PRIVATE INCENTIVE AND THE ROLE OF GOVERNMENT IN TECHNOLOGY ADVANCEMENT: SILICON VALLEY, STANFORD UNIVERSITY AND THE FEDERAL GOVERNMENT

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Abstract

Most of the literature concerning Silicon Valley consider the entrepreneurship and the presence of Stanford as driving force in technology advancement. However, few emphasis the function of education in Stanford and on the role of government in this process. Thus this paper focuses on the Department of Electrical Engineering at Stanford (DEE) and shows that:

- There exists a network of relationships between the DEE and Silicon Valley;
- The DEE provides to Silicon Valley highly qualified engineers, and by doing so assures technological improvement;
- The Federal Government, through its research support, acts as catalyst of this relationship.

Keywords

Higher education, Regional development, Technological change

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I would like to thank Masahiko Aoki and Nathan Rosenberg for their helpful comments and suggestions. This paper, supported by the Fondation Boninchi, was written when I was visiting the CEPR, Stanford University.

1. Introduction

In a report to president Roosevelt, "The Endless Frontier," which determined the American science policy of after World War II (WWII), Vannevar Bush[1] (1945) affirmed that "Basic research is essentially noncommercial in nature, it will not receive the attention it requires if left to industry," and solicited the government to support basic research activities. This view reflects the neoclassical approach where the level of research and development (R&D) activities that firms choose is sub-optimal, due to their characteristic of being a public good and having a spillover effect; thus government intervention is justified in order to correct this market failure.

In another respect, R&D activities, as the main source of new technologies, are expected to play an important strategic role from an economic growth and competitiveness point of view; therefore, most governments in industrialized countries, in spite of budget difficulties, consider investment in the R&D as a priority, hence they, with the aim of stimulating technological progress, implement different technological policies (OECD, 1994). The reinforcement of this relationship between industry and the university has became a steadily reoccurring feature of their government's policy.

As a result of the change of the economic environment, and possibly also as a response to scientific and technology policies, firms in some sectors exploit actively different arrangements with universities to acquire new designs and also to consolidate their technical capabilities, a tendency apparent in the United States. The presence of Stanford University is often cited as a key factor in the development of Silicon Valley's industries. Different programs, Stanford University initiated, such as Honors Cooperative Program, Stanford Industrial Affiliates Program, and centers of research such as Center for Integrated Systems, Stanford Integrated Manufacturing Association, Center for Information Technology, seem to reinforce this Industry-University relationship. This observation allows us to argue that the market force, even without government intervention, can drive R&D activities in the "right direction."

Two questions arise here. The first one being: "What is the incentive for both parties – Stanford and Silicon Valley's industry – to cooperate?", in other words, what rationality lies behind this apparent "symbiosis."[2] The second is: "What is the role of government in this process?" - if, in the absence of government research support, we would still find the same network of relationships between Stanford and the industry that we see today.

The purpose of this paper is the followings:

- to analyze the relationship between Stanford University and the Silicon Valley's industry from a historical perspective;
- to determine the driving force in this relationship;
- to examine whether there is a direct and/or indirect contribution of the government research funds on this relationship.

Today, literature on the Silicon Valley is abundant, most of it underlines the importance of the role played by Stanford University; however, few analyze this subject from the perspective of the educational function of university. Thus, I would like to focus this study on the School of Engineering at Stanford University, in particular the Department of Electrical Engineering, during the period 1945 - 1996. I have chosen this department because it seems to have a close tie with local industry from its beginning. More precisely, I would first like to examine, through

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[1] Professor in electrical engineering at MIT. He was among other things dean of engineering, vice president of MIT, president of the Carnegie Institution, and director of the Office of Scientific Research and Development.

[2] Sevilla (1992) utilizes this term to qualify the relationship between Stanford University and Silicon Valley.

the curriculum change at the Department of Electrical Engineering, the nature of the "symbiosis" between the Department and Silicon Valley's computer related industry. By choosing this historical approach, one can investigate Nathan Rosenberg's proposition (1994) that "the misreading of technological change, when viewed from a neoclassical perspective, should be apparent from the historical analysis." Secondly, I intend to present a structured view of the relationship between the Department and Silicon Valley's computer related industry, based on our finding on the analysis of the curriculum, and other secondly sources.

I intend to verify the following hypotheses:

- There exists a network of relationships between the Department of Electrical Engineering at Stanford University (DEE) and Silicon Valley's computer related industry (SV);
- The autonomy accorded to the Department enhances its responsiveness to the changing demand of SV;
- By entering in a close relationship, the DEE and SV pursue their own objectives, that is not necessarily convergent: the former searches for becoming a leading educational institution of "excellence," the latter for assuring a pool of highly qualified engineers and for technological improvement;
- These relationships are mutually reinforcing through a feedback effect;
- The government research support contributes to improve the quality of education but also gives a signal to SV that the DEE is solidly engaged into the race to discover new technology.

My hypotheses reflect the concept of "loose coupling" (Weick, 1976). Stanford University and Electronics Industry constitute two of the components of Silicon Valley considered as a whole system. My underlying idea is that these two components are characterized by the responsiveness and distinctiveness according the actions and reactions of the each other, and their interaction creates a certain momentum in the system as a whole.

The remainder of this paper is organized as follows. It presents briefly the historical background in section 2; it analyzes the curriculum of the Department of Electrical Engineering in section 3; it determines the characteristics of curriculum change, and examines if the curriculum change is related to the shift of the research agenda or to another external force. In section 4, it presents a structured view of the network of the relationship between the Department of Electrical Engineering at Stanford University and Silicon Valley's computer related industry - it identifies the structure of the inborn incentives for Stanford and for Silicon Valley industry to cooperate. In section 5, it inquires if the federal government has contributed directly or indirectly to establish this relationship, and concludes in section 6. One hopes that our study contributes to understanding of what lies beyond Frederick Terman's affirmation "The contributions that electrical engineering at Stanford has made to the industrial community are quite evident, as are the contributions both intellectual and financial that the continuous industry has made to the development of a strong electrical engineering department at Stanford" (Terman, 1976).

2. Historical Background

2.1 Stanford University

At the beginning of its history,[3] Stanford University was categorized as "untraditional,"[4] in the sense that the practical aspect of education was given high importance. Based on the German

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[3] Stanford was founded in 1887.

[4] See Stanford University History.

model of the university,[5] research activity was considered an important part of this educational institution; thus, “the Wind of Freedom blows,” which implies freedom of teaching and freedom of study, became the Stanford motto (Casper, 1995).

Before World War II (WWII), Stanford remained an “underprivileged university” (Terman, 1968) compared to MIT which was engaged actively in research activities funded by the federal government. During late in the 40’s and the 50’s, Stanford built its reputation as a leading research university, as illustrated by the affirmation of Terman in his correspondence to president Sterling (1951): “Although we cannot match MIT in size, we concede nothing to them in quality and in productivity in proportion to money expended by sponsoring agencies.” In the 60's Stanford became a “have university,” in regards of federal government research funds (Terman, 1968); it continues to consolidate its position among the other research universities in the United States (Casper, 1996) and also at a worldwide level.

How did this change of fortune occur? The School of Engineering,[6] in particular the Department of Electrical Engineering (DEE), played a key role in this process. The rise of Stanford was led greatly by the development of its under structure. To stipulate the importance of “electrical engineering” within the university an explanation is needed; according to Rosenberg and Nelson (1994), in the United States, “electrical engineering” was developed as an academic discipline and the training of electrical engineers belongs to the university, unlike in Germany where this discipline was considered as practical and vocational to the point where it developed outside the university.

In the DEE, little research had been conducted before the WWII, their activities were concentrated around the applications of electricity (Terman, 1976); however, the experience of the war on professor Terman[7] at Harvard and MIT was decisive in the future design of the Department at Stanford (Terman, 1984), and through it the future of the School of Engineering, and Stanford University as a whole. He recognized that, in a changing and challenging environment, the training of engineers had become inadequate due to the limited enrollment of graduate students in research activities and insufficient knowledge in fundamental science per se. Thus, he improved graduate education by restructuring the program and reinforcing the connection between federal government agencies and industry by coupling professors in engineering with the outside world (Terman, 1970). The post WWII environment was characterized by: an increasing support by the federal government in basic research conducted by the universities, a recognition of possible commercial applications of the technologies developed during the war; and the large pool of young men, who had worked on war projects, who were available as teachers (Terman, 1976). All of these elements facilitated greatly this organizational change.

This trend, initiated by Terman, is still being pursued today and Stanford has experienced a proliferation of its “innovative developmental periphery”[8] during the postwar period. Without wishing to overstate the point, one can mention the Industrial Affiliates Program[9] (in the 50s), the Honor Cooperative Program (1954), the Stanford Instructional Television Network (1967), the Tutored Videotape Instruction Program (1973), the Center for Integrated Systems

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[5] German model is characterized by the unity of research and teaching.

[6] Established in 1925.

[7] Former dean of the School of Engineering at Stanford (1944-1958).

[8] By “innovative developmental periphery,” Clark means new activities initiated by university beside its core educational and research activities, such as science parks, training programs, or consultancy services. He considers it as a key element of successful institutional change in higher education (1996).

[9] See section 4 for the detail of some of these programs and centers.

(1979), the Stanford Technology Ventures Co-op Program (in the 80s), and the Center for Engineering Management (1993) amongst others.

In 1997,[10] Stanford enrolled 6,550 undergraduate students of which 552 are taking engineering as a major (the second largest following humanities and sciences); and 7,261 graduate students, of which 2,604 are of the School of Engineering (the largest segment and far ahead of Humanities and Sciences). The Academic council is composed of 1488 members, of which 203 are in the School of Engineering. Stanford accounts for 194 members in American Academy of Arts and Sciences, 68 members in National Academy of Engineering (Stanford Facts, 1997).

With regard to the government sponsored projects evolved at Stanford University in the postwar period, its share in the total income used increased rapidly between 1950 and 1966, stabilized around 50% until 1980, then decreased to remain at the level of 40%. In 1996 Stanford received $577.7 million in contracts and government grants and $312.9 million in gifts. It spends $476.8 million in organized research.

Using MIT as a model at the end of the WWII, Stanford successfully implemented an institutional isomorphic change[11] and became one of the leading research universities in the United States.

2.2 Silicon Valley in its relation to Stanford[12]

Arthur L. Norberg (1976) places the origin of the electronics industry in Silicon Valley[13] at the beginning of this century as a result of the implementation of hydroelectric industry. The number of firms which specialized in producing components for the delivery and control of electricity increased rapidly. Innovative entrepreneurs were already present at this time. New products were introduced first to a small segment of this competitive market, followed by incremental technological improvements and the quantitative growth.

Nevertheless, during the 30's the job opportunities for the graduates of Stanford in Electrical Engineering were still limited compared to the East Coast, so Terman made an effort to help his students to establish themselves in the Bay Area and became a driving force in promoting the phenomenon of the start-up company[14] (Terman, 1984).

In the pre-war period the contrast between East Coast and West Coast was apparent: on the one hand the dominance of well-established big companies like RCA in the East, and on the other hand a few emerging "start-up companies" with their own technology together with small companies, producing condensers and resistors, in the West. The establishment of the West Coast Electronics Manufacturers Association (WCEMA) in 1943, as a mean of lobbying in Washington, consolidated the spirit of cooperation amongst the western companies (Saxenian, 1994).

After the WWII, the electronics industry of the Silicon Valley experienced a growth period induced by the increasing demand of vacuum tubes, microwave tubes, and others devices for military purposes (Sevilla, 1992).

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[10] For the evolution of the number of students and members of the Academic Council, see charts 2-1-1, 2-1-2, and 2-1-3 in Appendices.

[11] DiMaggio and Powell define "isomorphism" as a "constraining process that forces one unit in a population to resemble other units that face the same set of environmental conditions" (1983).

[12] See tables 2-2.1 and 2-2.2 in Appendices.

[13] We use here the term "Silicon Valley" to indicate Santa Clara county by simplicity though this nomination has been introduced by Don Hoefler only in 1971.

[14] For example Hewlett-Packard (founded in 1939) and Varian Associates (1948).

The return to Palo Alto of William Shockley, one of the inventors of the transistor, and the establishment of Shockley Transistor Corp. in 1955 marked a beginning of a new era characterized by the multiplication of “spin-off” and “start-up” companies in search of the technological frontier. Fairchild Semiconductors founded in 1957, a spin-off of Shockley Transistor, fathered a whole family of “spin-off companies” in Silicon Valley and formed a diversified and specialized electronics industry. Contrary to the “start-up companies” of the postwar period, the majority of this new generation of companies was initiated by non-Stanford teams (Gibbons, 1997).

The commercialization of the integrated circuit (IC) in 1961 marked a technological breakthrough. After a short period of recession at the beginning of the 60’s due to the importation of cheap Japanese transistors and the retrenchment of the military spending, the market for IC in Silicon Valley revitalized and grew. Sevilla (1992) characterizes the semiconductor industry of this period as “horizontal disintegration” formed of many of small specialized companies.

During the second half of the 70’s, the improvement of semiconductor products and the expansion of production capacity led to the vertical integration of semiconductor companies; as a result, the advantage of the decentralized network organization deminished to the point where their being less responsive and distant from the customers, coupled with fierce competition with Japanese firms, lead the semiconductor industry to a period of recession.

At the same time though a paramount technological breakthrough occurred in the Silicon Valley when the microprocessor was developed by Intel in 1971 which opened tremendous possibilities for the applications that remained to be discovered at that period. It is worth noting that like almost every previous simiconductor device, this technological breakthrough was initiated by industry. Some of the direct consequences of the above mentioned breakthough are the miniaturization of computer, the change in the way of constructing a computer, and the development of peripheral products. It also led to an emergence of multiple small specialized companies. During the 80’s in the semiconductor industry, a new breed of companies created a small niche in semi-custom or custom chip design, rather than producing in quantity standardized semiconductors (Saxenian, 1994). Silicon Valley rediscovered the flexibility and dynamics which characterized it during its early days.

The proliferation of microcomputers and the improvement of their capacity was conducive to the development of the software industry and opened new technological paths, such as networking and multimedia.

How should one characterize the Silicon Valley of today? Silicon Valley can be seen as a system composed of loosely coupled sub-units, composed of a great number of small companies and a small number of big companies. They are “coupled” in the sense that, even between two competing companies, they are apt to establish a network of communication; two companies working on a complementary product could easily coordinate their efforts in a specific task to exploit a new commercial opportunity. They are “loosely” coupled in the sense that these relationships remain temporal and subject to evolve with time as a response to the change of technology and the market structure. These companies amount to a “system” in the sense that they share the same “technical culture” (Saxenian, 1994) and have the same goal, which is to go beyond today’s technological frontier. As a response to an environmental change, each of these companies seeks to bring an incremental adjustment in an add-in process to reestablish an equilibrium and, by doing so, they generate a momentum of continuous renewal. In other words, they induce a dynamic equilibrium.[15]

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[15] According to Becher and Kogan (1992), a constant incremental adjustment of an organization traces a equilibrium path that they call dynamic equilibrium.

By describing Silicon Valley in this way, one is not saying that the boundary of a company has lost its reason for being. On the contrary, it is wise to think that the boundary has an important function of signalling the presence of a unit, that I may call "minimal action unit," which is founded on the solid cohesion of its members, and which has a capacity to act as one entity and the potentiality to act autonomously. Once this cohesion within the boundary is impossible, the movement towards a spin-off unit often occurs, conversely when a new idea brings together a group of people, a movement toward a start-up unit often occurs. In both cases, a new entity emerges establishing its own boundary and forming its own members around an idea or a project.

According to James Gibbons[16] (1997), what makes Silicon Valley different from other regions is its infrastructure, which lubricates the dynamics of this networked organization. He enumerates three characteristics in this infrastructure: technical, social, and educational. The technical characteristic consists of easy access to the basic technology and the close proximity of cheap suppliers. The social characteristic corresponds to the system where the same values are shared by the participants involved in the Silicon Valley. Here, we penetrate in a normative domain. In their daily lives, they takes risks, communicate with the competitors, fail in the businesses, even leave their company and to compete with the latter in the same market, all these acts are permited and, sometimes, encouraged. This environment makes Silicon Valley a place of "collective learning" (Saxenian, 1994). It offers a laboratory with real time apprenticeship for entrepreneurs and an immense source of information for insiders. The educational characteristic is represented by a set of training programs offered by a variety of educational institutions around the Silicon Valley, not only the research universities but also the community colleges; in fact, the latter are frequently considered by the small start-up companies as more accessible and suited to their needs (Larsen, 1997). In an environment of permanent change, it is crucial for the companies to keep their pool of employees at the leading edge of the knowledge in their niche, - for this, they have two possibilities: hiring new people with a specific qualification, or enrolling their employees in a continuing education program: either way, the educational infrastructure is capable of providing a solution to the companie's requirements.

2.3 Federal government science policy

During the WWII, for the first time, researchers and engineers of diverse backgrounds - coming from both research universities and industry - joined together around the military research projects initiated by the National Defense Research Committee[17] (NDRC) (Wildes and Lindgren, 1985). They worked together, bringing and testing new ideas, beyond the usual boundary of academic discipline and the normal division between the academic and industrial spheres, it was a whole new experience to them. As a consequence of their success, the academic researchers and their institutions won recognition by the government of the major contribution in the advancement of science and technology. Bush, as I mentioned in my introduction (Rosenberg, 1994), in 1945 addresses a report "The Endless Frontier" to the president based on his experience as director of the Office of Scientific Research and Development (OSRD), one of the subdivisions of the NDRC. This report greatly influenced the development of the science in the US of the postwar period. Noting that scientific progress is of vital interest to the government, he argued that the government should take on a new responsibility for the creation of new scientific knowledge - basic research, the development of

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[16] Former dean of School of Engineering (1984-1996). Since 1996 he is Counsel to the President for Industry Relations.

[17] The creation of the NDRC was initiated by the proposal of Bush.

scientific talent, more trained scientific personnel, etc. - beyond just military research. He also urged for an implementation of a national policy towards science.

Hence, a "social contract for science" was established between the government and the scientific community (Guston and Keniston, 1994). The government supported basic science by funding based on the peer review, in return the scientists contributed to the development of new knowledge that can be translated into "new products, medicines, or weapons." In 1950, the National Science Foundation (NSF) was founded with the objective "to strengthen research and education in the sciences" (Drew, 1985). Afterwards, other institutions, such as the Office of Naval Research (ONR), National Institutes of Health (NIH), Atomic Energy Commission (AEC), were established to promote research activities in specific domains. During the 50's, the federal research funds were greatly expanded, in particular, coinciding with the beginning of the Cold War, military applications.

The research universities gained the social acceptance as "pre-eminent centers of basic research" (Rosenberg, 1994). The leading research universities were expected to improve the social welfare through their research activities though, in fact, their research agenda until the end of the Cold War was strongly oriented towards military purposes.

These research activities did not generate social benefit directly but as a by-product through the application of their results in civilian use[18] and their function of training students. During this period, there was a "relatively clear division of labor between academic and industrial research" as noted by Rosenberg. Even in the fields of engineering, the research within the universities was qualified "basic," in the sense that it is "open to new things" (Gibbons, 1997). Sometimes, as noted Lowen (1997), the dissemination of knowledge, which is one of the fundamental functions of the academic institution, was distorted with the advent of the Korean War,[19] an event causing an increasing number of research results to be "classified."

During the 70's, the economic climate imposed restrictions in the federal funding for research, which in turn implied a decrease in research activities within the universities. Regarding academic research, the concept of an "uncheckable" social contract (Guston and Keniston, 1994) was distrusted: social accountability became one of the criteria for the resource allocation. The university entered in the period of retrenchment (Slaugher, 1993).

The end of the Cold War marked a turning point in American scientific policy. Public support for academic research lost one of its primary reasons for being, and by late the 80's a reorganization of academic research became inevitable due to the contraction of defense related research funds; again, during the first half of 90's, military funds continued to decrease (OECD, 1994). The Department of the Defense (DoD) devoted more effort to the research which had a potential for the civilian application. At the same time, to sustain federal support for academic research, a new rational appeared: a recognition of the role of innovation as a driving force in economic growth and as a means to consolidate competitiveness in the global market. The "Omnibus Trade and Competitiveness Act" introduced in 1988, which confers to the Department of Commerce the competence to coordinate R&D activities, illustrates this tendency, and by so federal government is expressing its support for the construction of the technological infrastructure.[20]

Today, in spite of the retrenchment of the federal budget for the R&D, the "social contract for science" remains the underlying philosophy of scientific policy in the US and poses the

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[18] For example the Internet which was first conceived for a military purpose, but largely expended for the academic, individual, and commercial use.

[19] The Korean War began in 1950.

[20] For example the construction of the information highway.

following question: How to expend the American scientific and technological capability? The Committee on Criteria for Federal Support of Research and Development (1995) distinguished two types of federal funding for the R&D: the first one is the federal fund destined to "demonstrate, test, and evaluate current knowledge and existing technologies," while the second one, focuses on the "creation of new knowledge and the development of new technology," called "federal science and technology"; the Committee recommended to promote the latter of the two. This new concept is based on the "Chain link model" of innovation[21] (Aoki and Rosenberg, 1989), which implies that the "basic and applied science and technology" must be considered as a whole. The Committee proposed to fund federal science and technology selectively and in a coherent manner, through the definition of their priorities and the coordination between the different federal agencies involved in R&D activities. Academic institutions, because of their educational function and their capacity to produce and disseminate new knowledge, are expected to play a central role in this process.

3. Curriculum change at the Department of Electrical Engineering

In this section, I intend to make a diachronic analysis of the courses and research programs of the Department of Electrical Engineering[22] (DEE) between 1945 and 1996. First, to identify quantitatively the pattern of transition, and examine if the rate of change in courses is related to that of research areas. Secondly, to focus on a qualitative analysis: I propose a typology of courses; and will determine how a new academic field is introduced and integrated into the existing curriculum. Thirdly, to examine if some paradigm shifts have occurred during this period, and if so, to identify the driving force of those paradigm shifts.

The objective of this section is to verify the first two hypothesis:

- there is a close relationship between the DEE and SV;
- the autonomy accorded to the Department enhances its responsiveness to the changing demand of SV.

I intend to show that the curriculum was adapted continuously to the changing environment by integrating new topics developed outside the university, particularly from SV itself, and by offering of specialized courses along the technological trajectory pursued by SV; that the curriculum change occurred as a response to the demand partly from SV for highly qualified engineers of industry; and that these relationships are tenable because the DEE enjoys a certain autonomy which allows it to rapidly ajust the curriculum and educational services that it offers.

3.1 Quantitative analysis

Between 1945 and 1966, there were two levels of courses, "Courses primarily for Undergraduate students" (CUG) and "Courses primarily for Graduate students" (CG). After 1967, to make program planning more flexible, a new level "Courses for Undergraduate or Graduate students" (CUG&G) was introduced.

If we look at the total number of courses, the CG continued to increase until middle of the 60's where it fluctuated between 80 and 100 courses. The existence of this upper-limit can be explained not only by the fact that there were financial constraints and the infrastructure was limited but also though also a deliberate choice of the Department, as illustrated by the affirmation of Terman that: "Courses proliferation has been discouraged," the principle reason being to keep "teaching loads very light, particularly for those involved in research" (Terman,

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[21] Contrary to the linear model of innovation, this model recognize the presence of feedback between different activities conducting to an innovation, such as research, design, test, production, distribution...

[22] Our data comes from Stanford Bulletin (1945-1996). For the qualitative analysis, we refer to "Annual Report to the President" of the School of Engineering (1945-1967) and the interviews with professors Key and Linvill.

1968). The trend since late the 80's though is toward growth. The CUG increased weakly during 40's and 50's, and once the CUG&G introduced, the CUG decrease rapidly and stabilize around 20 courses. Since late the 80's they have tended to increase. The general trend of the CUG&G has been growth with small decline in the middle of 70's and 80's. Thus, since late the 80's, the number of courses increase in all categories.

To measure the degree of regeneration, one can examine how the number of new courses (NC) and the number of courses eliminated (EC) have evolved. The characteristic of the CG is constant renewal: every year a certain number of NC are introduced. The rate of introduction of NC is very variable, but one can identify a big peak in the middle of 60's. Since the 80's the fluctuation has decreased. The CUG are more rigid, in the sense that the number of NC is fewer compared to the CG. The trend of the CUG&G is somewhere between that of the CG and the CUG. In the CG however one observes the same tendency though the number of EC is greater than the number of NC: a permanent phenomenon of elimination, and a large variability, whose peak noted in 1967 was essentially due to the introduction of the CUG&G; before 1967, there were two peaks in 1954 and 1964. Since the 70's, the number of EC in the CUG has remained low. The great degree of regeneration observed in the CG corresponds to the general policy of the School of Engineering, as noted in its Annual Report to the President in 1960 that: " New courses must be offered, eliminating unnecessary courses."

To capture the dynamics of this change, I sum the number of NC.s and EC.s. After 1967, the total variation tends to decrease in the CG, while during the same period, it remains under the limit of 10 courses in the CUG showing again the stability of the CUG and the flexibility of the CG although this tendency seems less since the later part of the 80's. The Annual Report to the President of the school of Engineering in 1953 stated a "policy of flexibility" regarding the CG; the report of 1966 explained the reason for this policy as "to meet the individual needs of students."

The comparison of the number of research areas (RA) and the number of graduate curricula areas (GCA) shows that the former increases constantly, while the latter remains stable. Almost every year, new RA are integrated, while few RA are eliminated. The following examines the qualitative aspects and explores whether they are related.

3.2 Qualitative analysis

First, I intend to identify the "suppliers" of courses attached to the DEE, my purpose being to state the presence, or the absence, of inter- or multi- disciplinarily courses. Then, I classify courses by their type: "lecture," "laboratory," "seminar," and "special topics," enabling one to examine if there is some difference in the way courses are organized among the three levels - CUG, CUG&G, and CG. My third step, will identify the process by which a new field is introduced and integrated within the curriculum. Lastly, I examine how the research areas of the DEE evolved through time. In other words, this qualitative analysis is to identify the paradigm shift of the department research activities.

Suppliers of courses

Of the CUG, due to the fact that the CUG are primarily intended for students who choose EE as their major, the majority of courses attached to the DEE are provided by the Department itself; in spite of this though, some students enroll in Computer Science, in Engineering,[23] in Applied Physics, and in Statistics. Regarding the CUG&G, in 1996 they were over 64 total number of courses attached to the DEE; 8 courses were for the enrollment in Computer Science, 4 in Materials Science, 3 in Engineering, 2 in Applied Physics, 2 in Music, and there

[23] Since 1959 the school of Engineering offers an interdisciplinary programs within the school called "Engineering."

were some others. In the past, other departments, such as Mechanical Engineering, Physiology, and Philosophy, provided some courses for the DEE. Of the CG, also in 1996, there were over a 100 total courses attached to the DEE; 10 courses were for the enrollment in Computer Science, 4 in Applied Physics, 3 in Engineering, and 1 in Materials Science and Psychology. The departments of Physics contributed also with those in Applied Mechanics, in Statistics, in Operation Research, and in Engineering-Economic System.

As illustrated by a series of Annual Reports to the President (1949, 1957, 1959, 1965), the DEE was considered favorably for its cooperation with other departments, a consideration which remains the same to this day. What are the reasons for this cooperation? Without wishing to be exhaustive, one can enumerate some of them. One of the reasons, and driving force, is the development of new fields overlapping several traditional academic disciplines (for example Microwave or Electromagnetic); these courses can be classified in the category of inter-disciplinarily courses. Again, the cooperation is also initiated by faculty members interested in research fields not previously developed in the Department, such as electronic computers, solid-state phenomena, or quantum electronics (Annual Report to the President, 1963). This pattern ends up with an introduction of multi-disciplinarily courses. The cooperation offers the possibility of exploiting other department’s infrastructure (for example applied physics measurements, quantum electronics laboratory). Some courses have been attached to the DEE due to the enlargement of the variety of electrical engineer's skills, such as computer programming.

On can conclude that the DEE has both inter- and multi- disciplinarily courses. This capacity to cooperate with other departments permits the DEE to be flexible in the way it develops its curriculum, therefore increasing its responsiveness to the changing environment.

Typology of courses

Here one examines the courses by type - Lecture, Laboratory, Seminar, and Project - in each of the categories of courses. In this section, the focus is on the curriculum of the DEE in 1996 to be exact.[24]

[24] See table 3-2-1.

Table 3-2-1 Courses by Type

		CUG *		CUG&G		CG	
Lecture	Introduction	6	Introduction to circuits	11	Introduction to VLSI systems	5	Introduction to information storage systems
	Fundamental theory	6	Electronics	12	Lasers	13	The science of semiconductor interfaces
	Special field			5	Bipolar analog integrated circuits	33	Solid-state sensors and actuators
	Interdiscipli-nary	2	Planetary exploration	12	Electrical and magnetic properties of solids	16	Medical imaging systems I
	Technical skill	1	Theory of probability	10	Basic physics for solid state electronics	6	Linear estimation
	Profession	1	The electrical engineering profession	2	The entrepreneurial engineer	2	Business management for electrical engineers
Lab	Techniques	5	Laboratory electronics	1	Integrated circuit fabrication processes	3	Laser laboratory
	Experiment	2	Advanced logic design laboratory	1	Wireless electromagnetic design laboratory	2	Integrated systems laboratory
Seminar		1	Special seminar	3	Seminar	9	Special seminar
Project		3	Special studies and report in electrical engineering		Design projects in VLSI systems		Special studies or projects in electrical engineering

* Number of courses and an example

Source: Stanford University Bulletin Series

The CUG are largely based on lectures. Their main purpose is introducing the students to electrical engineering and to its related disciplines, together with presenting fundamental theories and principles. One notes that since 1979 there has been a course investigating the electrical engineer profession. The second component of the CUG is the laboratory, where students are not only trained in the basic techniques but also in more advanced experimentation. At the undergraduate level, there is just one seminar. The projects allow students to work on a specific subject of their choice. The CUG provide principally basic knowledge and techniques to the students though there is also room for open projects.

The number of lectures increase when one now considers the CUG&G. The fundamental differences compared to the CUG are the presence of numerous interdisciplinary courses and those courses focused on a specific technical skill, together with the reduced role of laboratory.

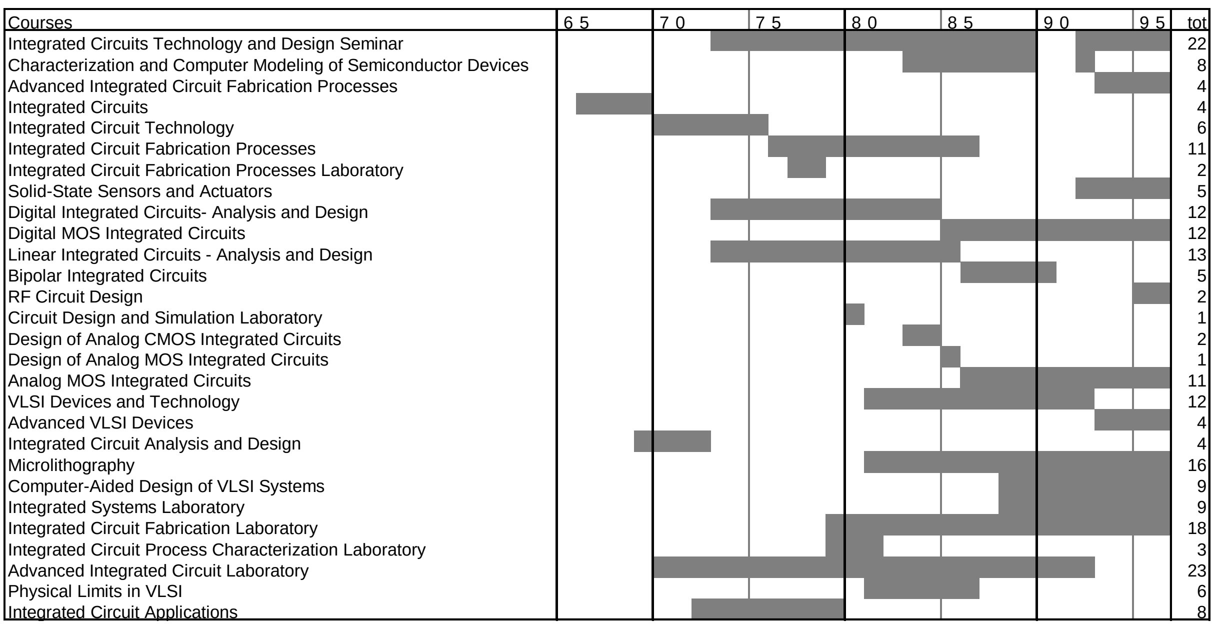
The CUG&G allow students to be in touch with a diverse domain of applications and to learn advanced technical skills.

Regarding the CG, the lecture focus on advanced topics in diverse fields, including interdisciplinary ones. Through its seminars the students proceed to a review the latest literature and the most recent theories in diverse specialized topics. Also, these numerous seminars help contribute to the incubation of new ideas. Invariably the topics discussed in this framework are not yet established as an academic discipline though they may be in process to becoming one. The students may also influence CG by elaborating of a new theory, or by proposing a research project, or by working within a laboratory. Thus the CG allow students to specialize in a specific field and to enroll in a research project in a field of their choice.

Curriculum change

To understand the evolution of the curriculum change in the DEE, it is best to examine how a new field is introduced and wholly integrated into the curriculum. This section then, mainly focuses on the CG, for the reason is that a new field is first introduced in the CG; and then, once this field is established as a academic field, some related courses are proposed at the levels of CUG&G or CUG. More specifically, one can take the case of integrated circuits (IC) to illustrate this process.[25]

Table 3-2-2 Courses on integrated circuits



One starts with a brief flashback to the history of the IC. In 1959 IC were invented by Fairchild. Two years later Fairchild and Texas Instrument commercialized them by cross-licensing for the first time. Thereafter, successive generations of IC were introduced on the market: MOS IC's in 1964, LSI in 1969 and VLSI in the middle of 70's. In the DEE the first course on the IC appeared in 1966, several years after the first commercialization. It was described as "A combination laboratory and lecture course in the fundamentals of semiconductor monolithic integrated circuits." In 1969, "Integrated circuit analysis and design" was introduced. Then in the next year "Advanced integrated circuit laboratory," with "emphasis on techniques for achieving advanced device performance." In the middle of 70's, analysis and design courses were divided into more specific courses; the fabrication processes

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[25] See table 3-2-2.

became a subject of curriculum. By the 80’s, several lectures and laboratories on the fabrication processes were added. The topics of VLSI were first introduced in 1981, and MOS in 1983. In time they were replaced by a more advanced course. The introduction and integration of the domain of IC followed a process of differentiation and specialization, moving from the point of conception towards its final fabrication. One notes that technological breakthroughs first occur outside the DEE then, after several years of being, they are integrated into the curriculum.

Research areas

At this point it is best to examine how research areas of the DEE have shifted over time. Before the WWII, the DEE’s research was concentrated on high voltage power transmission and the insulation of high-voltage lines (Terman, 1984). Terman affirmed (1976) that the “technological impetus generated by the war continued into the postwar period.” The War's development of technologies, such as radar, microwaves, and control systems, opened new areas of academic research. In the DEE, the postwar period started with the shift of their research areas toward communication-related technologies - vacuum tube, microwaves, and radio.

Late the 50’s, following the research agenda induced by the Sputnik effect, the DEE decided to develop the areas of solid state electronics and radio wave propagation (Terman, 1958). The successful development of the solid state electronics was largely supported by industry through the Affiliate Programs (Annual Report to the President, 1958 - 60).

During the 60’s, in cooperation with other departments, such as Materials Science or Computer Science, the DEE developed research activities in the areas of quantum electronics and the computer (Annual Report to the President, 1963). The DEE considered the computer systems as a “technical area of greatest promise” (Annual Report to the President, 1966).

The tendency then, is that there is a shift of graduate curricula areas which closely follows the path determined by the shift of research areas.

<u>3.3 Determinant of the curriculum change</u>

In the previous sub-section, the curriculum of the DEE in regards to its flexibility, adaptability, and responsiveness was characterized; therefore, during the period of 1945 - 1996 one may conclude that a continuous process of renewal occurred. This sub-section is addressed to the following question: What is the driving force of this change?

Growth of the knowledge

First, as Burton Clark (1996) argued, substantive academic growth has a powerful explanatory force. To reach the ultimate objective of academic research, the search for “truth,” the researchers try to surpass the actual frontier of the knowledge. By doing so, they enter into a more and more specialized field, or create a new field derived from the old one. Hence, the process of specialization and differentiation is inherent in the research activity. The same reasoning can be applied to the discipline of electrical engineering, except for the fact that the ultimate objective of its research is the technological breakthrough rather than the search for the “truth.” Once the differentiation and specialization of a discipline occurs in a research university, faculty members attempt to update their courses, by gathering and integrating the new information. This process is conducive to constant renewal of the curriculum. We note here that the enlargement of the knowledge could be also induced by government or industry sponsored oriented research, not only by the traditional non-oriented academic research.

The shift in the research areas, and consequently the shift in the graduate curriculum areas, that occurred in the postwar period follows this logic. As Terman affirmed (1956), “increased fragmentation of the broad field of electrical engineering is inevitable and necessary.”

Subsequently due to the academic growth and the "rapid obsolescence of knowledge," (Terman, 1970) the DEE proceeded to reorganize its curriculum: the undergraduate curriculum was focused on the basic principles; some traditional electrical subjects - materials, statics, dynamics, heat-power laboratory, etc. - were replaced by analytical electrical subjects such as the electromagnetic theory or the Laplace transform (Terman, 1956). Introduction of a common core of courses in 1966 (Engineering) and Courses for Undergraduate or Graduate in 1967 can be seen as a response of the School of Engineering and DEE to this environmental change. Another consequence is the change in the perception of the master's degree which gained "growing acceptance as the basic degree to carry on in professional engineering," as noted by Terman (1970).

The demand from industry

The second driving force comes from the industrial side. To maintain their pool of engineers, industy looks for qualified graduates among engineering schools - not only within research universities, but also within community colleges and other educational institutions. The rapid obsolescence of knowledge and explosion of new technologies has generated a need for engineers to up-date their professional skills throughout their carriers. In the past, on-the-job-training contributed greatly to improving the ability of employees; however, what at the rate of technological change today, a more formal education has become desirable, even necessary. The demand this places on an educational institution is twofold: first to provide well-educated students; secondly, to supply training for their employees in different programs of continuing education. For an educational institution to react positively to these demands it requires adaptation in its curriculum, and also organizational change; the emergence of "innovative developmental periphery", that we mentioned in section 2, can be seen as a reaction of this educational institution.

What was the reaction of School of Engineering at Stanford? In 1946, the School of Engineering reported to the president of Stanford that western universities "can train the type of men required to exercise leadership in an expanding industry." Thus, even from that time, the priority of the School was to serve industry by providing well-trained people. Regarding continuing education though, Terman (1956) affirmed that "on the job experience, while valuable, is not real substitute for formal training in a field where the technological complexity is increasing rapidly," and proposed the "curriculum change to produce better engineers." Today, the position of the School remains the same, as affirmed by Gibbons (1997) that the priority of the school is "always to educate students" and illustrated his argument by quoting Gordon Moore,[26] "The most important thing Stanford does is simply bring high quality students here and educate them for the Silicon Valley."

At the level of the curriculum, the adaptation created the "need for simplification and for better organization and presentation of the body of engineering knowledge" (Terman, 1956). The undergraduate curriculum became more concentrated on the basics and fundamentals, and more attention was paid to adult education. The master's degree acquired a new role: "to provide a strong general technical background" (Terman, 1976). As a consequence, the bachelor's program was revised and the thesis became optional. At the organizational level, the Honors Cooperative Program was implemented in 1954, opening a new way to enroll, in the graduate program, the employees working in industry. Part-time master's programs were introduced using new communication devices, such as closed-circuit talk-back television, or videotapes (the Stanford Instructional Television Network and the Tutored Videotape Instruction Program). The perception of the doctoral degree also changed. Whereas, before those gaining their doctoral degrees almost universally went to the university, now they had the

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[26] One of the founders of Fairchild Corp. and actual chairman of Intel Corp.

wider choice offered by industry. In the 80's, the Stanford Technology Ventures Co-op Program was created, providing the students with the possibility of experiencing the real world of start-up companies during the summer time.

The student's demand

One notes that the shift of student's need also induces a curriculum change. In the postwar period, the DEE's main concern was how to serve the students, as illustrated by the Annual Report to the President (1945): "curriculum possesses flexibility such that the student can adjust his program to serve a personal life plan." During the 60's, the increasing use of computer by the students induced a new course "Computer Programming" (Annual Report to the President, 1963). As noted by Terman (1970, 1972), the decision to introduce interdisciplinary studies and new courses relating to man and his environment was motivated partly by the desire of young people for more flexibility and by their interest in the impact of technology on the quality of life.

3.4 Summary

To sum up, one can characterize the curriculum at the DEE by its flexibility, and its concern towards the "real world of engineering" (Terman, 1972), including the technological trend, demand on the labor market, and the demand of students. The DEE continues to renew its curriculum in pace with technological breakthroughs to accomplish its main goal: to provide highly qualified engineers. Knowing that SV is one of the main sources of these technological breakthroughs and that it is also one of the principle employers of highly qualified engineers, one can affirm the existance of a close tie between the DEE and SV.

It is also notable that the dynamics of change are effectively induced by the factors that have been enumerated - the growth of the knowledge, the demand from industry, the student's need - because, according to William Keys[27] (1997), there are relatively few administrative constraints on the faculty members to decide which subject to teach, which field of research to investigate, and with whom to work. So they can easily initiate, test, and implement new things. Once this dynamic of change is initiated, its momentum appears and reinforces the responsiveness of the DEE.

4. Relationship between Stanford and Silicon Valley

In the previous section, one verified through the curriculum change the existence of a close tie between the DEE and SV and examined the nature of this relationship. One now enlarges the investigation of the DEE to its teaching and research functions. Ones purpose being to understand how the DEE and SV are related to each other through these activities, first, by analyzing the direct contributions of the DEE to the SV, and vice-versa, then by verifying our hypothesis that: the DEE and SV enter into a close relationship to pursue their own objectives though those objectives may not be convergent; the former strives to become a leading educational institution of "excellence," the latter to assure a pool of highly qualified engineers and technological improvement; this relationship is mutually reinforcing through a feedback effect.

4.1 The contributions of the DEE to SV

The DEE provides to society in general four basic services: transfer of knowledge that it produces through its research activities, training of engineers through its teaching activities, updating the intellectual pool of engineers through its continuing education programs, and formal and informal expertise that is provided by the faculty members. Here one examines if

[27] Former dean of the School of Engineering (1972-1984).

the SV benefits from these services and, if it is the case, tries to identify to what extent benefits are.

Transfer of knowledge

One first examines if the technology developed within the DEE was conducive, directly - for example through the transaction of patent or intellectual property - or indirectly - through the movement of people or ideas, to produce product innovation in the SV.

Terman (1964) affirmed that: “thesis projects, which have industrial implications are often moved from the university, at the completion of the doctor’s degree, into a local company and modified to become part of a commercial development.” Thus, the research conducted by the faculty members or students is translated into the innovative products in some cases, as illustrated by the establishment of Silicon Graphics (Dutton, 1997). Nevertheless, Robert Dutton[28] notes that the occurrence of this phenomenon depends greatly on the motivation of the person who generates the idea and on the environment. The desire to see if his idea works and, if so, to have his idea realized as a product moves him into industry. As one saw in section 2, Silicon Valley possesses an infrastructure which facilitates to the development of new products. Hence, the transfer of knowledge occurs more frequently at the individual level - people moving from the university to industry - rather than at the institutional level through the transaction of the patent or intellectual property. And with regards to the small start-up companies in Silicon Valley, the direct transfer of knowledge from Stanford is less (McGinn, 1997).

There exists a formal way to transfer the knowledge from Stanford to industry: the Industrial Affiliates Program (IAP). The first idea of this program was to extend the Annual Electric Research Review which is primarily addressed to those supporting the research in the Department - mainly the DoD - by opening an access to a large public for those who are not connected to government research but interested in the fields of research conducted within the Department (Linvill, 1997). It consisted of a 2-day session: the first day being the review of activities for the government and the second day being the same review of the companies who made an annual contribution. On this occasion, the students, who had enrolled in the sponsored research, also presented their paper (Terman, 1968). Gibbons (1997) figures the IAP to be a “window,” in the sense that affiliate companies do not participate actively to produce these works; they just come to the campus to pick up some new ideas in the basic fields related to their interest. Thus, the link between these ideas and product innovation remains relatively week. The IAP principally functions as an intermediary between people in industry, faculty members and students facilitating further contacts, though it is also as an interface between potential employers and future candidates for employment.

As a result, the DEE’s role is secondary in this process. By attracting outstanding students to the faculty, and by gathering people with diverse backgrounds, the DEE sustains and facilitates the transfer of knowledge. It provides not so much the technology directly related to product innovation, but an infrastructure towards it.

Gibbons affirmed that the contribution of Stanford to the Silicon Valley in terms of the transfer of knowledge is limited. In section 2, we noted that most major innovations were originated by industry rather than at Stanford. At the DEE, the research agenda tended to follow the technological paradigm shift and the curriculum was up-dated by “adding some faculty in selected spots” accordingly (Annual Report to the President, 1965). Mansfield (1991) expresses the same view. In his study on “Academic Research and Industrial Innovation,” he found that in the electrical equipment industry, “only a small percentage of new products were

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[28] Actual director of research at the Center for Integrated System.

significantly dependent upon recent academic research"; these observations seem paradoxical in regards to the growing amount of research funds that Stanford and other research universities receive.

There are possibly two explanations for this: the organization and separation of the university by its disciplines, and the division of labor between the university and industry. The former can be illustrated by the case of the semiconductor. The production of a semiconductor includes a chemical process. As related by Gordon Moore (1997), at the time when the first production process was developed, there didn't exist any academic discipline which covered the topic of semiconductors. Academic researchers working on this topic were dispersed throughout the university and not within a single department, the result being that the university did not play a leading role. As one noted in section 3, that once it was developed in industry, the semiconductor then became the subject of research and curriculum within the DEE, and not the other way round. The later explanation focuses on the exact nature of the university in that academic research is multipurpose in the sense that, even a finalized research project has the potential and possibility of opening new research agendas. Its goal is not only the search for "truth," but also, above all, to train students. Thus the university is well equipped to do basic work, but less prepared to pursue any specific goal, directly connected to the real world, such as product development. As noted by Rosenberg and Nelson (1994), "university researchers are poorly equipped for judging what is likely to be an acceptable solution to a problem and what is not," a remark Gibbons' (1997) follows the same direction: "the faculty don't know enough, even here (Stanford), about what a long term interest of industry might be." Academic research, by its nature, creates a boundary between the university and industry. In other words, the university and industry are of two distinct research environments. When an idea generated within the university reaches a certain maturity, it moves to be realized as a product in industry. When a product developed within industry causes a technological paradigm shift, academic researchers capture and reformulate its underlying ideas. Hence, the ideas and people supporting those ideas cross the said boundary, in either directions, seeking the most suitable environment for the development of those ideas. It would seem that the driving force of the advancement of technology is the presence of these two complementary research environments, and the facility by which ideas and people circulate freely.

To sum up, the contribution of the DEE regarding the transfer of knowledge in its norrowest sense, is limited though it exists: few product innovations were directly generated by the DEE; however, if one examines the transfer of that knowledge in terms of the flow of ideas and people, which constitutes the starting point of the process of innovation, its role must be reconsidered in that DEE's capacity to attract an outstanding faculty and students enhances its potentiality to generate new ideas. This openness characterizes the organization of the DEE and permits ideas to freely circulate within the boundary of the university. These then have been the characteristics which allowed the DEE to play this role of catalyst for technological innovation.

Provider of high quality engineers

According to Terman (1959), "universities are the sources of the highly trained young men who represent the most important raw material going into creative work." The DEE is no exception: its main goal was, and still remains, the education and preparation of students for the profession of engineering (Gibbons, 1997) but how has this goal been attained? The DEE makes a permanent effort to improve its training function: by selecting capable students, by adapting its curriculum to the changing environment of electrical engineering, by attracting high level researchers, and by actively pursuing research.

The undergraduate admission takes place at the university level. The selection is based on two principle criteria: academic excellence, that is "quality of academic preparation, achievement, and promise"; and personal achievement outside the classroom, which reflects "initiative, curiosity, and vigour" (Fetter, 1995). The DEE does not directly intervene with this process, but the vigorous discernment it places at the admission office assures that those who choose electrical engineering as their major possess a fairly high intellectual capacity. At the graduate level though, admissions are decided by the DEE. The DEE selects the best qualified students to its training process and its research agenda on the basis of quantitative performance and references (Linvill, 1997). After admission, the Ph.D. students are screened[29] several time before beginning their doctoral dissertation. As Gibbons (1997) noted, "the students are selected to be able to profit from the kind of teaching that high quality researchers will do."

In section 3, it was shown that the DEE has successfully adapted its curriculum to follow the mainstream of research in electrical engineering and to respond to the changing demand of the profession of engineering. Indeed, the DEE is conscious of industry's need for highly trained people: "industry requires broadly trained, creative individuals who are flexible, capable of working in interdisciplinary teams, and prepared to work on problems that need to be solved rather than on problems that are invented on the campus" (Terman, 1972), and the curriculum has been adapted consequently. At the undergraduate level, its curriculum provides to students that which is fundamental in electrical engineering in terms of knowledge, technique, and also business skill. The curriculum at graduate level allows students to be in touch with topics at the edge of the technology frontier and also to experience the real world of engineering through internship.

The curriculum sets up the structure of educational service, but the efficiency with which this service is provided depends greatly on the method of teaching and learning. The quality of faculty members, as teachers and as researchers, matters to the quality of education. As noted in section 2, within the DEE teaching and research were closely related. The students, when they attend a class, acquire the knowledge that science has established, but they also learn an "attitude about things" or a "habit of mind." In other words, they are trained "to think in the way a researcher thinks about an issue" (Gibbons, 1997). Thus the DEE is concerned about recruiting highly qualified researchers who have the potential of transmitting, these ways of thinking and being, to the students. In addition, the students must be prepared to capture the underlying message sent by their teachers because, as noted by Gibbons, "...they are selected for."

The quality of research conducted within the DEE determines also the quality of training. According to Terman (1958), this research includes two components of work: innovation work that he described as creative activities, and learning work which consists of acquisition of knowledge and the understanding of nature. By affirming that "the best way to train a student to the highest level of competence in science or engineering is to have him participate in either learning or innovation work," Terman closely coupled the learning process to the research activities. The latter provides the real environment of experimentation and transmits the way to do research through a learning-by-doing process.

With these strategies the DEE has contributed to the building of the reputation of the School of Engineering as a provider of highly qualified engineers. Gibbons quoted Moore: "you (Stanford University) graduate a lot of students every year, and then you replenish the intellectual pool in Silicon Valley." There is no doubt of this contribution of the DEE regarding the training of high quality engineers. Nevertheless, two things are worth noting: first, graduates of the DEE are recruited, not only from the Silicon Valley, but also in the East Coast, other states, and foreign countries; secondly that, the SV hires not only Stanford graduates, but also graduates from other research universities, colleges, as well as professional

[29] For example, they have to acquired a certain number of credits or pass a qualifying examination.

schools in the United States and in foreign countries. That is to say that neither the contribution of the DEE is limited to the geographical area of Silicon Valley alone, nor that the SV's pool of engineers is dependent exclusively on the DEE.

Continuing education

The rate of the obsolescence of knowledge grew rapidly in the postwar period. As we noted in section 3, the School of Engineering contributed actively to resolve this problem by allowing the people working in companies to attend graduate courses.

The first official program offered by the School the Honors Cooperative Program (HCP) was started in 1954. Since 1952, the University has opened the door to industry by approving "unit registration of graduates with industrial connections" (Annual Report to the President, 1952 - 1963). The School considered this fact as a new opportunity for graduate level education: and the following year, with the support of some electronics companies, it conceived a formal plan which became the starting point of the HCP.[30] At the beginning, the principle was as follows:

- The cooperating companies recruit young men who will work about 35 hours per week in industry, draw a full time industrial salary, and take 40% of a full-time graduate study program.
- The cooperating companies commit themselves to make a grant to the DEE of $15.00 for each unit of credit, in order to help pay the cost of expanding the number of DEE staff.

In 1954, the HCP started with three cooperating companies with 23 authorized billets; it enrolled 55 students from 13 cooperating companies the following year. The other departments, such as Mechanical Engineering, Aeronautics & Astronautics, and Industrial Engineering, joined the HCP in 1955. The number of students continued to growth rapidly; passing from 150 students coming from 29 companies in 1957 to 521 students in 1963. During the same period, the grants received by the School increased from $ 90'000 to $ 200'000. The HCP allows participating companies to attract employees who have the potentiality and ambition to improve their own capability using "Stanford's growing reputation in engineering" (Terman, 1968); to upgrade existing employees; and indirectly to establish a personal relationship with some faculty members working in their fields, meaning an easy access to the information and expertise (Larsen, 1997). In return, the School received tuition and grants from the participating companies, which "contributed to the educational strength of the DEE" (Annual Report to the President, 1954) and also other departments. Beyond its role of continuing education, the HCP contributed to the reputation of both parties, the School of Engineering and the participating companies. In effect, the HCP became a mutually beneficial and reinforcing process. Today, a large number of big companies in Silicon Valley participate to the HCP, whereas most small start-up companies turn to the community colleges to improve their continuing education (Larsen, 1997).

Due to the expansion of the electronics industry, the number of engineers working in the Silicon Valley has tended to increase, except during some periods of recession (Sevilla, 1992). With the rapid obsolescence of knowledge, the demand for the continuing education of engineers exceeded the supply. New communication technology was used to provide more widely the educational service.[31] The key idea was the follows: instead of students coming to

[30] It seems that regarding the HCP, MIT remained the model for Stanford. Indeed, in 1922 MIT established the Industrial Cooperative Program, at the beginning to provide students the real world of engineering, and later also "upgrade the educational background of new company employees" (Wildes and Lindgren, 1985). Terman referred to this program when he related the development of graduate study in EE during the postwar period (Terman, 1976). The fundamental difference is that HCP is based on the double tuition, while MIT's program is based on a separate arrangement with the companies (Linvill, 1997).

[31] It also contributed to resolve the problem of congestion of traffic around Silicon Valley, though slightly.

class, the class would go to the students. In 1967, Stanford Instructional Television Network (SITN) was implemented. This closed-circuit broad casting service allowed students within a 50 mile radius from the campus to attend and participate - via two-way audio - in the class staying at their workplace (Tajnai, 1997). The concept of this program was extended to another one, Tutored Videotape Instruction Program (TVI) in 1973. Stanford supplies the curriculum by means of videotapes and the tutorial. The latter consists in a support of students by a "tutor" selected from within the participating company and trained by Stanford (Gibbons, 1997). The presence of the latter creates a learning environment and generates group dynamics. That prevents the program becoming a passive one-way instruction.

Gibbons reported that some CEO in the Silicon Valley consider that the most important thing Stanford does is to "offer continuing education all over the country with the television network." These programs remove the capacity and geographic constraints that traditional instructions faced. According to him, what makes the School of Engineering at Stanford different from those in other leading research universities lies not in the curriculum itself, but in its disposition to "deliver it everywhere." They contributed also to the spread a common language, knowledge and the value of engineering at the leading edge, facilitating communication amongst engineers, and in some sense, creating the "community of technical scholars."[32]

The continuing education provided by the School benefits the local companies in the first place, though this service is not just limited to the Silicon Valley, as illustrated by the case of HP which uses the TVI at a worldwide level. The success of these programs allows Stanford to extend its reputation and its position in engineer education.

Expertise

Besides research and teaching, the faculty members provide their expertise to SV. They act as consultants, either as members in the boards of directors in high-tech companies, or more informally through personal relationships with industry's personnel.[33] They help to resolve problems facing industry, to bring new perspectives (Terman, 1959), or to initiate brainstorming.

There is no formal program for this category of service, but the DEE solicits its faculty members to provide it. By offering their expertise, the faculty members become more aware of problems in the real world and cultivate a business sense,[34] the consequence being a more close relationship between the faculty members and industry.

This close tie with some companies benefits the students. Indeed, the students gain more open access to the real world, and internships, or more informal exchanges, are readily implemented. Also these said companies might be their future employers.

Summary

The SV considers that the research conducted within the DEE contributes to advance the state of the technology only modestly, while its educational service is the main contribution of the DEE, and more generally of the School of Engineering. The latter recognizes the research activities as an integral part of training process[35] (Annual Report to the President, 1951, 1958).

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[32] It was the ideal of Terman (1964).

[33] They serve also as government advisors, members of different committees.

[34] Terman (1964) talked of "men of affair."

[35] The early policies in sponsored research of the postwar period affirmed that the "sponsored research would be a part of the educational operation; it would be performed by students, and faculty with a minimum of full-time professional staff, and only projects having substantial academic value would be undertaken" (Terman, 1968).

The quality of researchers and the way research activities are conducted influence the quality of educational services. Thus, by reinforcing these activities - research and teaching - the DEE consolidates its position as a “community of technical scholars” within the Silicon Valley and also at national and international levels. It creates an environment “conductive to the development of new ideas, and, in general, maintains intellectual activity at a high tempo both in the university and in industry” (Terman, 1964).

4.2 Contribution of SV to the DEE

As Terman (1959) affirmed, “the relationship between industry and educational institutions need not, and should not, be a one way street.” In return they “receive values that contribute to its own development.” In our case we can identify several direct contributions of the SV to the DEE. First, the SV constitutes a source of income for the DEE.[36] The latter receives the money in form of research funds, tuition, fellowships, or participation fees to the different programs it offers. Second, the transfer of knowledge also takes place from SV to Stanford: new topics developed in the industry side are presented within the seminar and lecture or transmitted through the informal discussion. Lastly, the SV provides a carrier perspective to the graduates of the DEE. In the following one can analyze these direct contributions and examine if there exists some other effects.

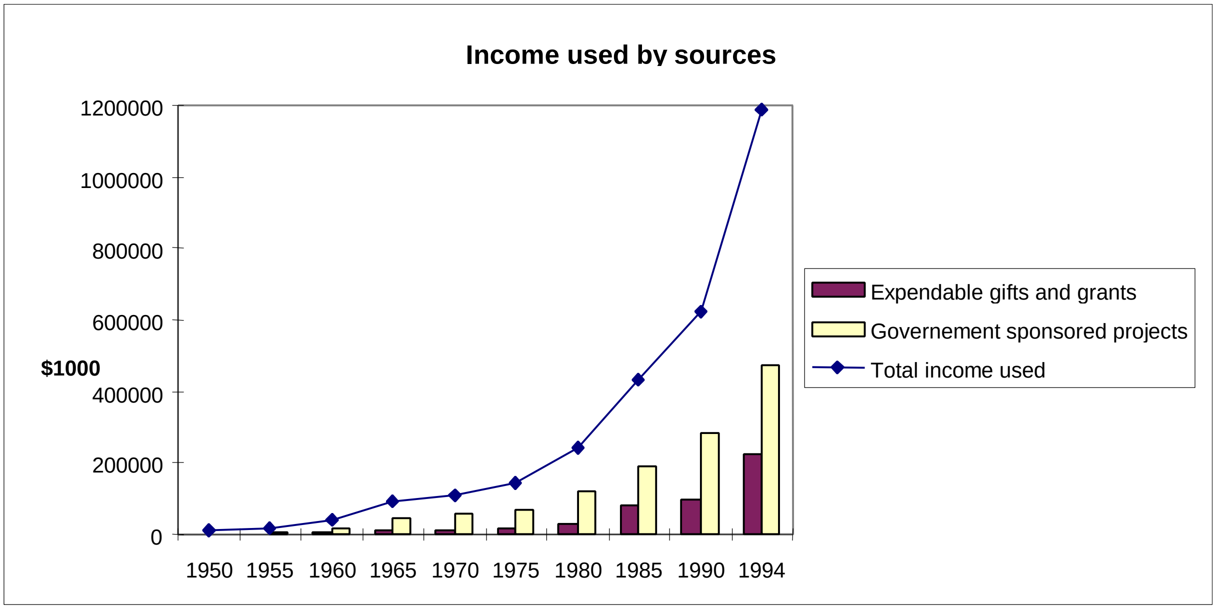
Financial contribution

There is no desegregated official data about the financial state of the School of Engineering. Thus one has to refer to the university level data in the Stanford University Annual Financial Report.

Chart 4-2-1 “The income used by sources” shows that the expendable gifts and grants increase constantly; their share attains 20% of the total income used in 1994; nevertheless the government remains the main financial contributor; the share of the tuition and fees stays stable around 25% until 1990, but decreases after. These observations lead one to suppose that the fund the school contributed by industry is gaining in importance, but is still dwarfed by that of the government.

[36] In this sub-section we exclude in our analysis the income coming from the Stanford Industrial Park and other auxiliary services which are not directly related to the DEE and the School of Engineering. See sub-section 4.2 for more detail about Stanford Industrial Park.

Chart 4-2-1



Sources: Stanford University Annual Finance Reports

Financial support, from industry to the DEE, fits into two categories: the first one is the donation without a direct counterpart; the second one is the compensation for the services which the Department provides. Included in the first is the fellowship that industry offers to the DEE. And to the second, we can enumerate sponsored research, the expertise provided by the faculty members, and the participation fees for the programs provided by the School, such as the Industrial Affiliates Program. Whichever the origin, the result of the implication of this financial support is quite clear: it allows the DEE to be better endowed in terms of physical assets - building or equipment - and to attract high quality faculty members and students; which in turn, improves the conditions of research, teaching and learning; which again allows the DEE to attract new financial support; to the point that at the end of this self-sustaining process, that Terman (1964) called “Snowballing effect,” Stanford reinforces its own position amongst the leading research universities.

Transfer of knowledge

The transfer of knowledge takes place in both directions. In sub-section 4.1 one noted that the transfer of knowledge from the DEE to SV was limited in terms of product innovation, but occurred more freely in terms of basic ideas or through the movement of people. In this part one examines how new technology emerged in industry is transferred into the DEE.

There are three main channels. First, industrial people come to the DEE as instructors. They give lectures or seminars on their latest findings. Keys (1997) remarked that in the 60’s the DEE engaged a quite large number of instructors from local industry for courses in demand.[37] The reason was that the Department did not have people to teach these topics. Terman (1964) affirmed also that the “seminars are given by a series of men from industry who are doing interesting, impressive, and important things.” In some cases, they were former students of

[37] In the 60’s, the invention of IC marked a technological breakthrough.

Terman (Lowood, 1996). As noted in section 3, this channel allows the DEE to integrate the newest topics in its program without delay, so playing a crucial role in the process of adaptation of the curriculum. Secondly, the faculty members go to industry to collect new information and to up-date their courses. The transfer of knowledge through this channel occurs in a non systematic manner and depends on the personal relation of the faculty members, on their interest in the problem of real world, and on their capacity to adapt to the changing environment. This channel is difficult to measure in extent being that it is informal and diffuse; furthermore, when there is a technological breakthrough it is inefficient. Thirdly, within a framework of collaborative research projects, the researchers or engineers from industry can transmit their know-how to the graduate students enrolled in these projects in a form of on-the-job-training (Murakami, 1997). The contents of which, compaired with the knowledge transferred by the previous channels, is more technical and more tacit.

There exists an indirect effect of the transfer of knowledge: this process allows the faculty members and students to be more aware of the real world of engineering. The extent of this effect depends on the channel through which the transfer of knowledge occurs. By interacting with people in industry, the faculty members and students learn how to pose and investigate the problems of industry. In this way, the School of Engineering can provide industry with engineers whose characteristics are more suited to what it expected of them. Here again, by this process, a "snowballing effect" occurs, and the reputation of the School is enhanced.

Carrier perspective for the graduates

There is no official follow-up survey on the students after their graduation from Stanford. Informally, according to Dutton (1997), probably 15% of his graduate students go outside the United States while 2/3 of the remainder are either on the West or South West Coast, between Texas and Washington. Hence, Silicon Valley does not employ exclusively the graduates of Stanford, neither do the graduates of Stanford search exclusively for work in Silicon Valley, as noted above. Nevertheless, by its geographical proximity, by its commitment to Stanford - financial contribution or participation to different programs - and by its dynamics, Silicon Valley represents important job opportunities for the graduates.[38]

In the postwar period, as noted in sub-section 2.2, job opportunities for the engineers were limited in the Bay Area (Terman, 1984). After his return to Stanford, Terman's first concern was how to retain his students around Stanford after their graduation. This preoccupation led him to say: "if somebody wanted to start one locally, you would cooperate as much as you could with him." Thus, to meet this goal, he helped start-up companies[39] to establish themselves and solicitated for their being potential employers of his graduates, existing companies and research laboratories, to locate in this area.

The Stanford Industrial Park (SIP) opened in 1953 can be seen in this perspective, though job creation is not their primary reason for being.[40] The project of an industrial park initiated by Terman was approved by the University trustees and by the City of Palo Alto early the 50's. It consists of 99-year lease of the land owed by Stanford to industry. Amongst the companies that relocated at this time were Varian Associates, Eastman Kodak, and Hewlett-Packard (Stanford Industrial Park, 1956). The idea of Terman was to attract electronics and research firms with his School of Engineering, and, by facilitating their interactions, to "contribute to electronic development." The SIP provides graduate students of Stanford the occasion to work

[38] Sevilla's survey on the employment practice in Silicon Valley (1992) shows that the majority of firms participating to the survey recruit "between 70 to 90% of their engineers locally."

[39] For example Hewlett-Packard (founded in 1939) or Varian Associates (1948).

[40] The SIP is one of the important sources of income to Stanford. Regarding the "income-producing purposes," Terman talk about "new attitude toward land development" (Norberg, 1984).

closely with the companies located in the SIP, and often this tie extends on after the graduation. Hence, one of the effects of the SIP is the creation of job opportunities for the graduates of Stanford.

What is emphasize here is the fact that the School of Engineering takes the initiative in encouraging Silicon Valley to seek Stanford graduates. One has already noted that the Industrial Affiliates Program plays a role of intermediary between companies and students. There also exists another arrangements between the School and companies - not only big companies but also small start-up companies (Larsen, 1997) - making the students in touch with companies. The School organizes for example visits or internship to companies located in the Silicon Valley; graduate students are enrolled in industry funded research projects. Those contacts allow companies to have a better information about the characteristics of their potential employees on the one hand, and the students to have a better idea of their potential employer on the other hand.

4.3 Underlying conditions to cooperation

In the preceding parts, one analyzed the main contributions of the DEE to SV and vice-versa. One noted that some of these contributions are mutually related. This part starts by giving a brief reminder of the primary goals of the DEE and SV, then presents a structured view of relationships between the DEE and SV around their objectives, and finally verifies if there exists some incentive scheme for this cooperatation, and if so, to identify what are the underlying conditions of this cooperation. In other words, this is trying to prove our third and fourth hypothesis:

- the DEE and SV enter into a close relationship to pursue their own objectives though those objectives may not be convergent; the former strives to become a leading educational institution and "excellence", the latter to assure a pool of highly qualified engineers and technological improvement;
- this relationship is mutually reinforcing through a feedback effect.

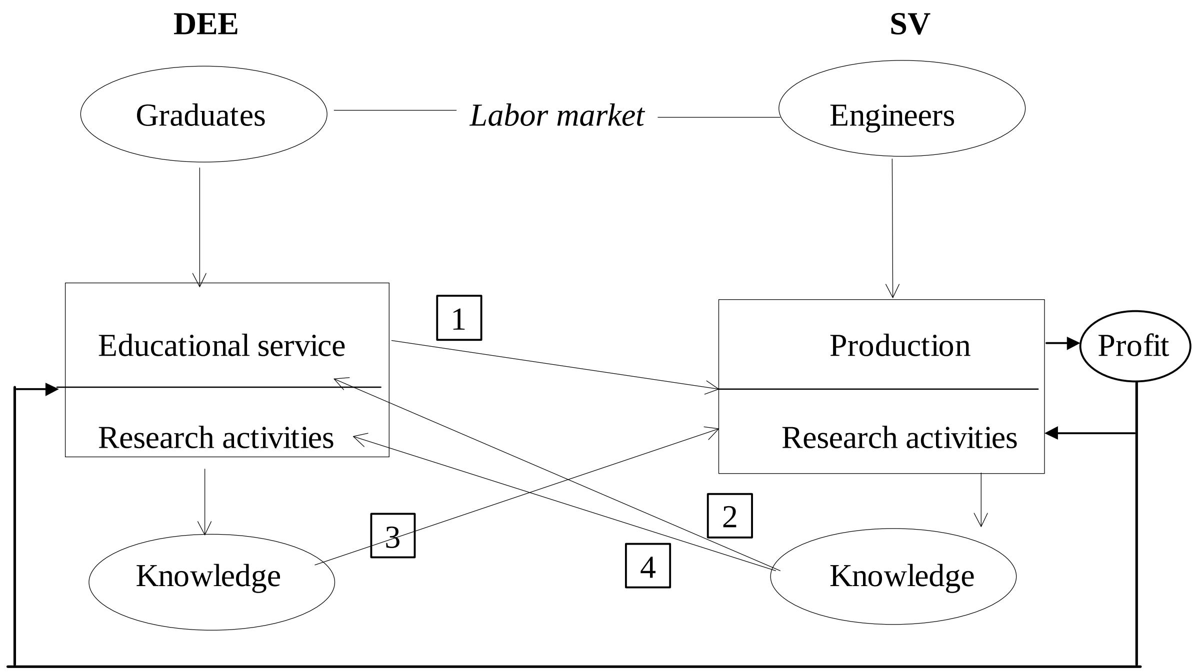
Primary goals

As noted in section 2, the main goal of Stanford University was above all to become and remain a leading research university by providing high level educational services and by doing research in promising areas. Also, noted in sub-section 3.3, the School of Engineering aligned itself to this policy by giving its priority to educate students and, according to Gibbons (1997), by focusing its effort to conduct high quality applied research. As the main component of the School of Engineering, the DEE contributed greatly to achieving this goal.

The primary goal of SV is to generate a financial profit by the introduction of new products or by improving the quality of existing products. They develop a specific technology by hiring highly qualified engineers and through research activities. However, as noted in sub-section 2.2, people in SV devote themselves to missions which are more related to technical culture rather than just simple profit seeking behaviour: they seek to go beyond today's technological frontier. The spin-offs and start-ups which characterize SV are often motivated by this missionary behavior.

Thus in terms of a primary goal, the DEE and SV's perspectives diverge: the former searching for the reputation as a leading educational institution and the latter searching for a financial profit. However, at the level of individuals, there is a convergence of their point of view: the people in the DEE and those in SV both share the technical culture: searching for a technological breakthrough. They plan and conduct research project to realize an idea. Nevertheless, it doesn't mean that they do the same type of research. On the contrary, as we noted in sub-section 4.1, the DEE and SV provide two different environments of research: the former is best fitted for the basic works and the latter for the product development. These observations lead us to inquire why there exists this close relationships between the DEE and SV in spite of this difference. One tries to answer this question in the followings.

Figure 4-3-1 Relationships between the DEE and SV



1. Continuing education
2. Instructors
3. Expertise, formal and informal transfer of knowledge
4. Formal and informal transfer of knowledge

Synthesis

Figure 4-3-1 presents a structured view of transactions between the DEE and SV that were analyzed above.[41] In real terms, there are three levels of transactions: labor market, educational service, and knowledge transfer. Through the first one, the DEE replenishes SV with newly trained engineers. Regarding the educational service, transactions take place in both directions: the DEE provides the continuing education to SV and some people from SV come to the DEE as instructors. The same is true in respects to the knowledge transfer: some results of research activities conducted in the DEE are transmitted formally or informally to SV and vice-versa. The financial flows are indicated by the bold lines. A fraction of the profit is reinvested into in-house research and into research conducted within the university.

What emerges from this chart is that all these transactions are inter-connected directly or indirectly. As a consequence, an improvement in a section of this chain positively affects the conected sections, and so forth generating a momentum which reinforces the link between the DEE and SV. One calls it “chain process.”

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[41] This figure is simplified in the sense that it doesn’t include the transactions with the third party - such as the state or consumers -, neither internal feedback - such as the effect of knowledge creation on the production or the interaction between educational service and research activities.

To argue this assertion, let focus first on the educational service provided by the DEE. As described by Terman (1964), “a substantial fraction of graduates take jobs in a local company, stay on in the Stanford community, keep coming back to the university to tell their old professor what they are doing, or to attend seminars. Some will even give seminar talks to the next generation of students.” Thus, an improvement of the quality of education implies an improvement of the quality of the future engineers, which in turn is likely to induce a better performance of the in-house research activities, calminating to an advancement of the knowledge. At this point one can identify two channels through which this educational service receives a feedback effect. Firstly, a new body of knowledge can be transmitted to faculty members, who, as a result, “try to keep their course up to date” (Gibbons, 1997). Through this channel research activities gain, by the reseach involved, a new dimension affecting the quality of training. Secondly, those who have contributed to produce a new body of knowledge may go on to present it to the students. In both cases, the quality of the educational service is enhanced as a result. The strategy of the DEE presented in the Annual Report to the President (1966) illustrates this chain process: the DEE proposes to identify promising areas and to appoint new faculty members who would contribute to consolidate existing courses or to introduce new seminars; then by establishing and developing industrial contacts in this field, it seeks to train an “adequately educated technical personnel.”

Another way to see the chain process is to focus on the continuing education that the DEE provides. It directly affects the employees within SV in that once the quality of engineers has improved, production and research activities gain in efficiency, something which correlates cleanly into the chain process proposed.

Furthermore, one could emphasize the aspect of academic research, in that, by reinforcing research activities, the DEE contributes to create both new knowledge and the provision of better trained graduates; the new knowledge could then in turn be transmitted to SV through various means - publication, expertise, or direct contract; the quality of its future engineers is likewise upgraded. Thus, through these two channels, the chain process may self perpetuate.

By adding the aspect of the financial flow to our analysis, the tie between the DEE and SV is reinforced: a greater profit may increase the amount of investment in in-house research or academic research, which in turn enhances the capability of knowledge creation, which, through the chain process, goes on to improve an existing product or the introduction of a new product, which may generate a greater profit, and so on.

Finally, one notes that this chain process is lubricated by the free movement of people and idea, by the flexibility in organization which characterize SV and the DEE, and by the presence of different arrangements between SV and the DEE, such as HCP, IAP, or SIP. Regarding the labor market, the presence of a personal relationship between faculty members and the people of industry contributes to resolve the problem of information gathering: the employers are better informed about the interest of, and potentiality of, their future employees; the employees gain a better knowledge of what the employers are expecting from them.

Incentive to cooperate

In identifying that this chain process is the driving force conducing the DEE and SV to cooperate together, the direct way to achieve their own objectives would be to reinforce their main activities. By doing so, through the process of the different channels that we described above, they would contribute to improve the other party’s potentiality, which indirectly would strengthen their own activities, and so on. Thus, by entering into this close relationship, they would take advantage of their complementarity. Both parties would gain in their efficiency.

However, the presence of this mere chain process alone doesn't include all the ties that we observed between the DEE and SV, therefore, contrary to the myopic vision hypothesized above, the long-term vision, which takes into consideration the direct and induced effects of the cooperation, adds a sobriety to the speed of the chain process. The fact that the DEE and SV are aware of the induced effect of the research cooperation on the quality of the training, as we mentioned in sub-sections 4.1 and 4.2, illustrates this argument.

This complementarity is favored by the characteristics of the DEE that we described in sub-section 3.3: the flexibility in its organization and the responsiveness to the external stimulus. These characteristics enhance the adaptability of the DEE to the changing environment, thus accelerating the course of the chain process. Regarding SV, in sub-section 2.2, one identified the network-form of organization, based on a loosely-coupled relationship between companies, which is the driving force of the dynamics of the SV. The same kind of relationship also exists with the DEE - this relationship being characterized by the presence of thier two distinct environments of research which share the free circulation of ideas and people, as illustrated in sub-section 4.1 -, ensuring the complementarity between the DEE and SV.

Finally one is reminded that Terman played a determinant role to induce this dynamic effect that characterizes the relationship between the DEE and SV. As we saw in sub-section 2.1, Terman was first to recognize the importance of SV for the School of Engineering and committed himself to build up a mutually beneficial relationship. His main contribution was to introduce a new way to manage an academic institution as follows: he oriented the activities conducted within the university in accordance with the current technological paradigm, put together people with diverse backgrounds, and facilitated a free flow of ideas and people between Stanford and Silicon Valley. His visionary approach has remains with us to this day.

In fact, Gibbons, one of his successors at the School of Engineering, went farther (1997). By founding the Center for Integrated Systems (CIS) in 1979, he attempted to "bring a long term commercial sensitivity to research at the university." The CIS conducts research projects along a research agenda that has a "long time significance, not to Silicon Valley only, but to industry at a large." The participating companies help to design research agenda, fund research activities, and "send high quality researchers to work with the faculty and students." What differs the CIS from other centers is that any results the center obtains are not filed for patent, they are open to everybody. Therefore the CIS operates as a forum where companies bring things together, and where the basic ideas designing a new technological paradigm emerge. As a result, the complementarity between the DEE and SV is reinforced.

To summarize the chain process is self-enforcing through feedback effect. It is activated by the decisions of both parties based on a long-term vision. The characteristics of the DEE put beside those of SV enhance their complementarity. Nevertheless, at the early stage, some individual initiative was needed to implement this new kind of relationship between an academic department and industry.

5. Role of Federal Government

The findings on the rational for the DEE and SV to cooperate leads one to the misleading impression that the government plays no role in this process. Hence in this section we focus on this point. One proposes to answer one of the fundamental questions on public finance: should the government intervene and lead the university and industry to cooperate? The following will first identify the contribution of the government to Stanford, then it will[42] inquire if the presence of the government was indispensable to initiate, or to maintain, the relationship between Stanford and the Silicon Valley industry.

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[42] In this section we focus on the university level, rather than the department level, to generalize our discuss. Nevertheless, by talking about Stanford, our reference remains the domain of engineering.

5.1 Contribution of the federal government to Stanford University

Direct contribution

As noted in sub-section 2.1, Stanford University reinforced its tie with the federal government during the postwar period. In spite of federal budget restriction, the federal government remains the main source of funds. In 1994, Stanford received from the government through its agencies and institutions $ 528 million, which represents 40% of the total fund received. Even excluding the Stanford Linear Accelerator Center, its funding holds 27% of the total (Stanford University Annual Finance Report, 1995).

Usually the federal government funds the university in three ways: contract, grant, and fellowship. Through the contract, the federal government gives to the university a financial "compensation for services rendered" (Terman, 1960). The university does research in a particular field with a precisely predetermined objective. The grant consists of a financial support for a research project proposed by the faculty members. It is best fitted for the basic research which has "no clearly predictable practical result." The fellowship awards "directly to individuals" or is established at a "particular promising place." The first two means are focused primarily on the academic research. They contribute to obtaining some specific results, to develop a new field of research, or more generally to promote the advancement of a science. Thus the primary motive of federal agencies "is not to aid education" (Terman, 1964); whereas the fellowship is directly related to education, in particular graduate education. It allows outstanding students to obtain a master or doctoral degree and the university to cover a part of the cost of graduate education.

Regarding government sponsored projects at Stanford, the total amount of grants is about double of those of contracts during the period we consider (Stanford University Annual Finance Report). At the undergraduate level the government fellowship support increased constantly. In 1991, 5841 students received aid of $ 5'713 on average. However, one notes that the tuition cost increases more rapidly than the average financial aid (Stanford Facts).

Indirect contribution

Though the government's support goes mainly to the research activities, the federal government and the university are aware of the educational value of these financial commitments. Terman (1960) went farther by affirming that "whether the quantity and the quality of basic research and graduate education in the United States will be adequate or inadequate depends primarily upon the government of the United States." The government's contracts and grants allow the university to hire and to keep outstanding researchers as faculty members, and through them to "attract outstanding students." The research projects conducted under their direction present a wonderful training environment. Besides the practical and technical aspect of a research, the graduate students learn the way to do research.

There is another indirect effect of the government contracts. New fields of study such as the space science, the solid state physics, and the materials science were "integrated into the university curricula" (Lowen, 1990). As noted in sub-section 3.2, the growth of the knowledge trigger off the process of curriculum change. Through contacted or granted research projects the students are confronted with the topics at the leading edge of science and also with the "problems of contemporary importance in the real world" (Terman, 1976).

Terman affirmed that the government sponsored research offered Stanford "a wonderful opportunity if we are prepared to exploit it" (Lowen, 1990). Stanford was successful to enhancing the quality of its education through this means.

To sum this up, government aid has an academic value, since it contributes to deepening of knowledge, and an educational value through its indirect effects. In fact, in spite of the difference in the primary objective, government funds act in the same way as the financial flow coming from the SV on graduate education, as noted by Gibbons (1997). One concludes that government aid magnifies the chain process described in sub-section 4.3 by acting on the two main functions of the Stanford, research and training.

5.2 The federal government as a catalyst

One of the questions that remains is: is government aid indispensable to initiate the relationship between Stanford and Silicon Valley industry? One can assert here that, by helping Stanford to build reputation as a leading research university, federal government played a essential role to attract the interest of Silicon Valley industry at its early stage just after the WWII, in other words it acted as a catalyst of the relationship between Stanford and Silicon Valley industry. To argue this assertion, one can focus on the Stanford Research Institute (SRI), which was Stanford's first attempt of affiliate with industry at the institutional level.

In 1945, the idea of a “Technical Institute” was evoked by the then chairman of the Chemistry Department Robert Swain to reinforce the tie between Stanford and West Coast industry, and hence, “to place Stanford in a leadership position with respect to regional industrialization” (Lowen, 1990). The “Technical Institute” was also considered as a new source of income, which would allow Stanford to attract high level faculty members, and also to be adequately equipped to deal with new fields of research.

The SRI was founded in 1946. Though, at the early days, it failed to mobilize neither regional leading companies nor the academic researchers. On the one hand, the openness that characterized the SRI was difficult to sell to industry, on the other, academic researchers were reluctant to participate to the SRI because of the lack of scientifically attracting projects.

This failure can be explained as follows: Terman perceived that, by bringing together the university and industry through SRI activities, a chain process could be initiated that would calminate in Stanford’s becoming a “prominent institution” with a “significant influence on national life.” However, most of the companies, in their funding of research projects, sought to obtain directly applicable results that they could then monopolize. Stanford also had a difficulty in that there was not enough recognition of it as a leading research university at this period to convince these companies of the benefits they would receive in the long run if they participated in cooperative research projects within the SRI. Merely putting together Stanford and industry was not a sufficient to initiate a close relationship between them. Through lack of a long term vision on industry’s side and a lack of a solid reputation on the university side, the SRI had a painfully start.

Then the SRI turned to the federal government whose sponsored contracts represented to the SRI an opportunity for accumulating the basic knowledge in some industry’s areas of interest, thus allowing the SRI to send a signal to industry, especially to the defense related industry, that, henceforth, the SRI can be considered as a partner for basic work. In the context and background of the Cold War and the Korean War, the government sponsored contracts increased rapidly. By reinforcing its tie with federal government, the SRI built up its reputation and to attracted funding from industry. Through the SRI, Stanford deepened its ties with Silicon Valley industry in a chain process, once firmly started, created the momentum leading them ever closer. One can conclude that the federal government contributed to the initialization of the relationship between Stanford and Silicon Valley industry.

5.3 The paradigm changes

The last question is: was the government’s aid indispensable to maintaining the relationship between Stanford and Silicon Valley’s industry?

The tripartite relationship - the federal government, Stanford, and the Silicon Valley industry - evolved over time. Originally, the federal government played a role of catalyst of the relationship between in the way noted above, though once Stanford's reputation was established, a reversal of roles occurred: Stanford played the role of mediator between the federal government and defense related companies (Lowen, 1990). One can call this the first paradigm shift. The second paradigm shift, initiated by Gibbons, consisted, in a sense, of the return to the source in that, by setting the CIS, he attempted to move the trajectory of the research agenda away from military purposes to a long term commercial interest, something which coincides with the original vision of the SRI conceived by Swain. In this context, federal government now plays a role, which is complementary to the relationship between Stanford and Silicon Valley industry, and takes over those funds which industry cannot cover. One illustrates the first paradigm change by analyzing the Electronics Research Laboratory (ERL) and the second paradigm shift by reexamining the CIS.

Electronics Research Laboratory

Within the School of Engineering, government sponsored research was in the order of $ 200'000 per year in 1945 (Annual Reports to the President), two years later, it had more than doubled to become almost $ 2 million in 1952. Stanford consolidated its status as a major academic contractor for defense related research. As its experience and knowledge in the fields related to military purposes, especially in electronics, accumulated, the School of Engineering became attractive both to the government and to military related industry.

The Electronics Research Laboratory (ERL) was established in 1951 to conduct basic and applied research programs (Lowen, 1990). What distinguished the ERL, from other laboratories attached to the School of Engineering, lay in its preference for providing the expertise rather than becoming "simply the supplier of technical products to particular industries with military contracts." This policy allowed the ERL to have control over its research programs and the access to the research results, which ensured the independence of the laboratory and the dissemination of the knowledge "throughout the electronics industry."

Within the ERL, military funds was used to conduct the basic works in defense related electronics areas. The subsequent results or devices were transmitted, through consultation, to the electronics companies that were carrying out the defense contracts. In this process, the federal government was first to perceive the positive effect of the dissemination of knowledge. The expertise provided by the ERL facilitated the development of defense related technology within industry. On the other hand, the defense related electronics companies, which were seeking highly qualified engineers and technical expertise to fulfil the government contracts, found Stanford a perfect partner. The solid reputation founded around the military sponsored research allowed Stanford to act as an intermediary between the military and these companies, and by doing so, Stanford strengthened farther its reputation.

What is important to underline here is that these relationship were mutually beneficial, as planned by Terman. The second point is that, as a consequence of the paradigm shift, Stanford gained a "dominant position in the relationship," as noted by Rebecca Lowen (1997).

The federal government allowed Stanford to consolidate its tie with the Silicon Valley industry, directly, by permitting the dissemination of research results, and indirectly, through government's contracts with electronics companies located in Silicon Valley.

Center for Integrated Systems

The CIS is "a partnership between [its] industrial partner companies[43] and the School of Engineering" (CIS, 1996) as described in sub-section 4.3. The principle of the CIS is as follows. For its part in receiving financial support, the CIS provides the partner companies new ideas in their domain of interest, a "clear vision of the future" regarding a technological

[43] Most of them are located or have an research center in Silicon Valley.

trajectory, and a "early access to [CIS's] world-class engineering and computer science graduates as employees." Through its different programs, such as the Fellow/Mentor/Advisor Program,[44] the Partner Visitor Researcher Program,[45] or the Students-Partner Information Exchange Program,[46] to the partner companies, the CIS allows the graduate students to experience a real world of research, to become aware of the interests of the partner companies, and to be in contact with their potential employers. By this principle, the CIS reflects the first ideal of the SRI.

Based on bipartite cooperation - the School of Engineering and industry -, "there is not direct government support," though, according to Dutton (1997), the government intervenes in two manners: first, when a research project initially started with an industrial partner calminates in a result presenting a big potential for further applications or a perspective towards some new research agenda, support from federal government may be solicited; secondly and conversely, a government contract may be turned into a new research project which could then be supported by an industrial partner within the CIS. Thus, the government contributes to "either promoting or recycling some useful idea into a new project." Industry money covers approximately 1/15 of the annual research budget. The most important part of research activities within the CIS are conducted under the government's contracts that brought the faculty members individually. Thus the CIS receives indirectly the government support. To sum up, the CIS constitutes the "confluence of both government and industry at Stanford" (CIS, 1996).

Who benefits of this arrangement? Industry partners, by investing "less than it costs" (Dutton, 1997), gain the access to the information generated during the full time span of the research project, including the government supported period. The government's support is important, even necessarily, for Ph.D. students in that a research project funded by an industry partner lasts on average two or three years which only covers partially the preparation of the doctoral thesis. For the School of Engineering, the benefits are twofold: improvement of the capacity and the quality of the training of graduate students, and the consolidation of its reputation as a leading research institution. In other words, this arrangement forms a mutually beneficial relationship.

The "snowballing effect," that was mentioned in sub-section 4.2, is also present. Governmental aid helps the School of Engineering to be more attractive, towards its industry partners, and to be more efficient in its function of education, the result of which is a better closer tie to industry; and it is this good close relationship with industry which in turn allows Stanford to be "successful to get the government money" as noted by Dutton.

One can thus conclude that the federal government plays a complementary role in the relationship between the School of Engineering and industry partners of the CIS. The School of Engineering successfully exploits this opportunity: it reinforces its tie with industry and achieves its main goals, of providing high level education and of conducting leading research projects.

6. Conclusion

The history of Stanford University indicated that the transformation of Stanford from a "small respected regional university" (Lowen, 1990) to a leading research university occurred during

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[44] The industrial partner provides a "mentor" who will participate to the supervision of a Ph.D. candidate. The latter is chosen by a faculty member working in the domain of interest of the industrial partner.

[45] Industrial partner's scientists and engineers visit the CIS during several months. This program aims to promote "contact and collaboration among the visitors, faculty and students."

[46] Through this program, the students visit partner companies and present their work. It facilitates the information exchanges regarding the current works at the CIS but also the job opportunities.

the postwar period. During the same period, Silicon Valley consolidated its reputation as a center of high-tech industry despite the several waves of recession it went through. Regarding federal government's science policy, the research universities gained the status of a center of basic research after the WWII. In the context of the Korean War and the Cold War, federal government money flowed into the university to support research projects, in particular in the domain of the defense. Stanford was successful to attract the government funds. One thus wonders how Stanford, Silicon Valley's industry, and the federal government are related to each other, and if these relationships have some explanatory power towards the transformation of Stanford?

First, in focusing on the curriculum of the Department of Electrical Engineering (DEE) at Stanford University, the purpose has been to examine how the curriculum has evolved during the period of 1945 - 1996, and to see if this evolution reflects the fact that there is a close relationship between the DEE and Silicon Valley's computer related industry (SV).

The DEE proceeded to a constant renewal of its curriculum at all levels - undergraduate and graduate. Most of the time, when a technological breakthrough occurred in the SV, a new research field was added in the DEE and, though with a certain delay, new courses were proposed at the graduate level. In other word, the curriculum of the DEE reflects the evolution of the SV regarding a technological aspect.

Secondly, one has examined the nature of the relationship between Stanford and Silicon Valley. Stanford allows Silicon Valley to have access to the results of its research activities, high quality engineers, and continuing education; furthermore, the faculty members also provide their expertise formally or informally. Conversely, Silicon Valley represents for Stanford a source of funds and employment opportunities for its graduates. There is also a transfer of knowledge in the direction of Silicon Valley to Stanford.

What can be emphasize here is that these relationships are mutually linked directly or indirectly, thus one faces a network of relationships. The result being that a change at a connection affects the entire network; a phenomenon one has noted as a "chain process." One has observed that this chain process is self-enforcing through a feedback effect, though initially some impetus was needed to initiate this process: that impetus being the very policies of Professors Terman and Gibbons.

Finally one has inquired if, and how, federal government alters this relationship between Stanford and Silicon Valley. The historical outlook has allows one to identify three functions federal government fulfilled. First, by helping Stanford to build up its reputation as a leading research university, federal government contributed to attract the interest of defense related industry to Stanford. Secondly, government contracts with defense related companies gave an opportunity to Stanford to gain expertise, thus ensuring a leading position facing these companies - Stanford became the compelling partner of industry. Thirdly, government funds facilitates the transition of a privately funded research project from, or into, a more basic research project. By doing so, federal government becomes a complementary to industry together with Stanford. In either cases, these tripartite interactions result in a mutually beneficial relationship.

The School of Engineering considers itself as a educational institution above all. Its priority, to train qualify engineer, is perfectly in concordance with the demands of Silicon Valley. Of course the responsiveness of Stanford to the changing demand in engineer training is beneficial for the high-tech industry as a whole. But Silicon Valley, by its physical proximity, benefits from the educational service Stanford offers more than anywhere else. Several arrangements, such as visit or internship of students within Silicon Valley based companies, provide the occasion to create personal contacts directly between the student and the entrepreneur.

The School of Engineering has not only reacted to the changing environment, but has actively worked on it. By doing so, the School has created and consolidated its reputation as a leading engineering school of the United States.

One hopes that a better understanding of this particular relationship contributes an insights on the eventual possibility of a duplication of "Silicon Valley Model" in another regions or other countries.

7. Abbreviations

AEC	Atomic Energy Commission
CG	Courses primarily for Graduate students
CIS	Center for Integrated Systems
CUG	Courses primarily for Undergraduate students
CUG&G	Courses for Undergraduate or Graduate students
DEE	Department of Electrical Engineering at Stanford University
DoD	Department of the Defense
EC	Eliminated Courses
ERL	Electric Research Laboratory
GCA	Graduate Curricula Areas
HCP	Honors Cooperative Program
HP	Hewlett Packard
IAP	Industrial Affiliates Program
NC	New Courses
NDRC	National Defense Research Committee
NIH	National Institutes of Health
NSF	National Science Foundation
ONR	Office of Naval Research
OSRD	Office of Scientific Research and Development
R&D	Research and Development
RA	Research Areas
SIP	Stanford Industrial Park
SITN	Stanford Instructional Television Network
SRI	Stanford Research Institute
SV	Silicon Valley's computer related industry
TVI	Tutored Videotape Instruction Program
WWII	World War II

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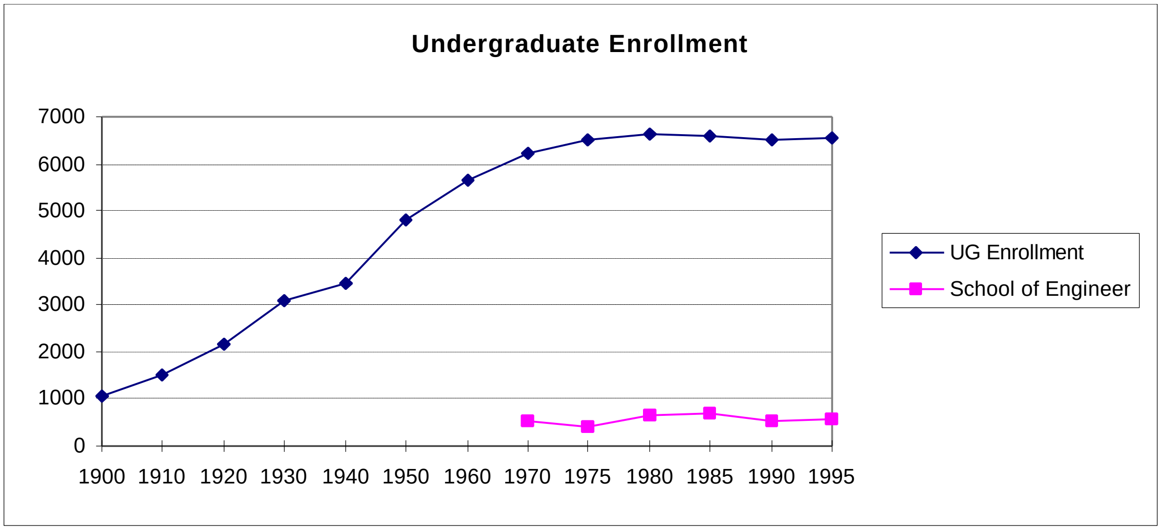
Appendices

Chart 2-1-1



Source: Stanford Facts

Chart 2-1-2

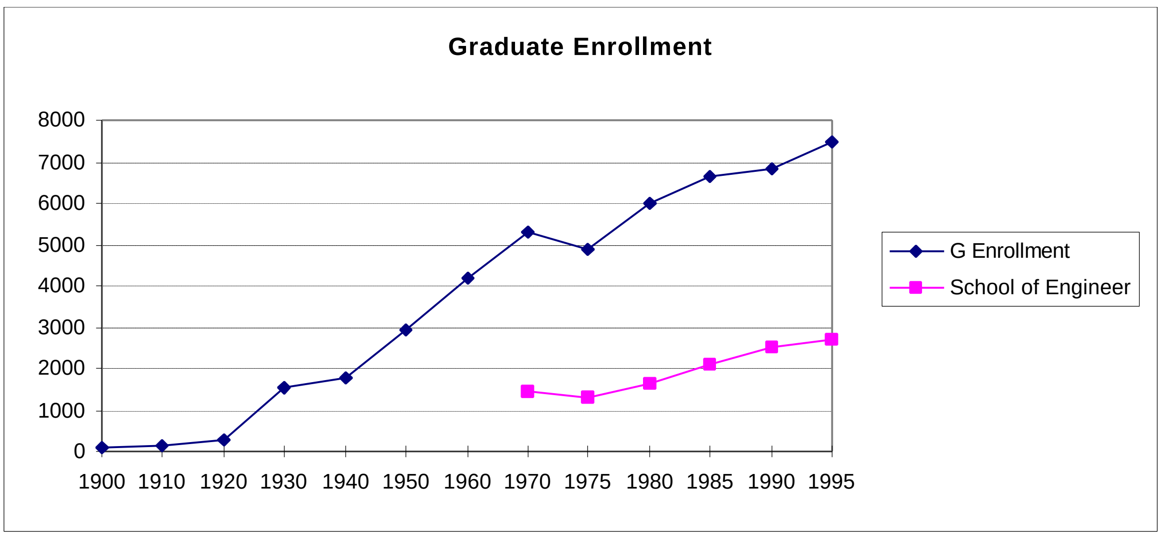


Chart 2-1-3