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The economic impact of engineering research centers: preliminary results of a pilot study

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Abstract This article describes the results of a pilot study that tested the feasibility of estimating quantitatively the regional and economic impacts of NSF-supported Engineering Research centers. For regional impacts, we combined estimates of the direct plus indirect and induced economic impacts of ERC expenditures generated from a regional input–output model with estimates of the additional impact on the state due to center-based start-up companies, licensing income from intellectual property produced by the center, the cost savings enjoyed by local firms that had hired center graduates, and advice and consulting to local firms by center faculty. For national economic impact, a suitably modified version of the regional approach was employed, supplemented by use of a consumer surplus model to estimate the net public benefits of newly commercialized technologies based in center research. As the project proceeded, it became clear that efforts to focus solely on economic impacts that could be quantified relatively easily would greatly underestimate the actual national economic impact of ERCs. The types of impacts included and the kinds of data collected from centers and their collaborating companies were therefore expanded in the later case studies. Results of the first three cases are described here; findings from the remaining two studies did not change our overall results or conclusions. The profile of regional and, especially, national economic impact estimates varied widely across the centers studied. Only some of these variations could be attributed to ERC characteristics; most were the result of variations in the amount and type of data that could be obtained from the centers involved and the companies they worked with. We concluded that even the most conscientious and costly data collection efforts would be unlikely to yield comparable data across centers because the accessibility of key data, especially proprietary data, will differ unpredictably from center to center. Further, focusing on narrowly-conceived, quantifiable economic data alone should be avoided in these kinds of impact studies. Doing so distorts the amount and characteristics of actual impacts, many of which—perhaps most of which—cannot feasibly be converted to monetary terms. Such a

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narrow focus will greatly underestimate the impact of ERC-like centers, masking the much broader and, based on our findings, larger and more significant impacts on society.

Keywords University research centers · Evaluation · Economic impact · Methodology

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1 Introduction and background

There is a long history of research on the economic impact of university research, ranging from more general studies of the overall impact on innovation, industry, and the economy (Mansfield 1991; Jaffe 1998) to more regionally-oriented studies linking university research (especially by state governments) to industrial innovation and/or regional economic growth (Audretsch and Feldman 1996; Jaffe et al. 1993; Zucker et al. 2007; Zucker and Darby 2005; Feller 1990; Adams et al. 2001). With some exceptions, few results of this research offer a guide to regional or state governments seeking more than a general rationale for public investment in a specific university-based research center such as a National Science Foundation (NSF) Engineering Research Center (ERC). The exceptions have typically focused on three broad expenditure categories: salaries, other institutional spending, and visitor expenditures (particularly for medical centers), although one rare approach (Feller and Anderson 1994) broadens the scope to include impacts on the quality of the workforce and increased employment. While some of these latter studies quantify the number of start-ups and intellectual property being generated by the research centers, few assign an economic impact to them. The majority of these studies use multipliers to estimate total economic impacts and ignore the value of human capital outputs.

The NSF's Engineering Research Centers (ERC) Program was initiated more than 20 years ago as a government-university-industry partnership with advancing U.S. industrial competitiveness as one of its primary objectives. Since then, as the question of U.S. competitiveness has assumed a less salient position among national economic issues, university-based research activities have become a focal point for regional economic development planning and public investment. As a consequence, the need to justify public expenditures for the support of university-based research centers exerts continuing pressure on federal program managers and state economic development agencies to document either overall program performance, individual center performance, or both. These pressures usually take the form of calls for evidence of economic impacts that can be measured in quantifiable terms. However, obstacles to measuring the economic impacts of university-based research centers, especially those with substantial education and technology transfer goals in addition to research, are formidable; see especially Feller (2004).

In an effort to estimate the regional impact of state investment in one university-based research center, in 2004 SRI International conducted a study of the regional (state) economic impact of the Microsystems Packaging Research Center (PRC) at the Georgia Institute of Technology, an NSF Engineering Research Center in its tenth year of NSF support (Roessner et al. 2004). The study, supported by the Georgia Research Alliance, was the first and only economic impact study of any single ERC; to date there has been no such study of the ERC Program as a whole. The results of the Georgia study suggested to NSF the potential value of conducting additional impact studies—not just of the regional economic impact of selected ERCs but of their national impact as well. Consequently, NSF requested that SRI apply an appropriately modified version of the approach used for the Georgia Tech study to cover the national and regional (i.e., state) economic impacts for five ERCs. This was intended as a pilot study to explore the feasibility of obtaining both regional and national economic impact estimates for ERCs, with the hope that the results of the study would demonstrate a method that could be used to document the Program's economic benefits to both states and the nation. Using evidence from the first three of five case studies, this article describes what can feasibly be obtained from such impact studies of individual centers, what the most significant barriers to data collection are, and what distortions are likely to result from efforts to emphasize the quantifiable economic impacts of ERC-like centers. The assessment was retrospective, i.e., it documented the *already realized* economic impacts of the ERCs' activities, rather than estimate the potential future economic impact of ERC activities and outputs to date (Table 1).

The primary objective of the pilot study was to determine the feasibility of quantifying national and state economic impacts of five specific ERCs at or near the end of their full award period, in this case 1994–95 to the present. By the end of 2007, three case studies had been completed[1]; the results to this point are described in this article. As of this writing (late 2008), two additional cases studies[2] have been completed, and the results of these two cases enrich and support rather than alter the findings and conclusions reported here.

2 Conceptual framework and methods

While analysts have worked for decades to better assess and understand the impacts of government research programs, projects, and activities, there are currently no standardized frameworks, methodologies, or even measures of impact (Tassey 2003). Indeed, government-funded R&D programs raise new issues in performance measurement and evaluation (Georghiou and Roessner 2000). This is especially true of programs such as the NSF ERC Program, which can be expected to have many different *types* of impacts because the centers conduct fundamental, long term R&D while simultaneously serving related educational and industrial service roles. As ERCs include characteristics of R&D programs (research), universities (education), and industry extension programs (infrastructure, start-up, and consulting services), it is useful to review briefly approaches to estimating the economic impact of these kinds of organizations and programs. These are summarized below.

2.1 University impact studies

University impact studies are normally undertaken by individual universities to quantify their economic impact on the communities in which they operate. Most of these use an expenditure-based impact framework that closely follows that developed by the American Council on Education (Caffrey and Isaacs 1971). Included are salary expenditures by the institution, non-salary purchases by the institution, spending by students, and spending by visitors. A smaller group of these studies also attempts to calculate the value of universities

[1] Caltech's Center for Neuromorphic Systems Engineering (CNSE), Virginia Tech's Center for Power Electronics Systems; University of Michigan's Center for Wireless Integrated MicroSystems (WIMS).

[2] The Center for Computer Integrated Surgical Systems and Technology at Johns Hopkins and the Georgia Tech/Emory Center for the Engineering of Living Tissue.

Table 1 Data needs and sources for ERC economic impact study

Data category	Specific data needed	Data source(s)
Quantifiable, already realized regional and national economic impacts	Licensing fees and royalties for IP attributable to ERC research, by payee location (partner state, other US, foreign)	SRI review of ERC annual reports with input from ERC records or staff for location information
	Financial support to ERC, including NSF program support, membership fees, sponsored research support, and value of in-kind support, all by location of source	SRI review of ERC annual reports, with input from ERC records or staff for location information
	Industry hires of ERC graduates by degree level (BS, MS, PhD) and by location of hiring firms. (The cost savings to the hiring firm were estimated to be approximately $100,000 per Ph.D., using the mentor's annual full compensation as the basis for this estimate. We extrapolated from this to estimate cost savings of $70,000 per ERC M.S. hire and $50,000 per B.S. hire. These estimates are supported by results of surveys conducted by the Semiconductor Research Corporation (SRC) and confirmed by SRI interviews with ERC company representatives	SRI review of ERC annual reports with input from ERC records or staff for location information
	Attendance figures by participant employment location (partner state, other US, foreign), and duration (number of days) for ERC industry workshops. (The value to industry of employee attendance at these workshops was estimated using the average loaded salary of typical attendees multiplied by the average number of days of attendance.)	ERC records and/or staff estimates
	Person-days of ERC staff pro bono consulting by location of client. (No center was able to provide estimates for this category of impacts.)	ERC staff estimates
	Identify 3–4 high-impact "nuggets" of potentially quantifiable economic impact on companies and related industries. Contact information for a person in each of the 3–4 companies who would be able to provide information on realized profits, unit sales, cost savings to customers	ERC staff suggestions; SRI interviews with company reps
	Employee-years for each ERC start-up. (Employment impact was estimated as the number of person-years of employment by start-ups multiplied by the loaded average salary of employees in the relevant industry.) Contact information for a person each of the 3–4 companies who would be able to provide information on venture capital attracted (if any); realized profits, unit sales, cost savings to customers (if any)	SRI review of ERC annual reports; ERC staff estimates and suggestions; SRI interviews with company representatives

Table 1 Data needs and sources for ERC economic impact study

Data category	Specific data needed	Data source(s)
	Contact information for a person in companies that relocate because of ERC existence who could provide information on employee-years created and extent of influence of ERC existence on decision to relocate. (Calculation of economic impact was the same as for start-ups.)	SRI review of ERC annual reports; ERC staff estimates; SRI interviews with company representatives
Non-quantifiable, already realized industry impact	Identify 3–4 companies known to have hired relatively large numbers of ERC graduates and/or to have adopted ERC concepts/ideas with major effects on the company. Contact information on people in each of the 3–4 companies who could provide examples of ERC ideas and student impacts on the company and on its customers, beyond specific profits and cost savings	ERC staff suggestions; SRI interviews with company representatives

in terms of improving a region's labor force and their role in fostering start-up companies; see, for example, Carr and Roessner (2002).

2.2 Research center/program impact studies

There are two broad categories of research center/program impact studies. One, like university impact studies, seeks to determine the specific local economic impact of having a research center in a given community. In other words, these studies estimate the economic impact of a center's *activities* (researcher salaries, equipment purchases, etc.), not the impact of the *outputs* of those activities (new knowledge, education, etc.). These studies tend to use an expenditure-based framework consisting of three broad expenditure categories: salaries, other institutional spending, and visitor expenditures (particularly for medical centers). While many of these studies do document the number of start-ups and intellectual property generated by the research centers, few assign an economic impact to them. A second set of research impact studies, often called net social benefits analyses, attempts to estimate the impact of research outputs (innovations, new knowledge, etc.) rather than inputs or activities. One approach used in these types of studies is to estimate producer and consumer surplus in order to measure the social and private returns to investments in innovation (Griliches 1958; Mansfield 1977). Another approach has been to construct a "counterfactual" model to determine the returns to public investments (Link and Scott 1998; Tassey 2003). Both methods rely on firm-level reporting of private investments and cost savings, detailed knowledge of the supply–demand conditions in each industry and, in the counterfactual approach, an estimate of what costs (benefits) would have been in absence of the publicly funded technology.

2.3 Industrial extension programs

Industrial extension programs, offering training, consulting, information sharing and other services, have been established to enhance the competitiveness of targeted firms (usually smaller firms) in order to increase overall economic competitiveness and raise standards of living. Impact assessments of these programs are most often based on micro, firm-level surveys that collect data on participating firm outcomes (profits, value-added, energy use, employment, etc.). These outcome measures for participating firms can then be compared with those of a control group of non-client firms.[3]

To assess the regional economic impact of investments in the selected ERCs, we employed the approach used in the study of the economic impact of Georgia Tech's PRC on the state of Georgia. This approach identifies the external (to the state) support that the ERC generated; the direct and indirect economic impact of spending by the center and its faculty, students, and visitors; cost savings and other benefits to center industrial collaborators; the income from university licensing of center technology; the value of center-generated local employment via start-ups; the value of center graduates hired by regional companies; and the value to regional companies (in terms of improved technical skills of workers) of the center's industry workshops. This approach combines fairly simple calculations with use of the Bureau of Economic Analysis' RIMS II input–output model to

[3] See Georghiou and Roessner (2000) for a brief review of these studies. Several extension program impact studies have been conducted since that time, generally following the same approach.

estimate the indirect and induced regional economic impact of ERC expenditures on the region (in most cases, the ERC's host state).[4]

At the regional level, ERC economic impacts are overwhelmingly a product of the expenditures made by the center attributable to income from outside the region that would not likely have occurred in the absence of the center. At the national level, it quickly became apparent that, in contrast to the regional impacts, the great bulk of national economic impacts of ERCs would be generated via spillovers from firms producing and selling new products based in ERC ideas and technology to markets that realize benefits (e.g., cost savings) from these innovations. Therefore, we drew upon the literature on social returns to innovation and the data requirements for using net social benefit models. The primary conceptual approach that guided our data collection and analysis for the national impacts was Edwin Mansfield's use of consumer surplus theory to estimate the total social benefits of industrial innovation. Basically, the consumer surplus approach defines the social benefits of innovation as the sum of the profits to the innovator and the benefits to consumers who purchase it (i.e., spillover benefits). In the simplest terms, total social benefits (returns to innovation) equal the sum of profits to the innovating firm plus the cost savings to users.[5]

Based on the extensive knowledge of ERC outputs and impacts that has been gained over nearly two decades of research and experience, we know that research-related center outputs (ideas, research results, models, proof-of-concept, prototypes, test results, algorithms) generally have not yet realized their full economic potential—they require substantial additional time and investment by industry. Like a portfolio of venture investments, the proportion of ERC outputs that have realized significant, measurable economic impacts even after 10 years is quite small, perhaps two or three per center. Thus, our estimate of national economic impacts takes advantage of the fact that the distribution of the value of outputs from programs that support risky ventures (e.g., research, entrepreneurship, venture investments) is highly skewed. Only a fraction of the unit outputs are highly valued, whatever measure of value is used, with the great majority of unit outputs generating a small proportion of the program's total impact. If the value of only the most successful outputs can be measured carefully and validated, the result would capture a large proportion of the value of the total output.[6] Thus, our plan for the pilot study assumed that a careful selection from each ERC of the 2–3 "nuggets" that indicate the highest (already realized) economic impact will permit us to capture the bulk of that ERC's measurable economic impact on industry to date. The practical implications for data collection were that, for each ERC, we sought to identify a small number of high-impact nuggets of technology transfer to industry and to collect data via interviews with the firms

[4] The limitations of RIMS II are well-known and need not be reviewed here. Despite its limitations, a more precise tool for indicating indirect and induced economic effects of new expenditures by organizations has not been developed, and the model remains widely used.

[5] See Mansfield (1996) for a discussion of how the consumer surplus model can be applied to assessment of innovation-related public programs such as the Advanced Technology Program, and Mansfield (1977) for the original paper illustrating the calculation of social and private returns to industrial innovation. We are aware of the limitations of this approach, as well as those of alternative approaches, but chose it because of its feasibility for this pilot study with its attendant resource and data access constraints. Notable among virtually all economic impact methods is their inability to estimate quantitatively the economic impacts of the research and education benefits of ERCs and similar university-based centers.

[6] Recently Scherer and Harhoff (2000) studied the size distribution of financial returns from eight sets of data on inventions and innovations attributable to private sector firms and universities. They found that the distributions were all highly skewed, with the top 10% of sample members capturing from 48 to 93% of the total sample returns.

involved that could be used to estimate the private and social returns for these high-impact examples.

The table below provides details on how impact measures were operationalized and the necessary data collected and analyzed to generate the quantified economic impact estimates presented in the cases.[7]

3 Results

3.1 Caltech's Center for Neuromorphic Systems Engineering

For the Caltech case, we show detailed tables for regional and national impact to illustrate the sources of various categories of quantifiable economic impact. To avoid repetition of the categories, in the other two cases, CPES and WIMS, we report only the aggregate major categories of regional and national impact.

3.1.1 Regional economic impacts of the CNSE

As indicated in Table 2, below, the majority of CNSE's direct impacts on the state are from the external support that the center attracted from sources outside California. These direct impacts from external support account for 29% of the total quantifiable impacts; indirect and induced impacts derived through this external support comprise 40% of the total (direct and indirect) quantifiable impacts of the CNSE on California. Direct and indirect workforce and employment effects together comprise the remaining 31% of the center's economic impacts on California.

3.1.2 National economic impacts of the CNSE

The total quantifiable economic impacts of the CNSE's activities on the United States are the sum of direct impacts plus indirect and induced impacts. The CNSE has had a direct impact on the U.S. economy of $165,599,927, with secondary impacts of $7,568,698, for a total economic impact of $173,168,625 over 10 years. As implied, the vast majority of impacts on the United States are direct impacts—of which net cost savings to U.S. industry comprise 82% of the total quantifiable impact; indirect and induced impacts comprise less than one-half of one percent of the total quantifiable impacts. The very large (relative to the other ERCs studied) direct national impacts were the result of just two examples of industry cost savings attributable to CNSE ideas and technology. One involved a member company's (IRIS, Inc.) new product line that embodied CNSE ideas and resulted in substantial cost savings to purchasers, and the other involved a highly successful CNSE start-up, DigitalPersona, whose major product was incorporated in Microsoft software operating systems. The detailed breakdown of these impacts is shown in Table 3.

[7] Space limitations prevent us from providing all details of the calculations involved. These and other details, such as the size, technical foci, and industry affiliations of the ERCs studied, are provided in our final report to the National Science Foundation, available upon request from the lead author of this article.

Table 2 Total quantifiable economic impacts of the CNSE on California

	Direct impacts	Indirect & induced impacts	Total
External income to California			
Support to CNSE from the National Science Foundation	$24,682,355	$34,695,986	$59,378,341
CNSE membership fees from non-California member firms	$157,500	$221,398	$378,898
In-kind support from non-California firms	$200,000	$119,860	$319,860
Spending by non-California attendees at CNSE workshops in California	$274,216	$348,966	$623,182
Value of increased employment in California			
Value of employment created by CNSE start-up companies located in California	$12,475,596	$7,476,625	$19,952,221
Improved quality of technical workforce in California			
Value of CNSE graduates hired by California firms	$6,430,000	n/a	$6,430,000
Value of workshops to participating California firms	$474,819	n/a	$474,819
Total quantifiable impact on California	$44,694,486	$42,862,835	$87,557,321

Table 3 Total quantifiable economic impacts of the CNSE on the United States

	Direct impacts	Indirect & induced impacts	Total
External income to the United States			
CNSE membership fees from non-US member firms	$65,500	$92,073	$157,573
Value of increased employment in the United States			
Value of employment created by CNSE start-up companies	$12,475,596	$7,476,625	$19,952,221
Improved quality of technical workforce in the United States			
Value of CNSE graduates hired by US firms	$6,430,000	n/a	$6,430,000
Value of workshops to participating firms	$918,831	n/a	$918,831
Net cost savings and profits in the United States			
Net cost savings to industry	$145,710,000	n/a	$145,710,000
Net profits	n/a	n/a	n/a
Total quantifiable impact on the United States	$165,599,927	$7,568,698	$173,168,625

3.1.3 Other impacts of the CNSE

Previous studies for the NSF of the impact on industry of member participation in ERCs and in other university-based industrial consortia indicate that the less tangible, longer-term, and difficult-to-quantify benefits of membership are substantial, usually far exceeding the costs of membership. The site visit to CNSE, as well as our initial communications with management of several other ERC staff, confirmed that it is important in impact studies such as this to describe the magnitude and variety of non-quantifiable impacts of centers. Examples of non-quantifiable impacts include effects of centers on firm competitiveness at both the firm and national economic levels, as well as a wide range of specific benefits that have positive but difficult-to-quantify economic implications for firms, including access to new ideas and know-how, access to facilities, improved information for suppliers and customers, and information that influences the firm's R&D agenda.

In the case of CNSE, several of these types of non-quantifiable impacts were identified by member firms, CNSE startups, and center staff. With regard to the hiring of CNSE graduates, a significant but difficult to quantify impact may be the reduction in time from concept to commercialization in the company's products, due to the advanced knowledge and R&D techniques derived from center research and experience. CNSE staff likewise commented on the importance of human capacity building efforts at the center, noting that over one-third of the Ph.D. graduates from CNSE went onto become faculty members at other universities, thereby extending the center's multidisciplinary approach in this new field to additional students and in different academic environments. More broadly, CNSE staff emphasized that, with NSF support, the center has succeeded in establishing an entirely new field—neuromorphic systems engineering—that has implications and applications for many industries and products. In this sense, CNSE's R&D supports the overall competitiveness and leadership of California and the United States in the science and technology arena and, in particular, in this emerging field.

3.1.4 Conclusions and observations

The process of documenting and analyzing the CNSE's quantifiable impacts at the state and national levels led to two key conclusions and observations. First, the investment of NSF funding in the CNSE yielded substantial returns at both the state and national levels, especially when one considers these returns in light of the conservative assumptions that we used to measure realized impacts and, uniquely in this case, the lack of data for some types of direct impact (e.g., industry sponsored research). Second, CNSE, despite operating as an ERC for nearly a full 11 years, focuses on upstream or transformational ideas and technologies, and so a long time horizon might be expected before widespread applications of its R&D and other tangible indications of economic impact occur. Given this focus, it is somewhat surprising that, at the national level, SRI was able to document nearly $146 million in cost savings to industry from the application of just two CNSE-derived ideas. The sizeable economic impact of these "nuggets" provides a suggestion of the potential scale of the still incompletely realized and unknown impacts that may be generated by additional CNSE outputs as well as outputs from other ERCs conducting transformational research.

3.2 Virginia Tech's Center for Power Electronics Systems (CPES)

The CPES case was the first fully realized example of the revised design for this pilot study. Beyond implementation of the consumer surplus approach to national economic impacts, the additional change in the design was to broaden considerably the range of impacts to be examined to include those that have obvious economic value to industry and academia, but cannot easily be quantified or expressed in monetary terms. The implications of this change for data collection and analysis were to focus more extensively on documenting the broader impacts on industry (where economic value of ERCs is more directly realized than, say, in academia) of ERC *ideas, technology, and graduates*. This entailed efforts to obtain examples from the next two target ERCs (CPES and WIMS) of the most significant impacts on industry of center outputs, regardless of whether the impacts could be expressed in quantifiable economic terms. Thus, at CPES and WIMS, we asked center staff to identify for us companies that had hired significant numbers of center graduates, that had realized significant benefits from one or a small number of graduates, and/or that had (as in the CNSE case) benefited economically from center ideas and technology. We continued to ask firms whether they could estimate the cost savings to industry from ERC-based technology embodied in the firm's products.

3.2.1 Regional economic impact of CPES

Unlike the two other ERCs studied during this first phase of the pilot study, CPES has partner institutions in states other than Virginia. (CNSE had no partner institutions, and WIMS partners all were located in Michigan.) In principle, this greatly complicates calculation of the regional economic impact of CPES because, strictly speaking, each partner institution's economically relevant inputs and outputs and their impacts on each state should be treated separately. It was immediately obvious that this was not feasible given our project resources and the burden it would have placed on CPES staff, nor was it necessary for the primary purposes of this study. We asked CPES staff to break the data we required for our regional economic analysis into three locational categories: sources/impacts within the five partner states (VA, NY, WI, PR, NC), within the U.S., and foreign. This was not greatly burdensome for most of our support and impact categories, since CPES industry workshops were held at VT; visiting researchers came to VT; and the location of members of the CPES industrial consortium, the location of sources of sponsored research support for CPES, the location of companies that had hired CPES students, and the location of start-up companies all were known by CPES staff.

The total quantifiable economic impacts of CPES activities on the five partner states are the direct impacts plus indirect and induced impacts. CPES has had a direct impact on member states of $62,911,303, with secondary impacts of $57,942,247, for a total economic impact of $120,853,550 over 9 years. The majority of the direct impacts are from the support that CPES has received from external sources. These direct impacts from external support account for 48% of the total quantifiable impacts, and indirect and induced impacts derived through this external support comprise 48% of the total (direct and indirect) quantifiable impacts of CPES on partner states. Direct and indirect workforce and employment effects together comprise the remaining 4% of economic impacts on the region.

3.2.2 National economic impact of CPES

To date, CPES has had a direct impact on the U.S. economy of $19,284,391, with secondary impacts of $2,010,583, for a total economic impact of $21,294,974 over 9 years. As implied, the vast majority of impacts on the United States are direct impacts, in CPES's case almost all of which are comprised of employment and workforce effects. These workforce effects, which do not generate indirect or induced effects, account for more than 80% of CPES' total quantifiable national impact.

To quantify impact at the national level, we sought to estimate both profits and cost savings related to commercialized center technology. Obtaining data for either element of societal impact proved difficult for all three ERCs, and in the case of CPES it was especially difficult. Although our interviews with a number of companies that have been members of, and/or hired graduates of, CPES (including Intel, General Electric, International Rectifier, DRS Power and Control Technologies, and Monolithic Power Systems), our interviewees were unable to provide us with verifiable estimates of additional profits or the total cost savings to their company or to industry attributable to CPES technology. Nevertheless, our industry interviews did yield some impressive, general estimates of the economic impact that CPES research and technology has had on the power electronics industry; these are presented below.

3.2.3 Conclusions and observations

The context of an ERC's research activity—the stage of development of its technical focus, the dynamism of the industry or industries with which it is associated—greatly influence the profile of its output and the time frame of its directly realized impacts on education and industry. As a "incremental" ERC (that is, one relatively downstream in the innovation process with a specific target industry or market), one might expect CPES' outputs and impacts to reflect a strong technological focus and relatively "hard" examples of technology transfer evidenced via licenses to industry. Yet even in this context, casting a broader view of the center's impact on industry shows that ideas and students, not technology per se, are cited by industry as the areas in which both individual firms and the industry benefit most from the center's existence.

In its regional economic impacts, CPES follows a pattern shown by such disparate ERCs as Georgia Tech's Packaging Research Center and Caltech's CNSE—sizeable direct and indirect economic impacts, of the magnitude of hundreds of millions of dollars—deriving substantially from the Center's ability to attract large amounts of financial support from external sources, primarily federal funding agencies and industry. But the *quantifiable* national impact profiles of CNSE and CPES are strikingly different, in some perhaps unexpected ways. CNSE, a transformational center far upstream in the innovation process and potentially relevant to a wide range of industries, nonetheless shows substantial direct, quantifiable economic effects on the national level from just two examples of technology transfer to industry: one in the form of a highly successful start-up company that generated both considerable internal profits as well as cost savings to its customers, and the other in the form of a member company that incorporated CNSE research in a new product line that also resulted in substantial savings to its customers. CPES' *quantifiable* national impact is quite modest by comparison, but our interviews indicated that the actual impact of its central concept, modular integrated power systems for a variety of applications, almost certainly has amounted to multi-billion dollar benefits for the national economy.[8] It is equally clear that CPES students have had very substantial economic impacts on the companies they work for, especially companies that have hired more than just a few of them. Those impacts, again according to our interviews, are attributable to the unique training they received at CPES, notably involving systems thinking, multidisciplinary perspectives, and sensitivity to the industry context.

This is not to say that CPES outputs will not generate significant, quantifiable national economic impacts in the future. In the power electronics industry, the time from new ideas to new products is relatively long—10 to 20 years. For CPES, the path to these future impacts is not through licensed technology or center-based start-ups, but rather through informal center-industry interactions and, especially, through center graduates who bring new ideas and new ways of thinking to the companies that hire them. It seems highly likely that we are now seeing just the early manifestations of CPES' national economic impact, the bulk of which will be realized well after CPES ceases to receive NSF support.

[8] Telephone interview with Richard Zhang and Vlatko Vlatkovic, General Electric Global Research, 27 July 2007; telephone interview with Mike Briere, Vice President for R&D, International Rectifier, 27 July 2007.

3.3 University of Michigan's Center for Wireless Integrated Microsystems

3.3.1 Regional economic impact of WIMS

WIMS has had a direct impact on the Michigan economy of $155,205,327, with secondary impacts of $101,239,787, for a total economic impact of $256,445,115 over 7 years. The majority of the direct impacts are from the external support that WIMS has received from non-Michigan sources. These direct impacts from external support account for 50% of the total quantifiable impacts, and indirect and induced impacts derived through this external support comprise 36% of the total (direct and indirect) quantifiable impacts of WIMS on Michigan. Direct and indirect workforce and employment effects together comprise the remaining 14% of economic impacts on Michigan.

3.3.2 National economic impact of WIMS

To date, WIMS has had a direct impact on the U.S. economy of $37,439,559, with secondary impacts of $8,840,328, for a total economic impact of $46,279,887 over 7 years. The vast majority of impacts on the United States are direct impacts, of which employment and workforce effects comprise 78% of the total quantifiable impact. Indirect and induced impacts, on the other hand, account for less than one-fifth (19%) of the total quantifiable impacts.

3.3.3 Other impacts of WIMS

In interviews with SRI, WIMS member companies repeatedly emphasized the positive qualitative differences that WIMS students bring to their companies as new hires. From the perspectives of member companies, WIMS graduates possess not only outstanding research skills (which would be expected of all Ph.D. graduates) but also many attributes that differentiate WIMS graduates from other hires, such as:

- Teamwork skills;
- Experience resolving implementation issues;
- Focus on directing research toward a commercially-feasible product;
- Ability to contribute beyond the narrow range of expertise typically held by a new Ph.D. hire; and
- Understanding or awareness of both business and technical issues.

Several companies indicated that WIMS graduates had been and continue to be pivotal elements of the companies' success.

According to SRI's interviews, WIMS brings together companies that would not otherwise interact, and this convening role facilitates companies' identification of potential new customers, suppliers, partnerships, and investors. WIMS' role in helping to forge linkages between small and large companies was described as particularly significant. The mixture of researchers, industry, financiers (especially venture capitalists), faculty members, and students that characterizes WIMS events also was mentioned as providing fertile ground for idea sharing, identifying new technologies, and learning from peers. Likewise, investment partnerships, both actual and potential, are perceived as a benefit of the WIMS network.

3.3.4 Conclusions and observations

Three central observations emerge from this case study of WIMS' regional and national economic impacts. First, it is clear that public investment in WIMS has resulted in significant economic impact on the state of Michigan. The impact of NSF funding at the national level is, to date, less dramatic than the regional impact. However, the question of what represents a realistic timeframe for observing measurable national impacts from the leading edge research conducted at ERCs is again raised through the WIMS case. In its seventh year as an ERC, WIMS has generated seven startups, which in turn have operated for as many as 7 years and as few as 1 year. Despite the startups' relatively short periods of existence, one company—Discera—has already introduced to the market a product (based on center technology) that has resulted in industry cost savings of $286,000 and has the potential to save industry millions of dollars. In light of this example of emerging impact from ERC inventions, the potential for significant future effects appears great.

Another observation related to WIMS concerns the importance of qualitative as well as quantitative impacts. The qualitative effects that WIMS' industry partners report receiving from interaction with WIMS are, in the view of the company representatives, as important as quantitative results. Though the precise value is not amenable to estimation, companies place great emphasis on the access WIMS provides to students; new ideas and technologies; sophisticated facilities; and networks of faculty, peers, potential customers, suppliers and investors. Accordingly, although adequate measures of qualitative effects are not currently available, such effects should not be ignored or excluded from overall assessments of ERC impact.

4 Summary and discussion

4.1 Quantifiable regional and national economic impacts of ERCs

Reading across the results of our efforts to identify and quantify the regional and national economic impacts of three ERCs shows how strikingly different the impacts are if a narrowly conceived notion of economic impacts is used—and the data collection limitations associated with that conception are kept in mind. Moreover, the estimated quantifiable impacts do not vary in ways that are readily explained by the obvious characteristics of the ERCs involved such as size, technical field, level of industrial support, dynamism of associated industries, or incremental or pre-incremental stage of technological focus. Digging below the surface of the data we collected, it becomes clear that only some of the differences can be explained by the characteristics of these ERCs. Rather, most differences in measurable economic impact are primarily the result of the vagaries of the data that could be obtained from the centers involved and the companies they work with, not the result of the center's characteristics or the degree to which they have achieved their intended goals.[9]

[9] Obviously we made no effort in this study to assess the performance or productivity of ERCs with respect to either their own specific objectives or NSF's mandated program goals. Nonperforming ERCs are quickly identified at an early stage in their history and either terminated or reorganized so that, by the end of their period of NSF support, it can be assumed that all ERCs are performing at a high level and achieving their basic research, education, and knowledge transfer goals.

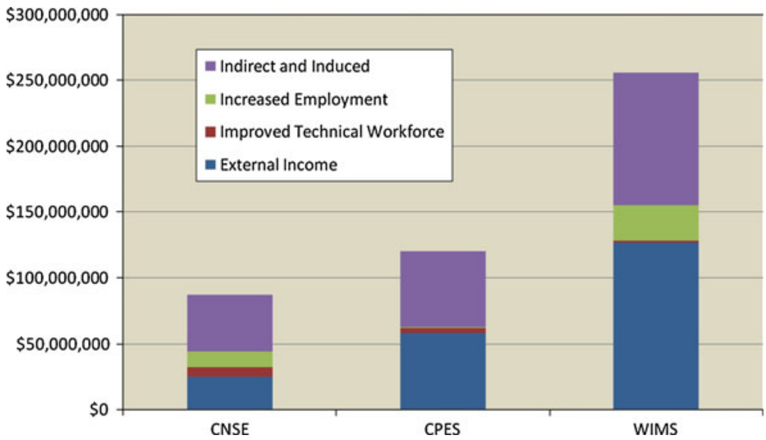

Fig. 1 Total amount and composition of quantifiable regional economic impact for three ERCs

Figures 1 and 2 summarize the quantifiable data generated in the three pilot cases. Let us begin with a discussion of the regional impact data, Fig. 1. Quantifiable regional impacts vary widely, from about $90 million to just over $250 million. Almost all of this variation is attributable to differing amounts of external income to the centers and the indirect and induced effects of that income. External income itself varies from about $25 million to $125 million across the three ERCs, so ignoring the indirect and induced effects makes the disparities a bit less drastic. In the case of CNSE, the considerable income to the center from sponsored research, which typically amounts to at least as much as the amount of NSF Program support, could not be included because CalTech's accounting system does not distinguish ERC-related sponsored research projects from projects attracted by other units of the Institute. In addition, although CNSE emphasizes start-ups as the most effective way of transferring knowledge and technology, and has been quite successful in this, data on the amount of venture capital generated by the center's nine start-ups—which was obtained for WIMS' eight start-ups and was sizeable ($42 M)—was not available. To complicate comparison further, even if venture capital figures for CNSE had been available, they would probably not have "counted" in the calculations of regional impact because presumably most of the funding would have been invested by California venture capital firms, and thus would not represent external funding entering the state. Note, too, that only WIMS and CNSE have spawned start-ups with significant employment impacts on the region. CPES presumably has not had the opportunity to do this given the mature industry that it serves.

Figure 2, below, shows the total quantifiable national economic impact of the three ERCs and the composition of the impact for each center. Disparities in both total impact and composition are much greater than was the case for regional impacts. Because two companies associated with CalTech, one a start-up and one a center industrial member, were willing and able to share estimates of the profits and cost savings to their customers for products attributable to CNSE technology, the total national impact of CNSE dwarfs that of the other two ERCs studied. But as we know from the interview data, this probably underestimates the economic impact of CNSE on industry. Further, there is a very strong possibility that the other ERCs studied had this much or more national economic impact, which could not be estimated reliably using the consumer surplus approach to measuring

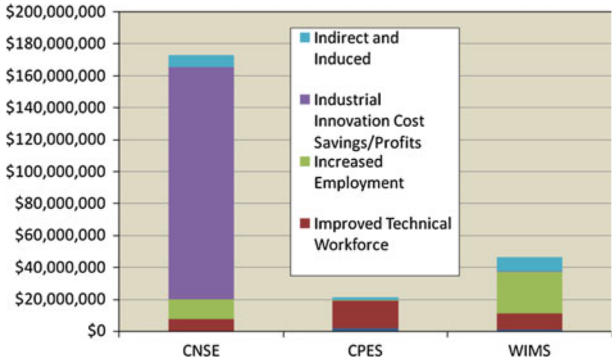

Fig. 2 Total amount and composition of quantifiable national economic impact for three ERCs

the impact of industrial innovation. One example is the multi-billion dollar impact that CPES' concept of modular integrated power systems appears to have had on the national economy.

The composition of individual ERCs national impacts shows very large variations apart from the magnitude of impact. Nearly all of the national economic impact of CPES is due to workforce improvement in industry—a combination of the value of center graduates to firms hiring them and the value to firms sending representatives to center workshops. In the CPES case, nearly all the technical workforce value is due to the value of student hires–$16.5 million. For WIMS, the greatest contribution to national impact is from job creation—over $26 million due to the success of the center's eight startups. Although the total amount was not large, CPES enjoyed relatively large contributions from foreign sources in the form of membership fees; in other ERCs, foreign support might take the form of sponsored research.

4.2 Other economically significant impacts of ERCs

Following the CNSE site visit, we broadened our data collection efforts substantially to include the economic impacts—quantifiable or not—of ERC ideas, technology, and graduates on both individual companies and their related industries. CPES has enjoyed very strong financial support from industry through its 9 years of existence. Yet despite generating a number of patents (42), the center, like most ERCs, issued few licenses (just one in this case) and took in very little licensing income. It required a number of interviews with CPES member companies and companies that had hired CPES graduates to discover that CPES' contributions to industry were related substantially to a idea or concept, the modular integrated power system, that found widespread application in not only the computer industry, but also in companies such as GE that make a wide range of products that require efficient, high performance power supplies. The concept did not generate intellectual property, and indeed CPES has deliberately moved toward an IP policy favoring non-exclusive, royalty-free licensing to member companies. And, the interviews clearly showed the very strong impact that CPES students have had on individual companies (e.g., as in the case of GE, leading new product development groups) and on their related industries—impacts that clearly had very high economic value but could not be reliably measured. Rough estimates, however, from several companies would put the national economic impact of CPES in the range of billions of dollars.

WIMS' regional impact was nicely augmented by the large amount of venture capital its start-ups attracted, data that were not available for other ERCs studied. Like CPES, however, our industry interviews showed that WIMS graduates have had very substantial (but not readily quantifiable) economic impact on individual companies, impacts that were not experienced in the case of other hires. In addition, companies mentioned the value of WIMS ideas, access to facilities (e.g., a dry etch tool), and contacts among companies that facilitated identification of new customers, suppliers, partnerships, and investors. In all cases, no dollar figures could be attached to these impacts, but there was no doubt in the interviewees' minds that they were substantial.

4.3 Lessons learned: identifying and measuring the economic impacts of ERCs

As a pilot study, many important methodological questions could not be addressed within its scope.[10] Nonetheless, the study resulted in a number of important "lessons learned" that are pertinent to future efforts to identify and estimate the economic impacts of ERCs—or, for that matter, similar university-based centers with multiple goals that span research, education, and knowledge transfer. First, despite the apparent value of waiting as long as possible in the history of an ERC before attempting to measure its economic impact, it is clear that such efforts should be made well before termination of NSF ERC Program support. The staff resources and records necessary to develop impact data, certainly of the quantifiable economic sort, are unlikely to exist following a center's graduation.

Second, there probably is no optimum time to attempt to measure ERC impacts. Each choice has its shortcomings. Given the long time for ERC economic impacts to be realized in industry, even at the ten-year milestone comprehensive impact studies are premature. This is especially the case for ERCs engaged in research on medical technology because of the extended development period. More feasible and meaningful would be to measure the impact that center graduates and ideas have had in industry, seeking data that are in principle verifiable but in most instances will not be quantifiable.

Third, the economic (and probably other) impacts of ERCs should not be compared across ERCs or against "standard" performance measures. Not only do ERCs differ from one another in formal, readily identifiable ways (e.g., size, technical focus, industry support, type of industry involvement, industry dynamism), they also differ widely in the timing and composition of the outputs that generate impact. Even the most conscientious and costly data collection efforts would be unlikely to yield comparable data across centers, because the accessibility of key data, especially proprietary data, will differ unpredictably from center to center.

And finally, in ERC impact studies, focusing on narrowly-conceived, quantifiable economic impact data alone should be avoided. Doing so distorts the amount and character of actual impacts, many of which—perhaps most of which—cannot feasibly be converted to monetary terms. The results of this pilot study suggest that such a narrow focus will greatly underestimate the impact of ERC-like centers, masking the much broader and, based on our findings, larger and more significant impacts on society.

[10] Future work should address, for example, questions such as: What types of data are needed to properly address the outcomes of ERC research and education activities? How can the benefits of developing a new workforce to lead innovation be captured? How can the effects that ERC graduates have on the firms that hired them be assessed more systematically? How might a wider range of ERC impacts, such as changes in firms' R&D agendas, new partnerships, stronger industry-university collaborations, enhanced competitiveness, and new relationships between firms and their suppliers and customers, be documented?

4.4 Implications for economic impact studies generally

Although the methods available for capturing accurately the quantitative national economic impact of ERCs are limited, this is not to say that the impact measurement tool kit is barren. The problem is that available methods have stringent requirements for data and context. In principle, consumer surplus approaches are appropriate for capturing quantitatively the economic impact of ERC-based innovations that offer cost savings to purchasers. It would be very expensive, very difficult, and very invasive—but not impossible—to obtain much of the necessary data from the innovating firms whose products were derived from ERC licenses or technology. Also, as far as we are aware, existing methods cannot capture quantitatively the national economic impact of innovations that enable things to be done that could not be done before—and often do not have obvious cost savings associated with them. To the extent that many ERC-based innovations are of this type, then their quantitative impact is probably beyond existing methods. And of course, focusing narrowly on relatively short-term (less than 10 years, say) quantitative economic impacts will miss perhaps the most significant ERC economic impacts.

If one wanted to justify the public investments in ERCs using a benefit-cost (B/C) framework and required that the analysis be limited to quantifiable economic benefits, then using the "nuggets" approach to capture the top, say, 10% of ERC-based innovations that have generated new product sales with cost savings associated with them would be an appropriate and credible approach. We have no doubts that the results would show a highly positive outcome. Of course, getting the data would be expensive, invasive, and almost certainly yield incomplete results, but in principle the method is appropriate. Even so this would greatly understate the actual B/C ratio for reasons illustrated throughout this article.

It is worth noting that a continued push for ever-greater precision in at least some of these kinds of economic impact studies may well be unnecessary. For many public policy purposes, it is sufficient to determine with a high level of confidence that a public investment by a public agency has generated outcomes whose value to taxpayers greatly exceeds the initial investment made. In such cases an incomplete or imprecise characterization of the full impact is perfectly adequate for purposes of accountability.

Following good program evaluation practice, mixed and varied methods and measures are best equipped to capture valid estimates of the full range of ERC impacts, economic and beyond. Broadening the evaluation scope to include less quantifiable impacts that have economic implications, as well as estimates of impact, is certainly appropriate and, basically, what we did in this pilot study. We showed that there ways to estimate the economic impact of ERCs, as well as ways that substantially underestimate and, indeed, distort the amount and profile of these impacts. We also showed that the time limits on an ERC's existence as an NSF-supported organization—10 years—make it very difficult (but not necessarily impossible) to identify longer term but sizable impacts 15–20 years after an ERC is initiated and attribute a portion of those impacts to the ERC.

In sum, there are methodologies available to reveal very useful data and information related to the economic impact of ERCs and similar programs, if such methodologies are used appropriately and with necessary caveats.

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