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## Science First

### Contributions of a University-Industry Toxic Substances Research and Teaching Program to Economic Development

In spite of ongoing concerns about how to protect the core mission of the University when it tries to meet the needs of industry (Campbell & Slaughter, 1999), most universities are expanding their programs that link university researchers and industry in a diverse set of relations aimed to address social and economic development goals (Cote & Cote, 1993, p. 71; Geiger, 1992). These programs do not link universities and industry for the first time (see for example, Etzkowitz, 1997; Osborne, 1990), but they aim to speed up the process of technology transfer and to remove barriers between knowledge production and its application (Rogers et al., 1999). Increasingly these linkages involve collaborative research programs in which industry funds all or part of university based research projects that are jointly selected with industry because of their high priority for particular firms. However, in some instances university resources are being asked to address a pressing public need for knowledge, workers, and technology in an emerging industrial field without established firms able to identify or fund collaborative projects, and in fields where the academic foundation for it is lacking as well.

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This article addresses the latter case, asking the question: Do university-based research programs without direct funding and collaboration from industry effectively transfer technology and increase economic development in emerging fields? Using the Toxic Substances Research and Teaching Program (TSRTP) at the University of California as a case study, this article will show how this program emphasizes scientific work on the problem of toxic substances but, nonetheless, has contributed to economic development and growth of the environmental technology industry. Two examples provide a context for our analysis.

Eric Gilbert, a doctoral student in the Environmental Toxicology Graduate Program at the University of California, Riverside, won the 1996 Collegiate Inventors award for discovering a chemical that works with bacteria to biodegrade the chemical PCB, a common toxic pollutant found in the soil of many contaminated sites. Gilbert worked in Professor David Crowley's lab with funding from the TSRTP, where they searched for a nontoxic chemical that could induce cometabolism of PCBs, since it is known that some bacteria can biodegrade PCB only in conjunction with another substance. Gilbert discovered that carvone, the aromatic chemical compound in spearmint, could be mixed with the bacteria to cometabolize the PCBs, making them nontoxic. This is an important discovery, since it could lead to low-cost field scale technology for remediating sites with PCB contamination. The discovery led to collaboration with EcoSoils Systems of San Diego, a company that manufactures bacteria fermentors able to be located near the polluted site and that operates irrigation systems to apply bacteria to soils. The research led to five academic publications and a patent for the process. Gilbert has since taken a professorship position, continuing this line of research, and the lab has received additional funding to continue research and applications using equipment provided by EcoSoils.

University of California, San Francisco, researcher Dr. Leslie Benet has received funding for his lab and graduate students through the TSRTP, where they have focused on the problem of orally administered drugs not being absorbed into the body. He discovered that the problem was not the commonly accepted explanation that the drugs were insoluble or unable to permeate cell membranes, but that the body treated them as toxic substances and either metabolized them in the intestines or pumped them back out of the cells by a transporter if they got that far. Through basic research, the lab team discovered both the enzyme that was neutralizing the drugs and an inhibitor of it that will permit absorption of beneficial drugs. Benet patented his discovery through the campus and later founded a company to produce and market it. The company has grown from 8 employees in 1996 to 11 employees in 2001, including several scientists who were students funded by the program. Clinical trials of the inhibitor are nearly completed now, and the company is expecting to expand rapidly as commercial production begins.

These two examples seem to be university research as usual, but in fact they are a result of an innovative research program of the 9-campus

University of California system. In the early 1980s California was faced with overwhelming pressures to manage toxic substances, which were causing air and water pollution, health hazards, disposal and cleanup crises, and untold legal and regulatory problems. Finding neither existing industrial capacity nor expertise capable of solving the problems within the state or elsewhere, the state turned to the University of California to establish a new program of research and teaching that would result in a cadre of trained students and a body of research that could be commercialized. As a field, research and teaching in toxic substances was minimal, and even the established faculty with interests in toxics were dispersed throughout many campuses, disciplines, and departments. California hoped that an early-stage university program would establish not only the intellectual basis but also the economic foundations for an environmental technology industry that would expand capacity in both the private sector and government regulatory agencies.

In the first example, finding a biological solution to removing PCB or related chemicals from contaminated soils is one of the most important environmental concerns of those working on toxic cleanup. The student's research, however, is an outcome of the incentive funding of the TS RTP, which provided funding for students and seed money for faculty to obtain additional research funding. As part of the TS RTP, the faculty and graduate students were able to work on the scientific problem of biodegrading toxic substances. Once the discovery was made, its conduit to commercial firms was speeded up because of linkages between the university and the growing environmental technology industry. The second example also benefitted from TS RTP funding of students and research, leading to an invention, patent, and eventually a new business that created new jobs. The basic research in toxics supported by the TS RTP provided a new perspective on a pharmaceutical problem that previously had not been considered a problem of toxics, but because of the network of collaborators in a multidisciplinary research program involving public health and epidemiology from several campuses, the toxics paradigm proved beneficial. In both examples, the links to industry were quick and beneficial, and both were facilitated by the catalytic role that the TS RTP had in bringing many other resources to focus on a toxics problem.

Although there are many models for university-industry technology programs (see Feller, 1988, pp. 236–237; Senker, Faulkner, & Velho, 1998; Walshok, 1995), we distinguish two contrasting models here—problem-based programs versus project-based programs, or what Etzkowitz (1997, p. 418) calls “science-push” aimed at solving a scientific problem, versus “firm-pull” organized around joint efforts to complete projects of interest to firms. Both these types of industry relations con-

trast with traditional disciplinary research centers or specialized institutes driven by fundamental basic research agendas (Stahler & Tash, 1994). The most well documented university-industry programs are firm-pull, in which firms and industry associations collaborate with a university research center to do a specific project of interest to the industrial partner, who also provides significant financial support for the project. Examples include the University of California's Micro program, New York's CAP (Feller & Anderson 1994), Ohio's Edison Centers (Mt. Auburn Associates 1992), Pennsylvania's Ben Franklin program (Etzkowitz, 1997, p. 418), or Ontario's Centres of Excellence (Bell, 1996).

In contrast, a science-push program identifies a generic problem faced by industry or the public and then mobilizes university scientists to do research on it and come up with a solution that can be rapidly commercialized. These program-oriented strategies are less visible and have not been as well documented as their more targeted alternatives. A science-push program is primarily shaped by strengthening university research programs (Feller, 1988, p. 236) to help solve a public or industrial problem and generate economic development. Typically, these programs are characterized by university dominance in the selection of topic, time frame, and financing, with immediate industry needs secondary. While faculty running a science-push program typically consult with industry leaders, industry usually is a passive participant rather than active leader in the process. Geiger (1992, pp. 276–279) notes that these generic research efforts can be commercialized through faculty consulting arrangements, memberships on science advisory boards for industries, personnel exchanges with industry, and other strategies. However, as Etzkowitz, Webster, and Healy (1998, pp. 5–6) point out, most science knowledge is transferred to industry by way of academic publication, and of course, by students being hired.

The purpose of this article is to report on how the University of California Toxic Substances Training and Research Program (TSRTP) used a science-push model of promoting industry through teaching and research, leading to considerable economic development. Since benefits from different programs are so hard to quantify (Feller, 1988) this is not a comparative study suggesting that science-push programs are better or worse than project-oriented university technology programs. The goal is simply to show that a science program addressing pressing public needs can have benefits similar to what has been accomplished by programs with direct industry involvement, contrary to the admonition in the literature best summarized by Osborn (1990, p. 57): "Put business in the driver's seat." Of course, such programs will succeed only in limited cases, which will be outlined at the end of the article.

*Impacts of University-Industry Technology Programs*

Although considerable research has shown that universities contribute general economic benefit from research and from students who graduate, much still needs to be learned about how that contribution works, especially the role that graduate students play in stimulating new industrial directions. One model for this research is Feller and Anderson's (1994) detailed cost-benefit evaluation of the New York State Centers for Advanced Technology Program (CAT), a project-based university-industry program. Their study is a valuable contribution to our understanding of the benefits of a broad multidisciplinary approach to science and technology programs with strong links to industry. By focusing on measurable benefits to firms networking with the CAT program, Feller and Anderson verify the positive impact of state programs that contribute to the research and graduate-education capacities of research universities linked to Fortune 500 companies. The authors demonstrate that public investments in university-based technology programs significantly leverage total economic impacts, concluding that:

estimated total state benefits related to increases in private-and public-sector research grants, technological innovation and increased productivity, increased or retained employment, and improved quality of the technological workforce ranged between \$190 million and \$360 million, or between three and six times New York's direct investment in the CAT program. (Feller & Anderson 1994, p. 127)

While Feller and Anderson show a significant economic benefit from the CAT program, their study also illustrates difficulties in applying cost-benefit principles to the evaluation of these programs, such as inadequate data and the need to use estimates for many benefits. For example, the economic benefit of training students who were part of the CAT program was estimated on the basis that students in the program would contribute to their new employer one year earlier than employees without the special training (Feller & Anderson 1994, p. 137), a value assumed to be \$50,000 per year. Also, they did not include information on the direct impact of other university activities, such as publication or creating stronger academic fields of benefit to industry or the public.

In spite of data problems, the analysis of CAT and related programs suggests that project-based science-pull programs are beneficial because they speed up the transfer of technology and expertise from university labs to firms in a promising field. The university knowledge base can serve as the intellectual capital supporting industrial growth, providing the foundation for applications and ongoing research, which provides an

expanding job market for students trained in the new field, and ultimately the commercial application of the research through new or improved products, processes, or regulatory procedures.

The science-push model works in a slightly different way. The program stimulates attention from faculty and students on a generic problem receiving public attention, creating a critical mass of research interest and expertise in a new field, which speeds the academic work applicable to industry. This also creates trained and skilled students who enter industry, bringing with them new technological skills being forged in university labs. Some students, such as Eric Gilbert, continue the research efforts by becoming academic researchers. Along the way the pressing public need for useful results is reinforced, leading to technology and products that can be commercialized in the new industry. The emphasis is not on developing technologies in the university labs that have direct conduits to particular firms, but developing a generic knowledge base supported by ongoing research and publications, which will be carried by students into their new workplace, or discovering things that can find quick acceptance by appropriate firms.

While there are many evaluative frameworks for assessing university-industry programs, our approach is not to attempt a formal cost-benefit evaluation that measures the scale of impact of the program relative to costs. We agree with Feller and Roessner (1995), who note that firms benefit in complex ways from university research partnerships and that the benefits from research programs are so “commingled with other related activities that it is not possible to isolate the contribution of specific events to larger outcomes or to attempt anything approximating a rate of return or cost/benefit analysis.” Instead, our approach is to trace how a problem-oriented university-industry program delivers economic benefits similar to those of the more common project-oriented program.

Based on analyses of a range of university-industry programs (e.g., Geiger, 1992; Matkin, 1990; Rogers, et al., 1999), various types of economic benefits can be expected from a university technology program. Etzkowitz (1997), for example, suggests a focus on technology transfer (knowledge), job creation, and firm incubation. Feller and Anderson (1994, p. 132) identify impacts in terms of external income from additional research grants and patent income, new products and companies, increased or retained employment, and higher quality workforce. Rogers et al. (1999, p. 703) emphasizes knowledge generation through publications, employment of former graduate students, spin-off businesses, and benefit to education (which is of less concern here). Reclassifying these interrelated factors, three major benefits can be expected from university-industry programs:

1. *Knowledge Benefits.* University technology programs are catalytic to the generation of knowledge within and outside the academic institution. The science-push program format gives emphasis to basic knowledge that becomes the basic building blocks supporting employment growth and firm creation. Basic research, as opposed to applied technology, does not always foresee products that can be sold by industry, and in many cases the firms potentially interested in the products are either small, unknown, or initially uninterested. One of the major objectives of a science-push program is simply to extend basic research as a scientific enterprise, with additional grant money and an expanding academic literature. In this way, knowledge, which is the most important of the university contributions to economic development, helps form new fields and subspecialties within the disciplinary structure of universities. In addition, a knowledge based program will assemble a critical mass of researchers to be competitive for grants and productive in publishing in an interdisciplinary field. Grant money and publications are measurable impacts.
2. *Employment and skill benefits.* A science-push university-industry program is much more likely than a project-based program to emphasize that its benefits are transmitted to industry via the knowledge carried by students who obtain employment or via spin-off firms that commercialize specific technologies. The key is that without the program students would not have the skills and credentials needed to fill available environmental technology jobs, but more importantly, without the knowledge base and its growing commercialization in existing firms and spin-offs there would be no employment demand either. Key employment benefits of a program such as this include the jobs created, the leadership assumed, and the organizational expansion derived from the special contributions that a trained person makes in an organization. The environmental technology industry is notoriously driven by governmental regulation, and in fact, the government works hand in hand with industry in shaping needed products as well as possible environmental solutions. While graduates of university programs are expected to find jobs, and they did not need the TS RTP to help them become employed, the benefit of the TS RTP is that it helped develop jobs in a particular industry or field that needed university research input.
3. *Technological applications and product innovation benefits.* Science-push programs do not measure their success only by the development of the new product or technology they set out to de-



velop, as would be expected with other university-industry programs. The university input is further away from the commercialization end of product development. However, when doing basic research the discovery of patent-worthy products and inventions can occur, as in the two examples leading this article. Technology transfer objectives include the development and deployment of new technology, new industrial processes, and new management approaches. Many of the important benefits from technology transfer occur when trainees work for industry after graduation. Since the toxics field is emerging, the industrial applications and industrial structure are neither clear nor well structured. The awareness of opportunities to put research to practical use allows graduates to generate products that start businesses and lead to a concentration of interrelated businesses.

The three benefits of university programs are themselves linked. The graduates find jobs based on their university training where they both generate knowledge based on external funding and help expand employment or create firms, which then leads them to develop new innovative products and patents. Other graduates develop a product, which then leads to the creation of a new firm or a new division of an existing firm, where more research is done and the product is marketed. Graduates also flow back and forth between industry, regulation, and academia, most often delaying work in the private sector while pursuing academic careers for a while.

#### *The Toxic Substances Research and Teaching Program*

The Toxic Substances Research and Teaching Program of the University of California is an excellent case study of the complex economic impacts of a problem-based university-industry technology program. The TSRTTP provides specialized funding to support training and research related to toxic substances for graduate and postdoctoral students (and a few selected undergraduates), at the nine University of California campuses and the affiliated National Laboratories (Livermore, Berkeley, and Los Alamos). This strategy was consistent with Tornquist and Kallsen's (1994, p. 536) finding that "an increase of resources to high-quality faculty located in established research departments is likely to produce the type of research industry is looking for." The program was established by the state legislature to help provide new research findings and scientific talent essential to solving the problems of toxic chemicals in the environment, problems that both were a barrier to economic growth and an

opportunity for economic growth. At the time the program was established, research and teaching on toxics was dispersed across many fields and campuses, lacking a consistent focus that would lead to either strong academic research or practical applications. Thus, the program was intended to serve as a focal point for communication about toxics among researchers, industry, the government, and the public.

The TS RTP as a problem-based program can be contrasted to New York's CAT program (Feller & Anderson, 1994). Although both are multicampus programs and have generated external linkages with high technology firms, they operate in quite different ways. Unlike the New York program, the California program supports existing labs and research programs rather than setting up new facilities and administrative units (except for a small office to disperse funding), requires that funds go to support students and postdoctoral research positions, does not require matching industry support for particular projects, and does not consider technology transfer a primary objective. Probably the most significant difference is that the TS RTP program is a teaching and research program in toxic substances, a multidisciplinary applied research field that lacked a solid footing (at least in California) before the program started. The model was to mobilize faculty to work on this new field, develop a body of research drawing upon expertise in multiple disciplines, and train graduate-level students to both staff new academic programs or to go to work in government regulatory agencies or private businesses. The program from the start has had strong linkages to industry, through advisory boards and explicit linking of academic and industry experts. Commercialization successes are reported in newsletters and at conferences. A total of eight industry leaders are on the TS RTP advisory committee, including representatives of Chiron, IBM, Amgen, and Tosco Oil. Representatives from up to ten large corporations and some smaller firms have attended statewide TS RTP conferences over the last several years.

In contrast, project-centered programs such as New York's CAT program let industry-driven technology transfer goals direct its research agenda, and they assume that teaching and training students will be accomplished as a matter of course. As well, the CAT program relies for partnerships on an existing industry that is aware of its research needs, not one that is newly forming. These two approaches represent different models, and the comparison of these different approaches is a critical policy issue for ongoing analysis, magnified by current concern over increasing industry funding of research.

Over the first ten years of the program (academic years 1985–1995), 661 students and postdoctoral researchers graduated after receiving TS RTP funding. This funding typically consisted of research funding or

fellowships for graduate students to work in collaboration with faculty members who were part of the program at one of the nine University of California (UC) campuses. Lead campuses for different components of the program were established: At Los Angeles (UCLA) the program brought faculty from Nuclear and Aerospace Engineering together with Civil and Chemical Engineering to focus on the process of risk assessment and standard setting; The Health Effects program brought together experts in molecular biology from UC San Francisco with epidemiologists from the School of Public Health at UC Berkeley; The fate of target species of birds and fish along with Ecotoxicology became the program focus at UC Davis; The Coastal and Marine Toxicology program was established in 1987 in response to a specific request from the state of California to study toxics issues in the bays, estuaries, and ocean coastal areas.

The essence of these problem-based programs was to mobilize multi-campus and multidisciplinary collaboration to solve challenging applied research problems. As soon as significant external funding and/or stable institutional resources were available to support a program focus, TS RTP resources were shifted to a new area. Internally, the program emphasis was on building interdisciplinary teams that could compete for large-scale external funding for research center support in addition to individual faculty research grants. These dual focuses of seed funding and team efforts leading to center funding helped use a small amount of state funding to attract larger amounts of external funding in areas that were of high priority to the state.

From 1985 to 1995 the TS RTP trained students and postdocs through approximately \$15 million in grants to over 150 faculty research sponsors. The program helped faculty develop interdisciplinary research groups that would continue funding students and postdocs beyond a nominal two-year limit on the use of TS RTP funds for any one individual. This investment by the state in funding toxic substances research has helped the faculty and campuses to win an additional \$270 million in funding from other sources. One example of leveraging research funds from other sources is the success of TS RTP-funded teams in winning three of the original five National Institute of Environmental Health Sciences (NIEHS) Superfund awards, resulting in more than \$30 million dollars in research funds being awarded to campuses of the University of California. It is not claimed that the seed funding generated faculty grants, because faculty get grants anyway. What is credited to TS RTP, however, is the leverage of faculty interest and organizational support into the toxics field, especially the capacity to obtain center funding.

*Research Approach*

In this report the economic impact of the TS RTP is evaluated through the graduate students and postdoctoral researchers who graduated from the program and generated benefits to the economy based on skills and technology developed through campus research. We attempted to survey all students who received TS RTP funding between 1985 and 1995.<sup>1</sup> The most daunting challenge (and time-consuming part of the project) was to find current addresses for students who had been funded by the program up to twelve years earlier. The addresses of some former trainees were available in TS RTP's records, but most of these records dated to the period of funding and were no longer current. Faculty advisors were a good source for some current addresses, but in many cases advisors had lost contact with their former students. Addresses of former trainees were also located by searching University of California alumni and departmental records, networking with former trainees from similar years, searching e-mail and internet lists, and carefully examining professional association membership lists.

Of the 754 students who constituted our initial study population, 93 potential respondents were eliminated from the survey because they were still students or because they actually received no direct funding from the TS RTP. The study universe was the remaining 661 students. Current e-mail or mail addresses were found for 378 student (57%). Trainees who had been undergraduate students were harder to find (33% located) than those who had been graduate students and postdoctoral researchers (64% located).

A survey was administered to all those trainees who were located. The survey instrument consisted of 27 questions. An interesting aspect of the survey design was the use of e-mail whenever possible. Two versions of the survey instrument were prepared—one for e-mail delivery and one for postal delivery. The text of the questionnaire was essentially identical in the two cases, except that the e-mail version had a cover note that included instructions about how to fill out the e-mail survey to allow for automated tallying using a script written in PERL.

In both cases, following the Dillman (1978) total design method, at least four attempts were made to obtain information from all former trainees for whom addresses were available. In the mail survey, the questionnaire was mailed, followed as necessary by a reminder postcard and then a second copy of the survey, with the final mailing sent by certified mail. In the case of e-mail surveys, the final was marked urgent. Many respondents reported that they appreciated the e-mail version, but we have no way of knowing how many nonrespondents failed to receive

the e-mail questionnaire because they no longer used the available e-mail address. Overall, the problem of poor addresses required additional phone calls and further efforts to locate students who moved using the techniques described above.

The response rates to both the e-mail version and the mail version of the questionnaire were essentially the same—63% for the e-mail questionnaires and 65% for the postal questionnaires. These rates represent an excellent response for those former trainees for whom adequate addresses could be located. Nonetheless, some bias remains from our inability to find addresses for all the graduates. Respondents for whom addresses are available are likely to be more professionally active and visible, maintaining contact with the university departments and having memberships in professional associations that maintain membership directories. They are also likely to be more involved with the toxics field as opposed to other professional directions.

These initial data were supplemented by two additional data collection efforts. During the summer of 2000 we again contacted the students for whom we had available e-mail addresses and asked them about their employment and economic development contributions. Through repeated requests, an 80% response was achieved to the follow-up survey. The project also surveyed 220 faculty at the multiple campuses of the University of California who had received support from the TS RTP, primarily by e-mail. We received 143 responses, for an overall response rate of 65%; another 10% were not reachable because of bad addresses due to death, retirement, or moving from UC with no forwarding address. The data from the supplemental surveys are utilized to support the overall findings and strengthen the empirical basis of the analysis.

### *The Economic Development Impact of the Program*

The TS RTP helped expand research, employment, and products in the toxics field at a level that shows the potential of a relatively small public investment to leverage many other resources to generate the core of an environmental technology industry. The program stimulated the emergence and growth of toxic substances research and teaching groups with the result that faculty get grants and publish research, students graduate and go to work in businesses and governmental regulatory agencies where they create environmental technology divisions, start toxics-related firms, help commercialize new technologies, and find economically viable solutions to toxic substance regulation. The program also helped to create a “social structure of innovation” (Feldman, 1994), and it addressed the primary barriers of economic development by

addressing what Walshok (1997, p. 23) claims is higher education's central problem—the "difficulty in communicating and collaborating across knowledge boundaries separating spheres of expertise and authority." Consistent with other programs such as CAT, the TSRTP had its goal to do what universities usually do, but in a "particular line of research and in collaboration with specific sets of partners." (Feller & Anderson, 1994, p. 133).

In the following sections we summarize the data on the economic impact of the TSRTP in each of the three ways the program benefitted the state's economy and the solution of toxic substance problems—by contributing new technological knowledge, by generating employment opportunities and new businesses, and by innovations that apply the technology to commercially viable products.

### *1. Benefits from Development of Multidisciplinary Technical Knowledge*

TSRTP has helped develop within California the technical expertise and knowledge needed for both the public and private sectors to address the long-term economic, environmental, and public health challenges posed by toxic substances. This basic science and technological expertise has provided direct and indirect economic stimulus through the technical and policy advances generated by TSRTP-funded research, the ongoing research of trainees funded by the program, and the application of the research to societal needs. The program, with its focus on research and training, started by increasing the basic knowledge directly related to toxic substances and more generally to the literature in the field.

A primary indicator of the central role of the program for recruiting students to the toxics field is responses to a question about how much impact the funding received from the TSRTP had on the subsequent development of their careers. As shown in Table 1, nearly two of three students replied that this program was a turning point or very significant in shaping their direction of work and research, giving them a focus on toxics that might not have otherwise been of interest. The students in the program were admitted to the University largely independent of funding from TSRTP, into departments where they would pursue a number of alternative specializations. The goal of the TSRTP program was to attract academic interest to topics related to toxics, and the data show that two thirds of the students responded to the incentive.

More interesting is the similar role that TSRTP funding had on the faculty. When asked the same question, about 60% of the faculty who responded to the faculty survey said that the funding from the TSRTP had a significant impact or was a turning point in directing their careers

toward toxics subjects. Moreover, the seed funding and lead campus components of the science-push model had a stronger impact on faculty associated with these programs. When looking only at the 41 faculty in a program that received multidisciplinary collaborative grants in the form of center funding, a whopping 85.4% of faculty reported that the TS RTP program was a turning point or had significant impact on their career. This shows that the concentration of resources into centers led to more intense focus on toxics. However, among the faculty not in centers, nearly half (50 of 102) still reported a turning point or significant impact from their TS RTP grants on their career.

The faculty credited the TS RTP with broad impact on changing their research and teaching. For example, 22% of faculty respondents said that "TS RTP funding shifted the primary focus of research from another field to toxics." Also, 67% said that TS RTP funding made toxics research a more important overall component of their laboratory's activities. Comments to the survey repeatedly included statements such as, "TS RTP funding moved us into a new field. It was an important source of student support that facilitated initial studies to garner external support." Another said, "TS RTP funding allowed me to develop new projects applying ecological ideas to problems involving pollutant impacts. It provided seed money and a setting that allowed me to learn about toxicology and environmental chemistry." Several others gave examples of how the TS RTP "encouraged me to pursue projects that I otherwise may not have." The survey results showed that the funding allowed 70% of the faculty respondents to increase their ability to recruit students to their program, and for 69% it created new sources of extramural funding. As a result of TS RTP funding 77% of faculty said that it allowed them to initiate a new research project. For example, one faculty replied that the TS RTP "allowed me and my research groups to undertake significant work that has been widely cited in municipal solid and hazardous waste management." Another said that their research "led to greatly increased visibility in the regulatory community and affected industries." Finally, TS RTP involvement helped 23% of faculty to develop a new course.

Our survey provides several measures that help assess the degree of technical expertise the program has helped foster. The strongest measure available from our survey of the economic impact of the TS RTP is the extent to which trainees have secured further research and development grants or contracts. Survey respondents reported gaining total grants and contract funding of \$100.4 million (Table 2). Half of all the former trainees reported receiving grants or contracts, with 43 respondents (19%) receiving over a half million dollars each. Twelve graduates

received more than \$2 million, and seven (3%) reported generating over \$3 million. Academics are more likely to have received grants and contracts than those currently in the private sector or government. Almost two-thirds of those currently in academia have secured grants and contracts, with nearly half of current academics reporting having received between \$100,000 and \$2 million. In contrast to the academics, only about one-third of the program graduates currently in either the private sector or government reported having received grants and contracts. However, trainees currently in the private sector reported great success in receiving large grants and contracts, with six of them receiving grants in excess of \$3 million. At the time of the follow-up survey during the summer of 2000, trainees we contacted had added another \$30 million in grants since the first survey.

Faculty at research universities are always in the business of obtaining grants, and participants in the TSRTP program are no exception. However, the faculty who obtained seed money from TSRTP accumulated a total of \$316 million in grants in the toxics field, grants that were related to the initial investment of seed money from the TSRTP. Moreover, the faculty competed for and won three national Collaborative Centers in toxics, bringing \$182.7 million to the state through competitive applications. In short, the relatively small amount of state funding for the program leveraged and focused a much greater dollar value of outside grants in toxics. Several faculty said that they used the TSRTP funding as nonfederal matches to qualify for programs that provided large grants. The key benefit claimed here is that the state funding led to new grants that would not have come to the state *in the toxics field*, though other grant money would likely have been won by the faculty. The focused state funding led to a rapid multiplication of funds in the emerging area with economic development implications, a concentration that would have emerged much slower or not at all without this targeted investment.

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TABLE 1  
Impact of the TSRTP on the Subsequent Development of Respondent's Career

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	Students Percent (number)	Faculty Percent (number)
Turning point	11.8 (29)	4.2 (6)
Significant impact	52.0 (128)	55.2 (79)
Limited impact	26.4 (65)	35.0 (50)
No impact	6.9 (17)	5.6 (8)
Total	(239)	(143)

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Research benefits economic development from publications that result from grants. The former trainees were asked to indicate how many articles they published in the open literature or in limited distribution technical reports. Over 76% of the respondents had published in the open literature, and 44% had published technical reports (Table 2). Overall, the respondents reported publishing a total of 3,674 articles, but this includes a variety of types of publications in addition to journal articles. As might be expected, those who are currently employed in academia have published in the open literature at a higher rate (83%, compared to 79% for those in government and 67% for those in the private sector). The academics averaged 11.4 articles each, compared to 6.1 articles for those in private businesses. In a similar fashion, those currently in government or the private sector are more likely to have published technical reports (62% in government, 49% in private industry, and 34% in academia). While this overall pattern is not surprising, it is worth noting that former trainees have contributed to the development of knowledge in the field through both types of publications in significant numbers, no matter what their current employment.

The total state economic impact from intellectual contributions is impossible to assign a dollar figure, because a scientific discovery or a publication may have only long-term value in combination with other discoveries. For example, Senker, Faulkner, and Velho (1998, p. 119) note that “company researchers obtain knowledge from academia mostly by a combination of reading the research literature and interacting with personal contacts, and occasionally by directly recruiting academic experts.”

Three examples of such research projects, currently at various stages of development, can illustrate the current and potential economic benefits of TSRTP-funded research. In 1985–1988, TSRTP funded a theoretical and bench scale study at UC Berkeley of the use of steam injection to recover solvents from contaminated soil and shallow aquifers. This methodology has matured to the stage of full-scale field demonstrations (in cooperation with Lawrence Livermore National Laboratory) and a start-up company to market this novel technology. More recently, a laboratory scale project at UCLA investigated the use of plasma technology to replace the need for solvents as cleaning agents in the semiconductor industry. This method is now being commercialized with the collaboration of two of the National Laboratories. The third project was an ambitious multidisciplinary effort to remediate a highly contaminated wetlands site at Mare Island Shipyard, a deactivated naval base on San Francisco Bay’s northern edge. This project included investigators from six of the nine UC campuses. It was highly successful and has served as

a model for other former military base clean-up actions in California (several of which are now being performed by former employees of Mare Island Shipyard who apply this technology and expertise as civilians trained by the UC research teams). In these three cases the expanded knowledge base led to a variety of economically beneficial outcomes that were not foreseen when the research was initiated.

## *2. Benefits from Employment in the New Toxics Field*

The TSRTP helped stimulate economic development by providing recognizable credentials for employment in various areas of expertise in toxicology and environmental engineering as these fields emerged in economic importance. For many TSRTP trainees, their participation in the program provided background, networks, references, and experience as an entrée into the rapidly changing environmental technology industry. For another group, this pathway has led to specialization in toxics issues in the growing biotechnology industry. In both fields, trainees have not only been able to contribute by their own work, but many have helped create additional jobs in these areas. Evaluation of the job creation activities and employment history of trainees provides a central measure of the program's economic impact.

Because of the extent to which government regulation has been central to the development of the industry, the environmental toxics field is an interesting example of an emerging industry that evolves in response to government agendas. While many technologically important industries have been dependent on government funding for their early development (e.g., aerospace and electronics being nurtured by defense funding), government regulation more than funding has played the key role in the creation and development of the toxics industry. For this reason, government agencies must be considered to be part of the overall toxics industry in addition to private sector firms and academic research. TSRTP itself was established as a result of the state government's recognition that toxic substances posed an important problem for the continued economic development and environmental integrity of the state. The program's origin reflected the realization that toxic substances posed a wide variety of complex problems that could not be solved by a few technical fixes, but instead required a strong base of professionals trained to understand and solve these problems.

As shown in Table 3, former TSRTP trainees currently work in academia (46%), private industry (36%), and the public sector (15%). The strong presence in academia is not surprising, since most of the trainees were in doctoral or postdoctoral programs, which are the primary train-

ing grounds for academic careers. However, even more impressive is the fact that about half of these students receiving academia's highest degrees did not follow an academic career but went to work in firms or governmental agencies needing their specialized training at the doctoral level. The presence of a significant block of former trainees in government positions is a reflection of the importance of the government agencies and regulatory programs in the development of the environmental technology industry.

An interesting pattern emerges when the respondents' current sector of employment is broken down by when the respondents were funded (Table 3). Those in the earliest cohort (last funded in 1989 or earlier) are more likely to be employed in the private sector than those funded most recently (last funded in 1994 or 1995). Part of the pattern is likely to result from changes in the environmental technology industry over time. The 1980s were a period of rapid expansion of this industry, especially for companies dealing with hazardous waste and materials. This expansion may have attracted many of the early trainees into the private sector. The early 1990s saw a consolidation of the environmental technology industry and a national recession, which may have kept trainees from that era from entering the private sector. We suspect that the small proportion of the most recent trainees who report themselves to be in the private sector may represent a slow transition for the trainees from their academic experience into private sector careers.

TABLE 2  
Contributions of Trainees to Knowledge in Toxic Substances

	All Grants and Contracts		Publications in Open Literature		Published Technical Reports	
	Recipients of grants or contracts (percent)	Total grants and contracts reported (\$million)	Number who published (% of respondents)	Number of articles (average # for all respondents)	Number who published (% of respondents)	Number of articles (average # for all respondents)
Total (n = 246)	51.6%	\$100.4	184 (76%)	2,258 (9.5)	106 (44%)	1,416 (5.9)
Current academics (n = 101)	62.7%	42.1	82 (83%)	1,160 (11.4)	35 (34%)	227 (2.2)
Current private sector (n = 81)	41.5%	42.9	53 (67%)	496 (6.1)	40 (49%)	845 (10.4)
Current government (n = 34)	35.3%	7.1	27 (79%)	200 (5.9)	21 (62%)	248 (7.3)
Other (n = 27)	51.8%	1.9				

\*18 respondents reported that they received grants and contracts, but did not report a total dollar amount. These respondents are included in the number of recipients, but no attempt was made to estimate the amount of grants and contracts they received.

The trainees moving out into the world of work are quite mobile from job to job. Many former trainees have worked in several sectors—academia, government, and the private sector. The 246 respondents report having worked in 1.6 sectors on average. Other data on the number of positions held indicates that respondents, who are still early in their careers, have held 2.3 positions on average. These data are probably typical of highly trained people working in cutting edge parts of the new economy.

Two-thirds of our former trainees (68%) have remained in California, with the remainder in other states (23%) or abroad (9%). Most of the economic impact reported in this survey is therefore likely to have remained in California, though this is declining over time. The international presence of former trainees suggests that the program has also had an impact in regions throughout the world. For example, one former trainee<sup>2</sup> reported that she started a nonprofit company conducting environmental assessments in the former Soviet Union, where she is helping improve public health and the environment. Some economic benefit from these students working in other countries may return to the United States and to California though the expansion of export markets for environmental goods and services.

Almost half of the former trainees reported that they helped to expand employment, create new divisions that employed people, or started a company (Table 4). Former trainees in academia and government also contributed to the expansion of employment. The rates at which respondents reported expanding employment and creating new divisions were very similar regardless of the respondent's current sector of employment. Information collected in the survey only allows a rough estimate of the number of jobs created. The trainees were asked to describe their job creation activities and they included the following.

- A vice president of an engineering consulting firm reported that the office he manages grew from 15 to 25 people over a two-year period.
- Another started an air quality services department for an existing environmental consulting firm, resulting in the hiring of 5 new environmental professionals.
- One former trainee now working at an internationally known research and consulting firm expanded its pharmaceuticals and metabolism program from three to ten individuals.
- Another former trainee reported being the fourth person hired at a new company in 1990; the company reached a peak of 17 employees based in large part on the R&D from the University program.

- A faculty member who had been a trainee reported starting a company that hired over 20 full time employees (many of them previous trainees).

Start-up businesses are a major economic impact. Nineteen respondents reported that their work had resulted in founding a startup company. At the time of the follow-up survey, an additional 4 businesses were started, for a total of 23 new businesses coming from TSRTP graduates. Since only 110 survey respondents reported having ever worked in the private sector, this means that more than one out of five former trainees who entered the private sector helped start a new business. However, only three faculty (2%) have been involved in start up businesses, though their students and research results have led to more start-ups. Faculty have more often worked as consultants to government and industry. Of the faculty respondents, 39% reported consulting *as a result of TSRTP funded research*. Of these, the largest number consulted for government agencies (32% of respondents), while 19% consulted for a private company (many of whom also consulted for a government agency). Former TSRTP trainees have not only found their own way into an emerging field, they have helped expand the network of businesses working in the emerging industry.

While we lack the exact number of new jobs that were created by TSRTP graduates, we can estimate that conservatively at least 200 jobs were the result of efforts by previous trainees. Of course, job expansions in businesses are only remotely linked to academic training, and we do not claim that the academic program alone led to employment expansion. What we do claim is that job growth is an indication of how trained students become leaders in their companies leading to job expansion in the toxics field, which is what the state wanted to have happen when it

TABLE 3  
Current Employment Sectors of Former Trainees by Year Last Funded

	Percent of Respondents (Number) Currently in Sector			Total
	Last funded 1987 to 1989	Last funded 1990 to 1993	Last funded 1994 to 1995	
Academic	33% (29)	47% (42)	70% (28)	46% (102)
Private Sector	47% (41)	37% (33)	13% (5)	36% (81)
Government	16% (14)	14% (13)	15% (6)	15% (34)
Other Sectors*	5% (4)	2% (2)	3% (1)	3% (7)

\* Other sectors include non-profit organizations, research laboratories, and foreign sectors.

initiated the TSRTP. Programs such as TSRTP pay off for the state because regardless of the sector in which students found employment, about half of them said that they were in positions where they contributed to job expansion. Although many who contributed to job expansion failed to describe the specific number of jobs they helped create, nine respondents who gave a count accounted for a total of 99 new jobs, or an average of 11 each. A total of 86 other individuals reported that their work resulted in expanded employment, but we could not determine how many; we assumed a total of one each to be conservative, leading to the conservative estimate that the trainees created a total of at least several hundred jobs in the toxics field. Interestingly, two years later the 115 follow-up respondents reported an additional 43 jobs created.

In sum, the academic program did what it is supposed to do, which is to train students who will become employed and become leaders in their field, resulting in expanding employment. Case studies and the limited quantitative data we collected confirm that in the toxics field this employment growth was a very positive side benefit of the program as it involved no additional effort or economic development incentive from the university.

### *3. Benefits from Technological Applications and Product Innovation*

Research and training programs also contribute to the economy through the development and dissemination of new technology leading to marketable products. While technology transfer was an indirect focus of TSRTP, research activities the program has funded have led to the development and deployment of new technology, new industrial processes, and new management approaches. Applications for patents and the development of new technology and processes are two ways to evaluate these impacts.

Product outcome from TSRTP trainee research has included several novel pollution prevention and cleanup approaches that have been commercialized and are being used by industry in California and elsewhere. For example, program graduates have made technological advances in air pollution and wastewater treatment, including innovative biological air pollution control technologies, the filtration and solidification of radio-nuclides from nuclear reactor cooling water, and the biological treatment of textile wastewater. While we cannot place a dollar value on these contributions, the linkage to the research done by TSRTP participants is well established. Moreover, the long-term benefit is certain to increase, because the program's graduates are still early in their careers—those most advanced in their careers were postdoctoral re-

searchers in 1985–86, and the typical former trainee is roughly five years out of graduate school.

Thirty-four former trainees reported having applied for 106 patents, with the survey respondents reporting that 42 patents have been awarded. Patents are a very important measure of the technological innovation process, and the fact that the graduates of the TS RTP who responded to the questionnaire applied for over 100 patents is indicative of a program with significant future potential. At the time of the follow-up, an additional 14 applications had been made, and several more patents had been received by the trainee cohort. The faculty responding to the survey obtained another 7 patents.

The trainees were also asked whether they had either expanded or improved an existing technology or created a new product or service. These data are reported in Table 5. Almost half of the respondents (considering overlap) reported having improved or created a new technology. Respondents described advances in a wide range of areas, including:

- contaminated site assessment and cleanup, including the development and commercialization of new test kits for environmental contaminants, and the use of microalgae for reducing selenium toxicity in the ecosystem;
- basic genetic research that may lead to bio-engineered bacteria for toxic metal remediation, processes for assessing individual susceptibility to environmental contaminant exposures, and new technologies for cleanup of contaminated groundwater;
- industrial process improvements, including bio-conversion processes for the production of fine chemicals, improved computer-aided chemical process control technology, and increased process efficiency and throughput for advanced ceramics manufacturing;

TABLE 4  
Expansion of Employment by Former Trainees

	Percent of Former Trainees Whose Work Resulted in:			
	Expanded Employment	New Division or Department	Startup Company	None of These
Total ( <i>n</i> = 246)	38.5%	18.4%	7.8%	52.7%
Private sector ( <i>n</i> = 81)	43.2%	17.3%	11.1%	49.4%
Academia ( <i>n</i> = 99)	38.0%	15.8%	4.0%	55.4%
Government ( <i>n</i> = 32)	38.2%	23.5%	0%	52.96%
Other ( <i>n</i> = 29)	27.6%	24.1%	20.7%	51.7%

NOTE: Totals do not add to 100% due to multiple responses.

- medical advances, including the development of new drugs and drug-development compounds (including at least one that has received FDA approval) technology to evaluate the clinical treatment of metal poisoning, and development of public health intervention plans in Chicago and elsewhere; and
- high technology advances, including improvements in the reliability of computer hard disks, improvements in materials and processes in the aerospace industry, and the development of organic photoreceptors for copy machines.

These examples illustrate the new technologies and processes that emerged from the program and how it can create large impacts on the regional economy, because emerging technologies are essential for the long-term competitiveness of the state's industry. Table 5 further illustrates the range of technological contributions due to the work of the former trainees. Improved technologies are the most common contribution, as indicated by about 42% of the respondents, but it is significant that an astonishing 19% of the respondents contributed a new product. The data show that just under a quarter of the TS RTP graduates in the private sector created a new product, while less than half this proportion in academia or government did so.

Many former trainees reported that they had helped develop new pollution prevention processes (41.5% of respondents). Within this category the respondents were split between those reporting the development of end-of-the-pipe mitigation processes and pollution prevention processes. Toxic cleanup technologies or processes were developed by 32 respondents (13%).

If innovation in improved technology is the goal of university contributions to an emerging industrial field, these data suggest that program graduates are substantial contributors regardless of the sector in which they work.

TABLE 5  
Technological Contributions by Former Trainees

	Percent of Former Trainees Whose Work Resulted in:			
	Improved Technology	New Product	Pollution Prevention or Mitigation Processes	Toxic Clean-up
Total ( <i>n</i> = 246)	41.6%	18.8%	41.5%	13.2%
Private sector ( <i>n</i> = 81)	45.1%	24.4%	35.4%	13.0%
Academia ( <i>n</i> = 99)	40.6%	13.9%	36.3%	16.0%
Government ( <i>n</i> = 33)	29.4%	11.8%	64.7%	5.9%
Other ( <i>n</i> = 28)	50.0%	28.6%	50.0%	14.3%

NOTE: Totals do not add to 100% due to multiple responses.



*Superstars and economic development*

One of the surprising findings of this research was the fact that a disproportionate amount of the economic development impact came from a relatively few persons outweighing modest contributions from many more average performances. We looked carefully at these results and tried to see if this was an error or not. While we could not verify every person's response to the survey, we conducted telephone interviews with selected individuals with the highest achievements to obtain additional details beyond this survey. We are convinced that it reflects the fact that the high achievers are superstars, and they are a legitimate product of the process of graduate education and university research. On further reflection, economic development programs have many instances of highly skewed impact from a relatively few high performers. For example, research on small businesses acknowledges the special role of the "gazelles," which are special fast-growth firms largely responsible for the overwhelming contribution of small businesses to overall employment growth in the US (Birch, 1987). In fact, this is also consistent with a "venture capital" model, based on the fact that in a typical venture capital effort a relatively small number of big winners provide most of the income for the firm to offset nonproductive investments.

In the superstar model, university-industry technology transfer efforts nurture many projects with a wide range of technological inputs, but it remains for a few highly successful ventures to return most of the benefits. Similarly, a few individuals going into academic careers will become most productive, generating a disproportionate amount of the research grants, publications, and discoveries.

Careful examination of the survey data reveals the extent of the superstar's role. Four respondents reported both more than 100 publications and more than \$2 million in grants and contracts. These four, representing less than 2% of the respondents, were responsible for almost one-fifth of the publications and almost one-quarter of the grant and contract money reported, consistent with a "superstar" model.

Across the three different types of benefits from the TSRTP, superstars play a significant role in more than one sector. Using selected indicators, we identified the stars in seven different areas: receiving over \$2 million in grant money, supervising more than 10 employees, writing more than 50 professional articles, writing more than 60 technical reports, applying for a patent, or creating a startup business. These indicators overlap so that a total of 85 instances are noted for high achievement by only 59 persons. In short, the 59 superstars we identified are

often high in more than one area and make a broad contribution not only to academic achievement but to the regional economy.

*Conclusion: University Basic Research and Graduate Training Has a Positive Economic Development Impact*

Our findings, following the logic outlined by Etzkowitz (1997), suggest that university programs designed to strengthen the university's traditional basic research and education role in strategic areas may be a very productive tool for technology transfer with huge economic development benefits. Science-push economic development that links universities, government, and industry is at the core of both regional revival and the emergence of new industrial policies, even without "industry in the driver's seat." The policies that support knowledge-based economic development, according to Etzkowitz (1997, pp. 421–422), go beyond the question of the immediate number of jobs generated to link new technology to the state's existing or potential industries. The TS RTP shows how this link can be forged. Students in graduate and postdoctoral programs carry the best technology of the university into industry, generating knowledge, expanding employment opportunities, and developing products. Some stay in university positions to discover more knowledge and to train the next generation of students, while others go into government, which sets the regulatory environment in which firms and scientists operate and from which governmental funding originates.

The total benefit, thus, is that the graduates of the university doctoral programs take technology and grant-getting skills into universities, industry, and government where they can build the collaborative institutional network essential for knowledge-based regional economic development (See Kenney & von Berg, 1999). Stimulated by the initial investment by the state of about \$15 million of state money, graduates have garnered \$130 million in grants, and the faculty received a reported \$316 million more. An identified 200 jobs were created by the graduates, along with at least 25 spin-off companies. If jobs create a \$50,000 benefit each, following Feller and Anderson, the economic development of just these measured outcomes of the TS RTP is around \$450 million, or 30 times the state's investment. In addition, patents and invented processes will result in productivity gains that benefit firms for years to come. We do not claim, however, that the investment increasing 30 times is all due to the TS RTP. These results came from the fact that the TS RTP leveraged a lot of other public and private resources. However, given the extent to which the TS RTP focused research and enabled faculty to train students in an emerging field, we do claim that without the TS RTP only

a fraction of the benefits would address the state's desire to expand its capacity in toxics.

As well, this research has extended Etzkowitz's concept of the role of the university for economic development to show how universities can assist in strengthening emerging industrial sectors. Fundamentally, the economic development role of the TSRTP is to help establish a viable environmental technology cluster in California, a geographically concentrated set of companies in the same industry that share infrastructure, suppliers, and distribution networks (Bradshaw, King, & Wahlstrom, 1999; Porter, 1998). The firms starting to make up the environmental technology cluster are in toxic substances monitoring, remediation, waste reduction, and reuse. The specialized linkages between the firms in this emerging industry are supported by university research and programs and are strongly influenced by government regulation, all of which are nurtured by research and especially by graduates of the TSRTP. While it is still too early to demonstrate that the emerging firms constitute a cluster, the range of these firms and their solid support provide what cluster analysts think of as the foundation for cluster development.

The benefits of a highly focused problem-based academic science-push academic program such as TSRTP are very attractive from a state policy perspective as an alternative or supplement to project-based programs. Research and teaching programs tap what universities do best—basic science and its applications. The focus on research and teaching helps faculty and administrators avoid the role conflict and goal ambiguity inherent in mobilizing university researchers to become entrepreneurial or to work within the time-frame, agenda, and financial incentives of businesses (See Campbell & Slaughter, 1999; Press & Washburn, 2000). Also, by contributing to university research through established departments and research programs, research and teaching programs to address public problems help establish a deep capacity linked to the basic research that is at the core of the university mission. Moreover, broader university-industry programs such as the TSRTP contribute multifaceted benefits to the state beyond industry or economic development goals, such as public health, environmental quality, safety, and quality of life. Solution of problems such as toxics requires more than just an academic discipline; it requires a network of researchers in many departments, disciplines, and campuses who have a long productive working relation with industry.

Finally, our claim is not that all university-industry programs should be science-push, and we do not think that all social problems can be solved by this model. Using the analytical framework suggested in this

article, we can hypothesize that science-push programs may have their greatest benefit when three conditions are right.

- First, science-push programs make sense when there is a core of university expertise that can achieve research benefits by becoming networked and focused around a pressing problem. Much of the technological and research framework was in place to develop multidisciplinary expertise in toxics before the TS RTP began, but it was not focused on the toxics issue. Graduate students were already in programs developing their skills in these fields. By stimulating faculty collaboration and by offering incentives to work on certain problems, the limited state money was able to build a field and obtain significant external funding for centers of expertise. More mature fields might not be expected to demonstrate these benefits. Also, given the pressing public concern about toxics, substantial funding became available.
- Second, due to increasing regulatory pressure there were strong employment opportunities for graduates of the program. They had multiple career paths open to them in industry, academia, as well as the regulatory agencies, and the graduates were readily able to utilize their expertise. Also, the industrial structure allowed both for employment in existing firms and for the creation of new units in larger firms, as well as forming spin-off businesses. However, the lack of established collaborators from industry who could fund project-based research seems not to have limited their need for skilled workers in the toxics field.
- Finally, the industry was ready for many small incremental inventions. The problem was not one of inventing a new automobile engine but of implementing thousands of creative ways to solve largely independent environmental problems. That there were so many opportunities for innovation was readily communicated to both faculty and students, and their awareness of these opportunities created a culture of innovation.

In conclusion, if we are right, these conditions shape the fate of science-push programs. This can not go on without limits, however. What is clear is that the economic development benefits of a science-push program such as the one studied here succeed because of their ability to mobilize and organize existing institutional resources and focus them on a problem that can leverage other resources. Faculty and students now in the Toxics program are not available to other science-push programs that might be proposed in fields where their expertise would be potentially

valuable. Students in major research universities have many competing opportunities, and faculty are finding it harder to recruit students for emerging fields, even if they have small amounts of funding. Nonetheless, academic interests are so fluid that opportunities emerge readily, and when the policy and economic context is right, science-push programs such as the TS RTP succeed.

### Notes

<sup>1</sup>Students funded after 1995 were not included in this study, which was conducted in early 1998. We assumed that most of these recent trainees are either still completing their education or are too early in their careers to have had significant impact on the economy or their field. For similar reasons, we also eliminated from the study trainees who reported that they were still in school even though their TS RTP funding ended.

<sup>2</sup>This student was an American citizen.

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