments of Southern California's flexible manufacturing system in general; and on this basis I shall then present a detailed empirical survey of the growth and current locational characteristics of high-technology industry in the region.

The distinctive character of flexible manufacturing in the region involves four main elements, as follows:

(a) A production system that makes use, to a significant degree, of microelectronic and/or labor-intensive technologies, as opposed to large-scale dedicated units of capital. In this manner, relatively rapid shifts of process and product configurations are facilitated, even in large manufacturing establishments.

(b) A tendency towards deepening social divisions of labor (dynamic vertical disintegration) and the recomposition of the production system into transaction-intensive complexes of production units. These complexes comprise both large and small establishments, with the smaller establishments performing important specialized subcontracting functions, especially for local firms.

(c) A definite restructuring of local labor markets, with two distinctive strata becoming increasingly evident (see Storper and Scott, 1989b). On the one side, there is a stratum of skilled, highly-paid workers, divisible into two subgroups, namely (i) a core cadre with much firm-specific human capital and relative job-security, and (ii) an auxiliary subgroup whose skills are more sector-specific and agglomeration-specific and where rates of interestablishment job mobility are often surprisingly high (see Angel, 1989). On the other side, there is a rapidly expanding stratum of low-skilled, low-wage workers for the most part comprised of females and immigrants who are subject to great employment instabilities, as manifest in high rates of turnover, part-time work, and temporary work.

(d) A persistent reagglomeration of production as an outcome both of the transaction-intensive character of production and of the volatility of external labor markets (where frequent rotation of workers through the system is common). The result has been a resurgence of specialized Marshallian industrial districts on the landscape of Southern California both for low-technology and for high-technology sectors (Scott, 1988a; 1988b). In the case of craft-specialty production, these districts are all situated in and around the area of central Los Angeles; in the case of high-technology industry, they comprise a series of technopoles which are for the most part located in the burgeoning outer cities of the region (see Soja, 1989).

These four principal characteristics of the manufacturing system of Southern California constitute some of the basic axes of its peculiar pathway to industrialization.
and regional development. They are the foundation stones of the innovativeness and the ever-expanding pool of external economies with its associated Verdoorn effects (Kaldor, 1970) that have helped to propel the economy of the region forward over the last four or five decades. They also represent the conceptual backdrop to the empirical investigations that now follow, and they hint at a number of currently unfolding research questions which have great relevance to the conceptual foundations of modern economic geography.

The high-technology industrial ensemble in Southern California: a brief description

For present purposes, high-technology industry is crudely defined as consisting of five three-digit industries as defined by Standard Industrial Classification (SIC), namely, SIC 357 (office and computing machines), SIC 366 (communication equipment), SIC 367 (electronic components and accessories), SIC 372 (aircraft and parts), and SIC 376 (guided missiles, space vehicles, parts). These sectors are all in various ways science-intensive and technology-intensive, and they are also foci of rapid technical innovation. The definition, to be sure, leaves much to be desired. It omits some kinds of industries, such as pharmaceuticals, biotechnology, or medical instruments, that have significant high-technology elements, and it includes others, such as some segments of the electronic components or aircraft-parts sectors, that are in no sense technologically advanced. It remains, however, the only feasible definition that allows us to assemble a reasonably indicative body of data on the basis of published statistics and to gain some overall insight into the temporal dynamics and spatial logic of high-technology industry in Southern California. The definition should therefore be taken as being quite specific to the immediate needs and purposes of the present study. That said, in the main body of the paper an attempt will be made to add nuance to the analysis by occasional reference to more detailed categories of industrial activity.

The broad pattern of growth in the high-technology industrial ensemble in Southern California between 1959 and 1986 is illustrated by the data laid out in table 1. By good fortune, the official definitions of the industrial categories shown

| Year | Industry by Standard Industrial Classification (SIC) | Total |
|------|-----------------------------------------------------|-------|
|      | SIC 357\(^a\) SIC 366\(^b\) SIC 367\(^c\) SIC 372\(^d\) SIC 376\(^e\) |       |
| 1959 | Establishments 46 77 194 603 na |       |
|      | Employment 5710 26626 11056 203289 na |       |
| 1968 | Establishments 74 206 360 371 na |       |
|      | Employment 16399 73568 34289 164208 na |       |
| 1977 | Establishments 186 335 595 314 37 | 1467 |
|      | Employment 29726 67735 41511 90469 6096 290437 |       |
| 1986 | Establishments 406 398 992 334 43 | 2173 |
|      | Employment 40091 125966 67173 129529 72741 435500 |       |

\(\text{na} = \text{data not available.}\)

\(\text{\(^a\) Office and computing machines;}\) \(\text{\(^b\) Communication equipment;}\) \(\text{\(^c\) Electronic components and accessories;}\) \(\text{\(^d\) Aircraft and parts;}\) \(\text{\(^e\) Guided missiles, space vehicles, and parts.}\)

Note: The data shown represent aggregates for the seven counties of Southern California. Occasionally, \textit{County Business Patterns} suppresses employment data for particular sectors in particular counties; where this has occurred, employment has been estimated from interval data provided by the source. Note that SIC 376 was defined as a distinct category only after 1972.

Source: US Department of Commerce, Bureau of the Census, \textit{County Business Patterns}. 

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Table 1. Number of establishments and employment in high-technology industry in Southern California, 1959–1986.
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in this table remain internally consistent throughout this period. However, SIC 376 was created as a separate category within the standard industrial classification only after 1972, and so data for this sector cannot be presented for the earlier part of the period under review. The impression suggested by the data in table 1 is one of sustained and massive growth in the high-technology industrial ensemble, with numbers of establishments and employment often doubling or trebling from one designated time-period to the next. Two sectors—SIC 357 and SIC 367—have growth with particular rapidity since the late 1950s and early 1960s, and all five sectors have grown apace since the late 1970s. Between 1966 and 1977, employment in SIC 366 declined (although not the number of establishments) largely as a result of a downswing in Department of Defense prime-contract awards; and since the late 1950s, SIC 372 has lost employment fairly steadily, despite various short-run upswings and downswings. As indicated later, at least some of this employment loss in SIC 372 has in the past been offset by countervailing growth in upstream sectors.

In table 2, recent data on high-technology industrial development are presented, broken down by county for Southern California. Obviously, Los Angeles county, with well over half of all employment, remains by far the main focus of high-technology industry in the region, although in recent years it has grown more slowly than any of the other counties and its relative weight within the region has been declining over time. The more peripheral counties are currently growing with notable rapidity. This is especially so in the cases of Riverside, San Bernardino, and Santa Barbara counties, although this growth is relative to a small base. By contrast, Orange, San Diego, and to a lesser extent Ventura counties have high growth rates and a sizeable industrial base at the outset.

The geographical dimensions of Southern California's high-technology industrial system are perhaps more distinctly delineated in figure 2, which shows the locations

Figure 2. High-technology industrial activity in Southern California as represented by establishments with 1000 or more workers. Major technopoles are shown by name. (Source of data: California Manufacturers Association, 1989.)
of large high-technology manufacturing establishments, and also names the main technopoles of the region (note that as these technopoles are primarily composed of many small establishments, they are in reality very much more densely and extensively developed than they appear to be in figure 2). Three of these technopoles represent the original high-technology industrial base of the region in the pre-World War Two years. They are (a) the Burbank–Glendale area, (b) the west central area of Los Angeles county, stretching southwards from Santa Monica and Culver City through the airport area to Inglewood, El Segundo, Hawthorne, and Torrance, and (c) the San Diego Bay area (of much less importance). In addition, a number of burgeoning outer cities have become important foci of technopole development in the region over the last two or three decades, as establishments have decentralized in search of cheaper land and access to suburban labor supplies. The more important of these outer technopoles are to be found in Chatsworth–Canoga Park and Van Nuys in the west and west-central area of the San Fernando Valley, in Irvine and its surrounding area in Orange county, in Kearney Mesa and La Jolla–Sorrento Valley in the suburbs to the north of the city of San Diego, and, beyond these well-developed districts, incipient technopole formation seems to be in progress in Ventura and Santa Barbara counties. Palmdale, in northern Los Angeles county, is also the site of a couple of large aerospace establishments (which are directly connected to the adjacent Edwards Air Force Base), but so far little or no secondary growth of industry has occurred in the surrounding area. Riverside and San Bernardino counties have at best only a thin scattering of high-technology industrial establishments, a phenomenon that is possibly related to their more traditional industrial base—now largely defunct—anchored in steel, metalworking, and machinery manufacture.

From table 2, it can be further suggested that, with the exception of Los Angeles and San Diego counties where a number of older and larger high-technology industrial establishments survive (mainly in SICs 372 and 376), the rate of growth by county in numbers of establishments exceeds (sometimes greatly) the rate of growth of employment. From this we may infer that in many of the outer technopoles, average establishment size is diminishing over time. This inference is corroborated by calculations of employment growth rates for different size-categories of establishments over Southern California as a whole between 1974 and 1986 (1974 being the first year for which data for SIC 376 become available). Data for this exercise are taken from County Business Patterns. Thus, if we now divide high-technology industrial

| County               | Establishments | Employment |
|----------------------|----------------|------------|
|                      | 1977 1986 change (%) | 1977 1986 change (%) |
| Los Angeles          | 867 1032 19.0 | 188254 258652 37.4 |
| Orange               | 335 589 75.8 | 59120 89564 51.5 |
| Riverside            | 14 39 178.6 | 5500 6519 18.5 |
| San Bernardino       | 18 63 250.0 | 2230 7598 240.7 |
| San Diego            | 160 293 83.1 | 23385 51667 120.9 |
| Santa Barbara        | 30 52 73.3 | 5900 8360 41.7 |
| Ventura              | 43 105 144.2 | 6048 13140 117.3 |
| Total                | 1467 2173 48.1 | 290437 435500 49.9 |

Source: US Department of Commerce, Bureau of the Census, County Business Patterns. Occasionally, County Business Patterns suppresses employment data for particular sectors in particular counties; where this has occurred, employment has been estimated from interval data provided by the source.
establishments in the region into small (1–99 employees), medium (100–499 employees), and large (500 employees and over), we find that rates of employment growth in the three categories over the designated time-period are 66.0%, 64.9%, and 23.9%, respectively (see also Scott and Paul, 1989). Clearly, growth attains high levels in all three instances, but is especially strong in the small to medium-sized categories of establishments. These simple statistics dramatize the importance of smaller establishments in the high-technology industrial economy of Southern California at the present time, and they are suggestive of a process of persistent vertical and horizontal fragmentation that has been observed to be going on in the region's high-technology industrial base at least since the late 1960s (see Scott, 1988a).

With this brief overview of the current state of Southern California's high-technology industrial system in mind, we face two major questions: How can we account for the genesis and the subsequent historical pattern of growth of high-technology industry in the region? And what factors underlie the detailed arrangement of the intraregional geography of the industry? I now broach these questions on the basis of a condensed empirical description of the historical geography of high-technology industry in Southern California over three major phases of growth.

**Origins: the aircraft industry in Southern California, 1920–1948**

During the 1920s and the early 1930s, when the aircraft industry was first emerging as a major sector of the national economy, it was located for the most part not in Southern California, but in the Northeast of the country (see table 3). At this time, New York State and Ohio were by far the leading centers of production, despite the claim that has sometimes been advanced that abundant sunshine and good year-round flying weather are essential locational attractions for the industry (see Cunningham, 1951). Certainly, Southern California was reasonably active over these years in aircraft manufacturing, but throughout the 1920s and the early 1930s the region remained a minor outlier rather than a driving focus of the industry. Over much of the interwar period, California rarely had more than about 10% of the nation's aircraft-manufacturing capacity.

The early aircraft industry in Southern California was dominated by two firms, the Douglas Aircraft Company (later McDonnell–Douglas) and the Lockheed Aircraft Corporation. Both of these firms appeared in the region in the 1920s, the former in Santa Monica (with an off-shoot located in El Segundo in 1932), the latter in

| State       | 1925 | 1931 | 1937 |
|-------------|------|------|------|
|             | 1925 |      |      |
|             | 1931 |      |      |
|             | 1937 |      |      |
|             | 1925 |      |      |
|             | 1931 |      |      |
|             | 1937 |      |      |
| California  | 4    | 10   | 24   |
| Connecticut | 1    | 5    | 3    |
| Kansas      | 2    | 8    | 5    |
| Michigan    | 2    | 9    | 3    |
| New York    | 15   | 19   | 17   |
| Ohio        | 5    | 10   | 13   |
| Pennsylvania| 2    | 8    | 7    |
| Total USA   | 44   | 101  | 92   |

na = data not available.

Source: United States Department of Commerce, Bureau of the Census, *Biennial Census of Manufactures*. 

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**Table 3. Major aircraft-producing states, 1925–1937.**
Burbank. In each instance, some prior personal tie to Southern California on the part of the firms' founders helps account for their choice of location. The two firms found ready financial backing from local boosters (Cunningham, 1951), and they flourished in the climate of the open shop for which Los Angeles was notorious in the days before the Wagner Act of 1935. Even so, it was only after the mid-1930s, when the two firms developed breakthrough technological and commercial successes, that they, and the rest of the aircraft industry in Southern California, entered a period of accelerated growth. Two such successes were critical. The first, and by far the more important, was the development of the Douglas DC-3 aircraft, and the second was that of the Lockheed L-10 Electra, both of which offered superior standards of efficiency and speed and rapidly became the preferred craft for US domestic airlines. Philips (1971) shows that in 1933, Douglas products accounted for only 1.2%, and Lockheed products 10.6%, of all new aircraft added to US domestic fleets. By 1935, these percentages had risen to 59.0% and 32.8% respectively, thanks to the DC-3 and the L-10; and by 1937, the equivalent values were 87.0% and 11.1%—virtually all of the new orders.

These remarkable advances formed the real foundation of the first phase of the high-technology industrial development of Southern California, and of the region's emergence as the 'Detroit of the aircraft industry' (Scott and Mattingly, 1989). Relative to the great technology-driven surge of production that occurred after the mid-1930s, the supposed climatic advantages of the region (which, in any case, are present at innumerable other places in the USA) must be seen as being of negligible significance in any attempt to understand the geography of the industry. Rather, an exploding industrial agglomeration was set in motion with a constantly widening circle of external economies in the form of rising numbers of specialized subcontractors, an expanding pool of skilled labor (aeronautical engineers, craft workers, and the like), and an accumulating stock of socialized know-how. Other major airframe assembly plants—no doubt attracted in part by this evolving 'industrial atmosphere'—developed in the region. In 1935, both the Consolidated Aircraft Corporation (later General Dynamics Convair) and North American Aviation (later Rockwell North American) moved into the region from the Northeast of the country, Consolidated to San Diego, and North American to Ingelwood. Vultee Aircraft Incorporated (which merged with Consolidated in 1943) located in Downey in 1936. In 1938–1939, John Northrop, who had earlier worked both for Douglas and for Lockheed, founded Northrop Aircraft Incorporated, in Hawthorne. Finally, Douglas Aircraft set up a third offshoot in Long Beach in 1941 in order to accommodate expanded wartime production. By and large, these aircraft manufacturing establishments set up shop in what were then the fringes of the built-up area of the region, so that they could be adjacent to airstrips for test flying and for the delivery of finished aircraft (see figure 3). Most of these establishments are still in active use today.

By 1937, Southern California contained 26.1% of all aircraft assembly plants in the country, and 48.0% of all employment (table 3). Note that Southern California specialized from the beginning in aircraft assembly and in parts manufacture, and that aircraft-engine production was then (as now) concentrated in the Northeast of the country. At the outbreak of World War Two, the region was indisputably the leading aircraft-manufacturing center in the USA. Its lead was greatly enhanced by the massive upsurge in federal spending on military aircraft that occurred as the War intensified, thus initiating a pattern of dependence by all the high-technology industries of the region on defense procurements that has continued to the present day. In table 4 employment in the aircraft-assembly industry of Los Angeles between 1939 and 1948 is shown. By 1943, the industry was employing 190 700 workers (40.0% of all employment in Los Angeles), representing an expansion of
almost 1100% over the situation in 1939. This rate of expansion was accomplished in part by a vast extension of the subcontracting system, and in part by a rapid, but entirely temporary, absorption of females into the labor force, thus creating over a short period of time a great increase in available productive capacity. As Cunningham (1951) has indicated, subcontracting in the industry increased nationwide from 10% of all work performed in 1940 to 38% by 1944. All of this growth was further potentiated by an infrastructure of advanced educational and research institutions which were installed over the 1930s and 1940s. As early as 1926, the Guggenheim Aeronautical Laboratory—forerunner of the Jet Propulsion Laboratory—was founded at the California Institute of Technology in Pasadena, with Dr Theodore von Karman at its head. In 1942, Northrop opened an Aeronautical Institute to train its own engineers. At the University of California—Los Angeles, a School of Aeronautical Engineering (later the School of Engineering) was set up in 1943. And at the University of Southern California, engineering programs focused on guided missiles and electronics were inaugurated in the late 1940s (Bloch, 1987).

![Figure 3. Major airframe-assembly plants in Southern California in the 1930s. The main urbanized area at the time is represented by shading.](image)

**Table 4.** Employment in aircraft-assembly in Los Angeles, 1939–1948.

| Year | Employees | Aircraft assembly as percentage of all employment in LA | Year | Employees | Aircraft assembly as percentage of all employment in LA |
|------|-----------|--------------------------------------------------------|------|-----------|--------------------------------------------------------|
| 1939 | 15000     | 11.5                                                   | 1944 | 152400    | 36.5                                                   |
| 1940 | 34800     | 21.0                                                   | 1945 | 95700     | 30.0                                                   |
| 1941 | 74200     | 33.0                                                   | 1946 | 50700     | 21.0                                                   |
| 1942 | 129100    | 39.0                                                   | 1947 | 48400     | 20.0                                                   |
| 1943 | 190700    | 40.0                                                   | 1948 | 44600     | 20.0                                                   |

Source: Wilburn, 1971.
These institutions were centers of technological innovation and they provided a ready local source of skilled scientific and technical workers.

As World War Two came to an end, the aircraft industry fell into a deep slump, which intensified during the late 1940s dragging the whole economy of Southern California into crisis with it. Recovery came after 1950 with the onset of the Korean War and the escalation of the Cold War, which led to large increases in US spending on armaments. By this time, moreover, the high-technology industrial complex of Southern California was beginning to emerge in something approaching its present shape as missiles and electronics became essential elements of the defensive arsenal of the USA.

Consolidation and growth: the aerospace-electronics complex in the postwar decades

The historical pattern

During and after World War Two, great advances were made in rocketry and electronics for military (and eventually space-exploration) purposes. These advances made possible, and were in turn pushed forward by, a widening circle of governmental demands for ever more sophisticated weapons and delivery systems. Aircraft, missiles, avionics, and advanced communication technologies constitute the essential hardware of such systems, and during the 1950s firms producing outputs of this sort started to multiply throughout Southern California. The already-existing aircraft industry formed the backbone of this erupting complex of productive activities. Indeed, throughout the 1940s and 1950s, all of the major airframe-assembly firms in the region branched out through new divisions into the wider defense and space contracting business. They had at the outset a strong command of the necessary technological expertise to perform successfully in these activities, and they were able to move rapidly into a favorable market position by reason of their long experience in working with the federal government. At the same time, a number of other major producers also evolved out of the local industrial base; and even defense prime-contracting firms that were located elsewhere in the country established branch plants in the region in order to reap the harvest of external economies that was becoming available there as the complex grew.

With the exception of the major airframe-assembly plants, few of the postwar defense and space prime-contractors in Southern California had roots going back to the prewar years. The missile industry is, of course, almost entirely a postwar phenomenon, although von Karman and his associates at the California Institute of Technology founded the Aerojet Engineering Corporation (later Aerojet General) to produce rocket engines as early as 1942 (Malina, 1964). The electronics industry in Southern California is also for the most part a postwar development. In contrast to such places as Berlin, London, Boston, and New York, with their great electrical engineering industries in the 1920s and 1930s (Hall and Preston, 1988), Southern California had only a negligible electrical industry in the prewar years. It did possess a small radio industry serving largely local needs, but only three firms out of this era—Collins Radio, Gilfillan Brothers, and Hoffman Radio—emerged as major defense electronics contractors in the postwar period.

Essentially, then, the second phase of high-technology industrial development in Southern California—a phase focused on early aerospace, avionics, and military communication technologies—began as World War Two came to a close. The primary participants in this new round of expansion were (a) the major surviving airframe assemblers (Convair, Douglas, North American, Northrop, and Lockheed) together with their specialized missile and electronics divisions; (b) a number of independent missile producers, such as Aerojet, and Marquardt; and (c) a series of rapidly-growing defense electronics manufacturers, such as Bendix, Collins Radio,
Garrett, Gilfillan, Hoffman Radio, Hughes Aircraft, Learcal, Litton, Ramo–Wooldridge, and Teledyne, most of which were Southern Californian ventures from the start.

The developmental trajectory of Hughes Aircraft—perhaps the most advanced electronics firm of its era—provides us with a sense of the dynamism present in the entire complex at this time. During World War Two, the firm had been engaged in R&D activities and aircraft-parts production in Culver City. In 1947, it received an Air Force contract to develop the Falcon missile, and a year later it won an additional Air Force contract to build and install radar fire-control units for the Lockheed F–94 fighter plane. This led to yet further contracts for sophisticated fire-control and avionic guidance systems. As the firm established itself at the forefront of arms manufacturing technologies, it grew from 750 employees in 1948 to 15,000 in 1952 (Hughes Aircraft Company, 1986). Among the many talented scientists and engineers on the staff of the company were Simon Ramo and Dean Wooldridge, who broke away in 1953 to form Ramo–Wooldridge (later TRW) in Inglewood. Within two years, Ramo–Wooldridge was managing the systems engineering for the entire Atlas project, overseeing the operations of 220 major corporations throughout the USA. Also in 1953, Tex Thornton left Hughes Aircraft to take over Litton Industries, which subsequently became one of the most important defense contractors in the region. Then, in 1960, Henry Singleton left Litton to form Teledyne. Today these four companies—Hughes, TRW, Litton, and Teledyne—carry out a major proportion of all defense electronics contracting in the USA.

This proliferation of major high-technology industrial producers in Southern California was matched by the continued growth of the dense and many-tiered agglomeration of large and small subcontractors that had developed throughout the region since the 1930s (see figure 4). And just as a number of important educational

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**Figure 4.** Prime contractors, principal subcontractors, and electronics subcontractors in the Southern Californian missile industry, *circa* mid-1950s. Electronics subcontractors shown are specialized producers of guidance, tracking, telemetering and checkout equipment. Map based on research performed by Mark Drayse. (Source of data: American Aviation Publications, 1958.)
institutions had helped to bolster the industrial and technological know-how of the region in an earlier period, so now an emergent network of advanced R&D facilities and scientific laboratories—such as the Rand Corporation in Santa Monica, Ford Aerospace in Newport Beach, the Hughes Research Laboratories in Malibu, and the Santa Barbara Research Center (purchased by Hughes in 1956)—helped to reinforce the competitive edge of the region's high-technology industries. This pattern of growth was secured by lavish and (with the exception of major downturns at the end of the Korean War and in the period from 1968–1974) generally rising Department of Defense outlays on prime contracts (see figure 5). The state of California has fairly regularly received about 20% of all Department of Defense prime-contract awards, and Southern California secures some 80% of the state total. By the early 1960s, according to Tiebout (1966), 43.5% of all employment in the Los Angeles–Long Beach Standard Metropolitan Statistical Area was tied directly and indirectly to defense spending. The capstone of this localized military-industrial complex was the Western Development Division of Air Research and Development Command, established in Inglewood in 1954, where it oversaw ICBM and IRBM procurement, and R&D for the Air Force (Hall, 1988; Air Force Systems Command, n.d.). It is the direct forebear, through various intermediate mutations, of the contemporary Space Systems Division of Air Force Systems Command in El Segundo.

The geographical configuration of the aerospace-electronics industry from the 1950s to the 1970s

On these foundations, the aerospace-electronics manufacturing system of Southern California rose swiftly to preeminence as the major focus of high-technology industry in the country. In table 5 some important trends in the aerospace-electronics industry over the critical decade of the 1950s are charted. The data shown in the table are taken from a report by Urbanomics Research Associates (1969) in which the aerospace-electronics industry is defined (less than satisfactorily) as comprising electrical machinery, aircraft, instruments, and ordnance (the latter sector covering guided missiles and other armaments in the 1950s and 1960s). Over the period from 1950 to 1960, employment in aerospace-electronics—thus defined—in Southern California rose 224.0%, whereas manufacturing employment as a whole rose a comparatively modest 97.4%. In the same period aerospace-electronics employment
increased from 25.2% of all manufacturing employment, to 41.4%. As we have already seen in table 1, the growth of high-technology industrial employment then continued more or less unabated over the 1960s, 1970s, and 1980s (with the exception of the aircraft and parts industry). In the 1950s and 1960s, as at the present time, Los Angeles dominated the region's overall employment pattern, but this was also a period in which a significant shift of high-technology industry into the outer cities of the region was beginning (particularly to Orange and San Diego counties and to the western San Fernando Valley area of northern Los Angeles county). As a corollary, various peripheral technopoles were starting to condense out as growth centers on the economic landscape.

The geographical dynamics of the high-technology industrial complex over this period can be comprehended in part by examining contemporary maps of the aircraft and parts industry and the electronics industry. The guided-missile industry is not shown here because maps for this industry are difficult to construct given the failure of the SIC to define this sector until the early 1970s; and, in any case, the geography of missile production in the region more or less parallels the geography of aircraft production. Two sets of maps are presented, one for 1956, representing

Table 5. Manufacturing and aerospace-electronics employment in Southern California, by county, 1950–1960.

| County/Industry         | Employment (thousands) | Change (%) 1950–1960 |
|-------------------------|------------------------|----------------------|
|                         | 1950       | 1955       | 1960       |                        |
| Los Angeles             |            |            |            |                        |
| Aerospace-electronics   | 101.8      | 274.3      | 295.9      | 190.7                  |
| All manufacturing       | 409.7      | 505.1      | 760.4      | 85.6                   |
| Ratio                   | 24.8       | 54.3       | 38.9       | -                      |
| Orange                  |            |            |            |                        |
| Aerospace-electronics   | 0.4        | 3.6        | 21.5       | 5275.0                 |
| All manufacturing       | 12.4       | 28.1       | 48.8       | 293.5                  |
| Ratio                   | 3.2        | 12.8       | 44.1       | -                      |
| Riverside–San Bernardino|            |            |            |                        |
| Aerospace-electronics   | 1.4        | 6.7        | 8.2        | 485.7                  |
| All manufacturing       | 18.9       | 31.3       | 36.0       | 90.5                   |
| Ratio                   | 7.4        | 21.4       | 22.8       | -                      |
| San Diego               |            |            |            |                        |
| Aerospace-electronics   | 15.2       | 35.2       | 52.3       | 244.1                  |
| All manufacturing       | 25.8       | 47.2       | 69.5       | 169.4                  |
| Ratio                   | 58.9       | 74.6       | 75.3       | -                      |
| Santa Barbara           |            |            |            |                        |
| Aerospace-electronics   | -          | 0.2        | 4.0        | -                      |
| All manufacturing       | 2.0        | 3.0        | 8.1        | 305.0                  |
| Ratio                   | -          | 6.7        | 49.4       | -                      |
| Ventura                 |            |            |            |                        |
| Aerospace-electronics   | -          | 1.3        | 3.0        | -                      |
| All manufacturing       | 2.2        | 4.5        | 6.9        | 213.6                  |
| Ratio                   | -          | 28.9       | 43.5       | -                      |
| Southern California     |            |            |            |                        |
| Aerospace-electronics   | 118.8      | 321.3      | 384.9      | 224.0                  |
| All manufacturing       | 471.0      | 619.2      | 929.7      | 97.4                   |
| Ratio                   | 25.2       | 51.9       | 41.4       | -                      |

a Ratio: aerospace-electronics as a percentage of all manufacturing.
Source: Urbanomics Research Associates, 1969, pages 170–171.
the period of early growth in this second phase of development, and one for 1972, representing maturation and consolidation (figures 6, 7, 8, and 9). Consider first figure 6, which shows individual establishments in the aircraft and parts industry (SIC 372) in 1956. This figure indicates that the aircraft and parts industry in the mid-1950s was in essence still clustered around its main original locational bases that were established in the 1930s in the Burbank–Glendale area and the west-central area of Los Angeles county, with a small outlier in San Diego. This locational pattern was composed of a series of critical major nodes corresponding to major assembly plants, each surrounded by a mass of smaller input providers and subcontractors. Now let us examine figure 7, in which the location of the electronics industry in 1956 is depicted, and where the industry is for present purposes defined as an aggregate of office and computing machines (SIC 357), communication equipment (SIC 366), and electronic components and accessories (SIC 367). In 1956 the electronics industry (which was devoted in large degree to avionics and communication systems) assumed a locational structure that more or less ran parallel to the geography of the aircraft and parts industry in the region, with a pronounced central core and a minor presence in peripheral areas. At this stage in their growth, both the aircraft industry and the electronics industry were almost entirely confined to Los Angeles county.

By 1972, some decentralization of the aircraft and parts industry and the electronics industry was under way, most especially in the case of the electronics industry, which was now moving rapidly westwards through the San Fernando Valley, and also colonizing the northern half of Orange county and the northern suburbs of San Diego (see figures 8 and 9). As shown in detail elsewhere (Scott, 1988a) the rise of the Orange county technopole was set in motion by the accelerating shift, in the late 1950s and early 1960s, of large systems houses—especially sophisticated communication-equipment producers—from Los Angeles southward in search of cheaper land and of access to technical and scientific labor. Then, from

Figure 6. The aircraft and parts industry (SIC 372) in Southern California, 1956. One dot equals one manufacturing establishment. (Source: Scott and Mattingly, 1989.)
Figure 7. The electronics industry (SICs 357, 366, and 367) in Southern California, 1956. One dot equals one manufacturing establishment. (Source: Scott and Drayse, 1990.)

Figure 8. The aircraft and parts industry (SIC 372) in Southern California, 1972. One dot equals one manufacturing establishment. (Source: Scott and Mattingly, 1989.)
the late 1960s onwards, a remarkable process of dynamic vertical and horizontal disintegration came about as was manifest in the accelerated growth of small, specialized units of production providing an ever-widening array of inputs and services for local (and nonlocal) producers, and the concomitant intense agglomeration of the manufacturing system around its own center of gravity. Employment in the aircraft and parts industry was in some decline in Southern California in the early 1970s and this decline is evident in figure 8, in the marked thinning-out of the spatial pattern of establishments compared with the situation in 1956. This employment decline was in part a reflection of the looming economic crisis of the early to mid-1970s, and in part an outcome of (a) the steady displacement of aircraft by missiles in Department of Defense procurements, (b) the long-term substitution of white-collar workers for larger numbers of blue-collar workers in the aircraft production process, and (c) the increasing importance of out-sourced subassemblies (especially electronic equipment) in modern aircraft. In terms of the real value of the final product, the aircraft and parts industry has in fact continued to expand fairly consistently at a vigorous pace over the last few decades (see Scott and Mattingly, 1989).

By the mid-1970s, the second phase in the growth of the high-technology industrial base of Southern California was more or less complete. The aerospace-electronics complex was firmly ensconced both in its original (though relatively diminished) base in Los Angeles county and in a series of burgeoning outer technopoles. These technopoles now became intense foci of employment growth surrounded by dense local labor markets comprising not only skilled scientific and technical labor but also increasing numbers of Hispanic and Asian immigrants drawn in to the local area by the job opportunities in a vast undergrowth of sweatshops and subcontractors that was engendered by the direct and indirect input demands of the core high-technology producers.

Figure 9. The electronics industry (SICs 357, 366, and 367) in Southern California, 1972. One dot equals one manufacturing establishment. (Source: Scott and Drayse, 1990.)
The modern technopoles of Southern California

As the 1970s were coming to a close, the third and contemporary phase of Southern California's high-technology industrial evolution was already well under way, as was manifest both in the continued growth and internal differentiation of the aerospace-electronics industry, and in the emergence of entirely new kinds of high-technology industrial activities in the region.

Consistent with its prior trajectory of growth and development, the high-technology industrial complex of Southern California today encompasses both an array of dense technopoles of diverse ages and sizes, and also a wide secondary scattering of establishments across the entire area. This basic structure is made up of innumerable small and medium-sized establishments locationally intercalated with a number of giant lead plants, the most important of which are R&D-intensive systems houses and airframe/missile assembly plants, whose great size presumably reflects the internal economies of scale and scope that flow from the managerial and technological synergies embedded in the defense prime-contracting process. Despite these economies and the organizational gigantism that they foster, the major lead plants of the region still outsource an enormous range and quantity of components and subassemblies to firms located in the adjacent complex and beyond. Moreover, the work and materials that are outsourced in this way are constantly changing, as the product and process configurations of major manufacturers change to accommodate rapidly shifting technologies and demands.

In figures 10 and 11, the basic geography of the overall complex in 1988 is summarized; and here once more our two symptomatic sectors—aircraft and parts, and electronics—serve as exemplars of the whole. From these two figures it can be seen that the industrial development of the outer cities continues unabated, as is indicated especially by the intensification of the high-technology industrial agglomerations in the west San Fernando Valley, in northern Orange county, and in the

Figure 10. The aircraft and parts industry (SIC 372) in Southern California, 1988. One dot equals one manufacturing establishment. (Source: Scott and Mattingly, 1990.)
northern suburbs of San Diego. Additionally, incipient clusters seem to be emerging in Santa Barbara county, in Ventura county, and in the area southeast of Irvine, in Orange county. Much scattered development has also occurred to the east of Los Angeles and is now beginning to spill over into Riverside and San Bernardino counties. The internal constituents of this basic geography are in constant flux, with new subsectors continually coming into existence (such as specialized computer products or new kinds of electronic components), and with older-established manufacturers shifting periodically into radically redesigned products (such as Northrop's B-2 bomber, and McDonnell-Douglas's MD-11 civilian aircraft). To this catalog of innovation we must add two entirely new high-technology sectors that are growing with especial vigor at the present time—the biotechnology industry and the medical-device industry. Both of these industries have prospered in Southern California with its wealth of high-technology expertise and its skilled and multifaceted labor markets.

The biotechnology industry in the state of California is roughly equally divided between the Bay Area and Southern California. In Southern California, the industry has flourished since the late 1970s on the basis of expanding markets for medical and agro-alimentary products. The industry is locationally disaggregated into two main clusters in the region, one in the Irvine area of Orange county, the other (and more important cluster) in the La Jolla–Sorrento Valley area of San Diego county (see figure 12). The latter cluster can largely be traced back to the founding of Hybritech, a manufacturer of monoclonal antibodies, in 1978. A very high proportion of the other biotechnology producers in San Diego county are direct or indirect spin-offs from this original firm. The Orange county and San Diego county biotechnology clusters are both juxtaposed to key medical schools and research facilities, in the former case to the University of California at Irvine, and in the latter to the University of California at San Diego and to the adjacent Salk Institute, and Scripps

![Figure 11. The electronics industry (SICs 357, 366, and 367) in Southern California, 1988. One dot equals one manufacturing establishment. (Source: Scott and Drayse, 1990.)](image-url)
Figure 12. The biotechnology industry in Southern California. Map based on research performed by Alan S Paul. [Source of data: Coombs and Alston (1987), supplemented by various industrial directories.]

Figure 13. The surgical and medical instruments industry (SIC 3841) in Southern California. Map based on research performed by Jan-Maarten de Vet. (Sources of data: California Manufacturers Association, 1989; Directory Systems, 1987; Disclosure Information Group, 1989.)
Clinic and Research Foundation. This circumstance has been of major significance for the emergence and subsequent development of these two industrial clusters. For example, Ivor Royston, the founder of Hybritech, was a professor at the University of California at San Diego, and in 1985 the same university launched an active technology-transfer program (known as CONNECT), with special emphasis on biotechnology. This program has helped to create several new firms in the area. A recent survey by CONNECT identified a total of fifty-seven biotechnology firms in San Diego county, employing 2755 workers in 1988, with fifteen new start-ups in the same year.

Southern California is now also one of the nation's principal locations for SIC 3841 (surgical and medical instruments), and especially for high-technology medical devices with applications in such areas as anesthesiology, neurology, and cardiovascular and pulmonary medicine (de Vet, 1990). A scrutiny of figure 13 reveals that Orange county is the main intraregional focus of the industry, and particularly the Irvine area where, again, the medical school of the University of California at Irvine has played—since the early 1980s at least—a crucial role in helping to promote the industry. As de Vet (1990) has shown, the industry was initiated in Orange county in 1961, when Lowell Edwards, a retired engineer, and Albert Star, a cardiovascular surgeon, opened Edwards Laboratories in Santa Ana. In 1963, a first spin-off occurred in the guise of Shiley Laboratories, which was established to produce a new type of artificial heart valve. Bentley Laboratories (specializing in the production of oxygenators) was then spun-off in 1964, and Hancock Laboratories (producing porcine heart valves) in 1967. Other direct and indirect spin-offs from Edwards Laboratories occurred throughout the 1960s and 1970s, echoing the familiar genealogical model of active splitting and new-firm formation that is so frequently invoked in accounts of Silicon Valley's genesis and growth. Further medical-device firms were founded by aerospace and electronics engineers in the region looking for new outlets for their talents. By the late 1970s and early 1980s, the medical-device industry in Southern California was growing at a rapid pace, and today SIC 3481 has close to 10000 employees in 120 establishments, the most dynamic concentration coinciding, again, with the Orange county technopole.

Each particular technopole in the region represents, of course, a unique combination of production activities and labor market conditions. Something of the individual character and internal dynamics of each may be gleaned by examination of two particularly well-developed cases—the Chatsworth-Canoga Park area in the west San Fernando Valley (see figure 14), and Orange county (see figure 15). The Chatsworth-Canoga Park technopole dates mainly from the late 1970s, and today it is one of the fastest growing high-technology industrial areas in the region, rivalling even Orange County. Indeed, if we count the number of high-technology manufacturing establishments—shown in figures 14 and 15 within a two-mile radius of the main industrial clusters in Chatsworth-Canoga Park and Irvine, we find seventy-eight establishments in the former case and sixty-nine in the latter case. This observation needs to be tempered with the qualification that the source of data on which the two maps are based is known to be strongly biased against small establishments—and there are certainly very many such establishments missing from the two figures (see Scott, 1988a). The Chatsworth-Canoga Park technopole is concentrated around a number of large guided-missile and electronics production facilities, such as Hughes Aircraft (Missiles Systems Group), Rockwell International (Rocketdyne Division), and Litton Industries (Guidance and Control System Division), imbricated within a mass of smaller parts and electronic components manufacturers. The Orange county technopole, focused on the Irvine Business Complex industrial park, has a similar manufacturing base, and, as noted, it also has a rich complement
Figure 14. The Chatsworth-Canoga Park technopole as represented by establishments in SIC 357 (office and computing machines), SIC 366 (communication equipment), SIC 367 (electronic components and accessories), SIC 372 (aircraft and parts), and SIC 376 (guided missiles, space vehicles, parts). (Source of data: California Manufacturers Association, 1989.)

Figure 15. The Orange county technopole as represented by establishments in SIC 357 (office and computing machines), SIC 366 (communication equipment), SIC 367 (electronic components and accessories), SIC 372 (aircraft and parts), and SIC 376 (guided missiles, space vehicles, parts). (Source of data: California Manufacturers Association, 1989.)
of biotechnology and medical-device industries. Notice the emerging cluster of high-technology industrial establishments to the southeast of Irvine. This is the Irvine Spectrum development, and over the next decade it will almost certainly grow to rival the currently dominant Irvine Business Complex within the Orange county technopole. The Chatsworth–Canoga Park and Orange county technopoles are both marked by an advanced form of vertical disintegration and local interlinkage, though both are also intimately caught up in a far wider sphere of economic interactions. Both are also surrounded by socially-differentiated residential neighborhoods, which provide a ready supply of skilled scientific and technical workers and low-wage immigrant workers from Latin America and Asia.

**Technopole development: an analytical review**

Let us at this stage reconsider in more analytical terms the material that has been described empirically above. What, we may ask, is the inner logic of the changing locational patterns we have examined? Why is so much of the high-technology industry in the region arranged in spatial agglomerations? And what accounts for the appearance of not just one major technopole, but of six or seven individual cases scattered over the landscape of the region? In an attempt to deal with questions such as these I now draw selectively on some earlier research findings, described in much greater detail elsewhere. These findings concern above all the logic of interindustrial linkages and local labor markets in the region. They are primarily based on investigations of the aircraft and parts industry and the electronics industry, but they are also almost certainly generalizable to a very much wider group of high-technology sectors.

**Interindustrial linkages**

Within both the aircraft and parts industry and the electronics industry in Southern California, significant social divisions of labor—in the sense of highly-differentiated arrays of specialized industrial subsectors—are strongly in evidence. There are also many indications, as I show below, of the concomitant existence of systems of dense local interlinkages which bind the different subsectors of the system into agglomerated networks of industrial activity. To be sure, virtually all of the high-technology industries of Southern California are linked to a much wider economic system, and the larger firms in particular operate consistently over a global range of operations. The point here is not that such wider interactions do not occur, but that there is, in addition, some critical range of interindustrial activities whose cost–distance relations encourage agglomeration of groups of producers into distinctive industrial districts and regions. This critical range would seem especially to be made up of transactions-intensive (hence high cost) linkages involving above all flexible, rapidly-shifting, small-scale, and nonstandard connections between producers.

Consider tables 6 and 7, which contain input linkage information from two questionnaire surveys of the aircraft and parts industry and the electronics industry carried out in 1988 and 1989. In both tables, establishments are divided into two groups depending on whether their annual sales figures are smaller or larger than the median for each sample group (that is, $2,250,000 in the case of aircraft and parts manufacturing establishments, and $2,000,000 in the case of electronics establishments). In table 6, the locations of the top three suppliers (of materials or subcontracted work) of thirty-nine sampled aircraft and parts manufacturing establishments who provided usable information on this issue are shown; in table 7, equivalent data for subcontractors to thirty-three electronics establishments are shown. The tables indicate at once that a very high proportion of the top suppliers
and/or subcontractors of the sampled establishments are located in the local area (over 80% for aircraft and parts establishments, and over 90% for electronics establishments). In the case of the aircraft and parts industry, small establishments are clearly more tightly tied to suppliers in Southern California than are large establishments, which suggests in turn that economies and diseconomies of scale in transacting are strongly operative in this industry. In the case of the electronics industry, the top subcontractors to small and large establishments alike are almost all exclusively located in Southern California, signifying that this industry has a markedly localized pattern of development.

The data laid out in table 8 provide important amplification of these findings. Sampled establishments were asked what proportion of the transacting time leading up to the sale of either an off-the-shelf (standardized) item or a batch of (unstandardized) subcontracted work was allocated to different modes of communication. Table 8 contains a summary of the results of this enquiry for four modes of communication—face-to-face contact; telephone; mail; and telex/fax. Not surprisingly, the telephone is the preferred mode of transacting in all cases. However, face-to-face contact—a particularly intensive mode of communication—is also significant, especially where subcontracting is at issue, and in the case of electronics establishments, face-to-face contact is virtually equal with the telephone as a

Table 6. Supplier linkages of sampled aircraft and parts manufacturing establishments in Southern California.

| Size of establishment (annual sales) | All establishments |
|-------------------------------------|--------------------|
| less than $2 250 000 | more than $2 250 000 |
| Number of respondents | 22 | 17 | 39 |
| Total number of suppliers reported | 62 | 51 | 113 |
| Suppliers with known locations | 53 | 43 | 96 |
| Suppliers located in Southern California | 51 | 28 | 79 |
| Ratio | 96.2 | 56.1 | 82.3 |

a Ratio: suppliers located in Southern California as a percentage of suppliers with known locations. The percentages for the two groups were found to be significantly different from each other at the 99% level on the basis of a difference of proportions test.

Source: Scott and Mattingley, 1989.

Table 7. Subcontractor linkages of sampled electronics manufacturing establishments in Southern California.

| Size of establishment (annual sales) | All establishments |
|-------------------------------------|--------------------|
| less than $2 000 000 | more than $2 000 000 |
| Number of respondents | 18 | 15 | 33 |
| Total number of subcontractors reported | 48 | 34 | 82 |
| Subcontractors located in Southern California | 46 | 29 | 75 |
| Ratio | 95.8 | 85.3 | 91.5 |

a Ratio: subcontractors located in Southern California as a percentage of the total number of subcontractors reported. The percentages for the two groups were found not to be significantly different from one another at the 99% level on the basis of a difference of proportions test.

Source: Scott and Drayse, 1990.
means of dealing with sales of subcontract work. Indeed, for electronics producers, face-to-face contact in the sale of off-the-shelf items is almost as important as face-to-face contact in the sale of subcontract work for aircraft and parts producers. On the basis of these data, the electronics industry appears to be rather more transaction-intensive in its external dealings than the aircraft and parts industry is, and this is consistent with the observed high level of dependence of the electronics industry on local subcontractors.

Despite these differences between the two industries, both are emphatically reliant on strong external linkages to the local economic environment. This point is driven home by the observation that for sample establishments in both industries, an average of close to 65% of their total revenues come from subcontract work—a finding that suggests in turn that much of the production process is embedded in flexible and transaction-intensive networks of interlinkage. The net result, again, is a marked proclivity towards agglomeration, especially for small producers who cannot take advantage of economies of scale in transacting.

Two further pieces of empirical evidence help to underpin these claims about the relations between interlinkage and agglomeration. One of these concerns the locational pattern of manufacturers of printed circuit boards in Southern California. Printed circuit boards are a critical input to all manner of high-technology manufacturers. They are invariably produced on the basis of subcontract orders from consuming firms, where each order is typically a special case with its own individual design specifications, so that great flexibility of the contracting and recontracting process is necessary. As a consequence, the manufacturers of printed circuits converge locationally upon the major technopoles of the region where they can be readily accessible to their main customers, as is confirmed by the spatial pattern depicted in figure 16. The second piece of evidence involves the 'putting-out' functions of printed-circuit manufacturers themselves. As shown in earlier work (Scott and Kwok, 1989), printed-circuit manufacturers commonly subcontract out various sorts of specialized functions. In figure 17, the locations of establishments providing some of the more important of these functions in Southern California are indicated. The strong locational symbiosis between these producers and the main cohort of printed-circuit manufacturers is immediately apparent.

The data displayed in figures 16 and 17 encourage the further inference that there is a definite hierarchical ordering of the transactional chains that occur within the technopoles of Southern California, with subcontract orders flowing from level to level down the system. At the same time, however, as demonstrated recently by Scott and Mattingly (1989), there is considerable cross-cutting and short-circuiting through the levels of the hierarchy. In addition, much interfirm exchange of

|                      | SIC 372 sales |                      | SIC 367 sales |                      |
|----------------------|---------------|----------------------|---------------|----------------------|
|                      | off-the-shelf | subcontracted        | off-the-shelf | subcontracted        |
|                      | (n = 23)      | (n = 38)             | (n = 53)      | (n = 50)             |
| Face-to-face contact | 12.0          | 22.8                 | 19.0          | 37.6                 |
| Telephone            | 54.5          | 46.1                 | 58.7          | 38.6                 |
| Mail                 | 21.8          | 21.1                 | 8.6           | 8.4                  |
| Telex/fax            | 9.5           | 7.6                  | 10.1          | 9.7                  |

Sources: Scott and Mattingly, 1989; Scott and Drayse, 1990.
Figure 16. The printed-circuit industry in Southern California. One dot equals one manufacturing establishment. (Source: Scott and Kwok, 1989.)

Figure 17. Subcontractors serving the printed-circuit industry in Southern California. The isolines shown are defined in terms of the logarithm of a gravity-potential measure of accessibility to all printed circuit producers in the region. Areas where this gravity-potential measure exceeds $-0.5$ are shaded. (Source: Scott and Kwok, 1989.)
information and strategic-alliance formation seem to be occurring. Indirect evidence in favor of the latter proposition may be found in recent work by Gordon, Dilts, and Kimball (1989) on semiconductor producers in Silicon Valley. These analysts have demonstrated that strategic alliances between manufacturers, even small ones, have multiplied of late in Silicon Valley, and presumably the same phenomenon is occurring among Southern Californian high-technology producers. All such interfirm activities as these undoubtedly combine with more conventional forms of interlinkage in order to maintain and intensify the agglomerative tendencies of Southern California’s high-technology industry.

Local labor markets

Although much detailed research has been accomplished of late on the interlinkages between Southern Californian high-technology producers, comparatively little has been done on high-technology industrial labor markets in the region. One of the few recent studies that touches on this issue is an analysis of the spatial organization of aircraft workers’ local labor markets (Scott and Mattingly, 1989). This study helps to throw some small additional light on the wider question of technopole development, and therefore a few of its main conclusions are now summarized below.

One of the empirical findings of this study is that the local labor markets of aircraft workers in Southern California extend over a remarkably limited area. Even at the detailed intraurban scale, local labor markets are highly circumscribed, and in an examination of eight large aircraft-manufacturing establishments, scattered across Los Angeles county, it was found that in each case over 50% of the labor force lived within fifteen miles of the place of work. In figures 18 and 19, the residential locations of workers at three Lockheed establishments in the north of Los Angeles county (figure 18), and at three McDonnell-Douglas establishments in the southern half of the county (figure 19), are indicated. The spatial split between the two local labor market areas is highly conspicuous, and is, perhaps, all the more surprising in view of the fact that the dense network of expressways in Los Angeles permits more extensive commuting than in many other large cities. In fact, given that the main Lockheed establishment at Burbank employed as many as 12,015 workers, and the main McDonnell-Douglas establishment in Long Beach 30,110 workers at the time the research was performed in 1988, the split is particularly dramatic.

One possible deduction that can be made from these observations is that a powerful and relatively durable interdependence exists between large centers of employment (that is, not just large individual plants but also large clusters of interlinked plants) and their local labor markets in the urban environment, such that each reinforces the spatially-polarized character of the other. Presumably, this interdependence then helps to anchor jobs and workers to particular places over some extended time-horizon. Because these local labor markets are so constrained in geographical extent, it may be that there is some limit to their efficient size (for example, some critical isochrone beyond which workers will be reluctant to travel in the daily journey-to-work). If so, this would be likely to encourage large individual foci of employment in the metropolis to diverge locationally from one another, leading in part to the disaggregation of the entire industrial system into geographically-distinctive industrial districts. Thus it may be that the internal spatial order of local labor markets combines with interestablishment transactional structures to accentuate and replicate the phenomenon of multiple technopole development. Shifting land-price differentials over space would no doubt serve to reinforce any tendency of this sort.
Figure 18. Residential locations of workers employed by Lockheed plants at Burbank, Palmdale, and Rye Canyon. Each dot represents 30 workers. Number attached to each establishment name represents total employment at that establishment. (Source: Scott and Mattingly, 1989.)

Figure 19. Residential locations of workers employed by McDonnell-Douglas plants at Long Beach, Carson, and Torrance. Each dot represents 30 workers. Number attached to each establishment name represents total employment at that establishment. (Source: Scott and Mattingly, 1989.)
Additionally, in the high-technology industrial agglomerations of Southern California, a system of bipartite local labor markets has come into existence, with skilled professional workers at one end of the scale, and unskilled, low-wage, immigrant workers at the other. With the exception of a privileged cadre of workers in the upper stratum who embody significant quantities of firm-specific human capital, there is evidently much employment turnover among both groups, a tendency underlined by Angel (1989) in his recent study of local labor markets in Silicon Valley. High turnover rates lead in turn to rapid rotation of workers through the local job system (at least for the more skilled workers who generally experience relatively short bouts of unemployment between jobs), and this further accentuates locational agglomeration by imposing a premium (both for firms and for workers) on information and accessibility to alternative opportunities. This sort of labor-market flexibility is rendered all the more intense by reason of the low rates of unionization among high-technology industrial workers in Southern California. In a few of the larger aerospace establishments, labor unions persist, although they are a declining force; and in the remainder of the high-technology ensemble, union organization is virtually nonexistent (Scott and Paul, 1989).

The mainsprings of technopole formation
The growth and spread of the technopoles of Southern California can therefore be seen as a phenomenon that has been activated primarily by the dynamics of inter-establishment linkages and by local labor markets. These dynamics are in turn rooted in flexible structures of production, stimulating institutional fragmentation of significant parts of the system and calling for rapid readjustability of labor-contracting arrangements. The agglomeration economies that are then generated by these processes are magnified by (and in turn help to create) additional externalities, such as educational institutions with programs directed to local needs, research laboratories, specialized marketing outlets and organizations, and the like. The whole process is reinforced by the massive urbanization economies that are set in motion as the local economy advances, and these are further enhanced where multiple industrial districts occur. As we have seen for the case of high-technology industrial development in Southern California, the operation of these broad structural axes of regional growth is always in practice greatly modified by the idiosyncrasies of local history and geography.

Conclusion
In the above account I have attempted to show how high-technology industry in Southern California can be traced back to its origins in the aircraft industry in the 1920s and 1930s, and how it then developed in the decades following World War Two into a great complex of flexible-production activities, rooted in a series of evolving high-technology industrial districts, or technopoles. Its historical trajectory, at least in the postwar decades, contrasts markedly with the trajectories of the Fordist mass-production systems that flourished (and then declined) in the large metropolitan regions of the Manufacturing Belt. High-technology industry in Southern California has gone from strength to strength, and it continues to draw vitality from its endogenously-created pool of localized external economies. In this environment, technical innovation and entrepreneurial activity thrive as outcomes of an ever-expanding field of structured opportunities on the margins of current practices and possibilities.

The major vulnerabilities of the system are twofold. First, it is heavily dependent on defense spending and hence is endemically susceptible to the vagaries of federal budgets and politics. Second, and in contrast to the Japanese model of industrial
organization, it suffers from what appears to be a certain failure, both publicly and privately, to provide institutions of collective order and coordination which might facilitate joint decisionmaking and orderly patterns of development (see Dore, 1986; Storper and Scott, 1989a). What little strategic planning there is exists at the level of the US high-technology industrial system as a whole, and ironically it is largely focused on the needs of the Department of Defense—the very agency whose continued support is subject to sudden shifts of direction as the national and international political climate changes. Even at the level of the wider urban region of Southern California, there is no public agency authorized to provide the kind of integrated planning that might harmonize the overall developmental pattern of the area.

In spite of these apparent vulnerabilities, the region has thus far successfully weathered a series of potential threats to its continued growth and prosperity, no doubt in high degree because of the robustness of its adaptable and competitive manufacturing system, combined with a rich stock of fertile external economies. Notwithstanding some evident decentralization over the last couple of decades (including the establishment of overseas branch plants), the high-technology industrial complex of Southern California has resisted the sort of dramatic spatial restructuring to which the more traditional industries of the Manufacturing Belt have been subject since the late 1960s. It needs especially to be emphasized that the aircraft and parts industry (one of the oldest and still the largest industry in the region) has remained quite immune from any long-term crisis of restructuring, even though it is predisposed to rapid technological change. The industry persists in the form of large assembly plants (internally organized around batch production processes) that are still to a surprising degree tied to their original prewar locations and that are surrounded by innumerable smaller establishments providing specialized parts and services. This striking degree of geographical stability is without doubt a side-effect of the continual priming of the industry by lavish defense spending, and at the same time—unlike textiles, cars, or domestic appliances—the industry has hitherto been largely sheltered from foreign competition. If in the 1990s, competition from Japan and Europe should escalate, as seems likely, then it is probable that at least some of the nonmilitary segments of the industry will decline significantly. Should this occur on a major scale, there could well be a sort of delayed replay in Southern California of the scenario of local economic crisis and job loss that marked places like Buffalo, Detroit, or Pittsburgh during the 1970s. As things now stand there seems little reason to suppose that the dynamic of innovation, growth, and constant internal readaptation begun in the high-technology industrial complex of Southern California in the 1930s cannot continue more or less successfully over the long-run, providing that appropriate policy safeguards have been put into place. This latter remark, however, presupposes that at least some public debate over the issue of national and local industrial planning will not be long in forthcoming.

In order to prepare the groundwork for any debate of this sort, much further study of the peculiar dynamics and logic of technopole development, both in Southern California and in other parts of the world, needs to be carried out. The present paper is offered as a modest summary of what is known thus far about the problem of Southern California's technopoles and about the ways in which their geographical attributes are shaped by the imperatives of flexible-production organization. It is also a foretaste of the immense and multifaceted research program that lies ahead.

Acknowledgements. This research was supported by the National Science Foundation under grant number SES 8812828. The author wishes to extend his gratitude to Mark Drayse, Eric Kwok, Doreen Mattingly, Alan Paul, and Jan Maarten de Vet, all of whom have contributed in significant ways to the research underlying this paper. All maps and diagrams were drafted by Chase Langford.
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