Empirical Support for Global Integrated Assessment Modeling: Productivity Trends and Technological Change in Developing Countries' Agriculture and Electric Power Sectors

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Abstract

Integrated assessment (IA) modeling of climate policy is increasingly global in nature, with models incorporating regional disaggregation. The existing empirical basis for IA modeling, however, largely arises from research on industrialized economies. Given the growing importance of developing countries in determining long-term global energy and carbon emissions trends, filling this gap with improved statistical information on developing countries' energy and carbon-emissions characteristics is an important priority for enhancing IA modeling.

Earlier research at LBNL on this topic has focused on assembling and analyzing statistical data on productivity trends and technological change in the energy-intensive manufacturing sectors of five developing countries, India, Brazil, Mexico, Indonesia, and South Korea. The proposed work will extend this analysis to the agriculture and electric power sectors in India, South Korea, and two other developing countries. We will also examine the impact of alternative model specifications on estimates of productivity growth and technological change for each of the three sectors, and estimate the contribution of various capital inputs – imported vs. indigenous, rigid vs. malleable - in contributing to productivity growth and technological change.

The project has already produced a data resource on the manufacturing sector which is being shared with IA modelers. This will be extended to the agriculture and electric power sectors, which would also be made accessible to IA modeling groups seeking to enhance their empirical descriptions of developing country characteristics. The project will entail basic statistical and econometric analysis of productivity and energy trends in these developing country sectors, with parameter estimates also made available to modeling groups. The parameter estimates will be developed using alternative model specifications that could be directly utilized by the existing IAMs for the manufacturing, agriculture, and electric power sectors.

1. Background and Significance

1.1 Introduction

Integrated assessment (IA) modeling of climate policy is global in nature, with models constructed or modified to incorporate regional disaggregation. The existing empirical economic basis for IA modeling, however, largely arises from research on industrialized economies. Given the growing importance of developing countries in determining long-term global energy and carbon emissions trends, filling this gap with improved statistical information on developing countries' energy and carbon-emissions characteristics is an important priority for enhancing IA modeling.

LBNL has been conducting in-depth econometric studies of energy-intensive manufacturing sectors in a number of developing countries (India, South Korea, Mexico, Brazil, and Indonesia), examining long-run trends in productivity, technological change, energy and other input uses, and their relationships. This work has resulted in 11 reports and journal articles and a database that is available to IA modelers. It is being supported by the DOE-OER program on Integrated Assessment of Global Climate Change.

The proposed research will extend this effort to account for two additional sectors, agriculture and electric power. We will assemble and assess consistent time series and panel data on output, input, and price trends for those sectors for selected developing countries. Using these data, we will conduct statistical and econometric analyses of productivity and energy trends in these developing countries' sectors. Within these analyses we will also examine the issues of factor rigidity and technology diffusion. The result of the project will be a consistent data resource accessible to IA modeling groups seeking to enhance their empirical descriptions of developing country characteristics (the parameter estimates will again be made available to modeling groups).

1.2 Background

Existing IA models originally emerged primarily from economic and energy modeling approaches that were for the most part developed for, and applied to, industrialized economies (Sanstad and Greening, 1998). Increasingly, however, these models have been enhanced and extended, and in many cases created, to encompass the global economy at various levels of regional and sectoral disaggregation. For example, the SGM2000 model of Edmonds et al. contains 24 sectors (plus subsectors for electricity generation, transport, and building energy services) and 13 regions (Sands et al. 1999 (draft version); Edmonds et al., 1992, 1994; Fisher-Vanden et al., 1993 and 1997); the MERGE combines a bottom-up representation of the energy supply sector together with a top-down perspective on the remainder of the economy in 9 regions (Manne and Richels, 1999); the MIT-EPPA model contains 8 production and 4 consumption sectors looking at 12 regions (Yang et al, 1996; Jacoby et al., 1999); and the ABARE-GTEM model considers 16 sectors (including electric power, agriculture and several energy-intensive manufacturing industries) in as many as 18 regions, with a focus on Asia (ABARE, 1996; Tulpulé et al., 1999).

The increasing emphasis on regionally and sectorally disaggregated global IA modeling reflects the emerging recognition of the global character of climate policy and the importance of developing countries in formulating policy, particularly following the Kyoto agreement. Currently, non-Annex I countries' energy demand per capita, and carbon emissions, are relatively low. However, as noted by Ellis and Treanton (1998), "[the] combination of significant unmet energy demand, low levels of current per capita energy use...rapid economic growth...and large indigenous fossil fuel resources...makes the potential for considerable future energy and emissions growth." This likely increasing role of developing countries in determining future world energy and carbon trends places a premium not just on regional disaggregation but also on improved intra-region and intra-country representations (outside the developed world) in IA models.

By nature, the sectoral focus of IA models is on energy-related sectors. The level of sectoral disaggregation differs by model, but uniformly a division of the economy into four broad categories (agriculture, energy production sectors, energy-intensive industrial sectors, and transportation or 'everything else') can be observed. For all models energy production is further split up into subsectors including at a minimum electric power, coal, crude oil, and natural gas. Additional sectoral disaggregation is prevalent in most models accounting for specific energy-intensive industries (paper, cement, chemicals etc.), different modes of transportation, agricultural production etc. The gain from increased sectoral disaggregation for the understanding of economic and energy flows has been realized. The recent version of the SGM (SGM2000), for example, proposes to analyze in total more than 34 sectors and subsectors in order to enhance the ability to combine top-down economic structures with results from detailed process models.

Analysis of technological change, energy trends, and related phenomena in developing countries is subject to the ongoing methodological problems well-known to this area. (See, e.g., Sanstad and Greening, 1998, for a recent discussion.) These problems have been the focus of such debates as those over the assumptions of price vs. non-price induced technological change that occurs exogenously or evolves endogenously within the model. An "autonomous" improvement in energy efficiency and the so-called "autonomous energy efficiency improvement" (AEEI) parameter appears (in one form or another) in most IA models. Technological trends and biases of technological change analyzed endogenously within the model can substantially alter the projections of economic costs of carbon mitigation. Jorgenson and his collaborators (1981, 1987, 1991) developed a model which incorporates non-neutral technological change. That is, in employing a flexible functional form to model production behavior (translog cost function), technological change is responsive to changes in relative factor prices (that is, it is non-neutral or "factor-price biased") as well as having a pure time-trend component. They have demonstrated the significance of this refinement in the context of the US economy, showing that productivity externalities resulting from carbon taxes could have substantial welfare costs in the long run (Hogan and Jorgenson, 1991), an effect that cannot be captured in a model with neutral or even exogenous technical change. Using a parallel methodology, similar results have been concluded for the manufacturing sectors of the Indian and Korean economies (Roy et al. 1999, Schumacher et al. 2000).

The methodologies applied differ by IA model. Sands et al. (2000) in their new version of the SGM, for example, allow for non-neutral (Hicks-biased) technological change in a constant elasticity of substitution (CES) production function framework. The MERGE as well as the MIT-EPPA model on the other hand assume an exogenous increase in AEEI. The production behavior in the MERGE model is presented by a series of nested CES production functions without a link to technological change. Similarly, the ABARE-GTEM model assumes a set of nested CES production functions for most of their industries. For electricity and iron and steel production, however, a 'technology bundle' approach is used which allows the consideration of different production techniques to generate a homogeneous output. Each of these production techniques is represented by a Leontief production function. In the MIT-EPPA model, production behavior is modeled twofold depending on the flexibility of capital input. The malleable part of the production structure is represented by a set of nested CES production functions, while the more rigid part of the production structure (rigid capital) captured in a series of Leontief production functions. The debate on the preferred approach remains unresolved. Nonetheless, obtaining developing-country-related productivity and related parameters that are closer to their industrialized country counterparts in terms of empirical foundation and technical rigor would be a substantial contribution to the enhancement of IA models in their present form.[1]

The hurdles to such enhancements, however, are well-known. Primary among these is the problem of limited data resources that are difficult to access. With some exceptions, developing countries do not have the statistical infrastructure that exists in developed countries. A number of studies has been conducted on productivity trends and technological change biases in both the agricultural and the electric power sector of developing countries, which are the focus of this proposal. Sharma (1991), for example, investigates technological change and patterns of substitution in the agricultural sector in South Korea. Similarly, Desai and Namboodiri (1997), Wong (1989) and Abler et al. (1994) analyze the determinants and trends of factor productivity change in Indian agriculture. Related studies can be found for Mexico (Fernandez-Cornejo et al., 1997), Indonesia (Eng, 1996), Albania (Hatziprokopiou et al., 1996), China (Kalirajan et al., 1996), and for three South Asian countries (Rosegrant et al.,1992). A pioneering study on induced innovation in the U.S. agricultural sector was conducted by Binswanger (1978) and a more recent one by Chavas et al. (1997). A cross-section of developing countries is analyzed in Hayami and Ruttan (1985). An intercountry comparison of productivity change and growth in both agriculture and industry is given by Nishimizu and Page (1989). Pioneering the analysis of technological change biases and economies of scale in the U.S. electric power sector was a study by Christensen et al. (1976). Shah (1982) and Khanna (1995, 1999a, 1999b) focus on the electric power sector in India. While each of these studies individually provides valuable insights into the development of productivity and technological change in those sectors, the results are hardly comparable due to the

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[1] More fundamentally, many analysts have questioned such basic elements as the application of the usual assumptions of perfect competition and general equilibrium to developing economies. (See Sathaye and Sanstad (1997) for a discussion.) Ideally, for example, approaches such as that of "structural general equilibrium" (Taylor, 1990) might eventually be incorporated into IA modeling to improve the treatment of departures from perfect competition in non-industrialized economies. More currently, the design of IA models is subject to the ongoing dispute regarding "top-down" vs. "bottom-up" (roughly, economic in contrast to engineering) approaches to energy and carbon-abatement analysis. Many believe that further fundamental advances in linking these two approaches are required to accurately assess climate and energy policies. While further theoretical and technical developments in modeling developing and transitional economies, and technological change and diffusion, may find future application to IA, we take the view that improving the parameterizations of existing models using existing and well-established methods has a clear benefit in the shorter run.

difference in the underlying data, input factors, time periods considered, methodologies applied, etc.

None of these studies aims at providing comparable results that can uniformly find input into a larger analysis of the costs and benefits of carbon policies. The result is that existing IA models tend to parameterize their developing country components using either developed country data as a proxy or relatively aggregate statistics from the developed countries. Thus, building an improved statistical base for IA modeling of developing countries making best use of what data resources *are* available is an important component of the further development of IA model capabilities.

2. Preliminary Studies

Toward this end, LBNL is currently analyzing energy and productivity trends in energy-intensive manufacturing sectors in five developing countries, India, South Korea, Mexico, Brazil, and Indonesia. Our results to-date provide a detailed picture of key trends in those countries' sectors, comparable to previous findings on industrialized economies. Following is an overview of methods and results of this research. (A detailed description for India is given in Mongia and Sathaye, 1998a, 1998b; Roy et al., 1999, Roy et al., 2000; for Korea in Schumacher et al., 2000; draft reports for Brazil, Mexico and Indonesia are in progress.)

We combine growth accounting, and econometric time series and panel data analysis to report on productivity growth and input trends in the energy-intensive industries and aggregate manufacturing of our study countries. The growth accounting approach is used to decompose growth of output in terms of growth of inputs and a residual which is attributed to growth in productivity of input factors[2]. In contrast to most other studies and the conventional approach we consider a four input factor model, i.e. capital, labor, energy and materials as far as adequate data are available. The analysis covers the period from about 1970 to today. Using a translog cost function approach[3] with an explicit relationship defined for technological change we econometrically estimate rates and factor price biases of technological change for this time series. This methodology is an advance over earlier studies to the extent that it relaxes the assumption of Hicks neutrality in allowing for technical bias parameters. It also allows for non-constant returns to scale which enables us to draw links to important structural factors such as capacity utilization, plant size etc. Substitution elasticities and price responses are derived from the model parameters.

In order to draw conclusions on the role and direction of technological change in reducing the use of individual (e.g. high carbon content) fuels, we further conduct a two-stage panel data analysis for three Indian manufacturing sectors within the same translog cost function framework with non-neutral technological change and non-constant returns to

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[2] The growth accounting approach is pioneered by Solow (1956, 1957) and further developed by Denison (1974, 1979, 1985), Kendrick (1957), and others (Kendrick and Vacona, 1980). Because of its more general nature we employ a translog index throughout our analysis. The translog index is based on the translog production function, (introduced by Christensen, Jorgensen and Lau (1971)) which is a second-order approximation to an arbitrary production function that is twice differentiable. The translog index provides an approximation to the Divisia index for discrete time periods. (See Mongia and Sathaye (1998a) for a further discussion of indices to measure productivity growth.)

[3] As developed by Jorgenson and his collaborators (1981, 1987, 1991).

scale[4]. The two stages relate to the level of disaggregation in input factors. In a first stage, we estimate fuel biases and interfuel substitution processes of coal, oil and electricity, and in the second stage we estimate input biases and interinput substitution possibilities as above.

In collaboration with counterparts in the study countries, a substantial database on input and output as well as price data for energy-intensive industries of these countries has been compiled. The data originates from national sources, mostly from industrial surveys that were conducted on a regular basis. Growth accounting and econometric analyses of these data reveal diverse patterns for rates and directions of technical change and substitution possibilities. In India, for example, most of the analyzed energy-intensive industries (aluminum, cement, glass, paper, aggregate manufacturing and total industry) show an energy using bias of technical change over the twenty year study period (1970-1993). An energy saving bias can be observed for the fertilizer and iron and steel industry. (Roy et al., 1999) In Korea, for the period 1980-97, an energy-using bias can be found for the cement, iron and steel and paper sector, while the fertilizer sector and aggregate manufacturing show an energy saving bias (Schumacher et al., 2000). Scale economies as well as patterns of substitution differ by country and industry, and are sensitive to the time period considered.

Own-price responses indicate that price-based policies would be effective in reducing energy use for most sectors and countries. However, an energy using bias of technical change as found for some sectors suggests that such policies could have a negative long run effect on productivity (and thus welfare) in these sectors. Note that these results are in line with those of Hogan and Jorgenson (1991) regarding the U. S. economy, that is, price-based policies to reduce energy and carbon emissions could have negative long-run impacts on manufacturing productivity. An optimal policy strategy therefore needs to take these factors into consideration.

The panel data analysis for India reveals an electricity-using bias for the three industries studied (aluminum, cement, and paper). In addition, a coal-using bias can be observed for the aluminum industry. In the context of policy modeling, these results imply that with constant relative fuel prices technological change leads to the use of more carbon intensive fuels in these industries. In addition, a dual interpretation indicates that an increase in fuel prices could potentially affect welfare growth negatively. Interfuel

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[4] This approach is similar to the approach followed by Fuss (1977) and Pyndick (1979).

substitution possibilities vary significantly by state. Except for oil input, most elasticities show low or moderate flexibility within the industries to adjust to rising fuel prices. These findings suggest that price based policies alone may only have a limited impact on carbon emissions. A check for economies of scale reveals increasing returns to scale in nearly all states for cement and paper – although often at insignificant levels - and in a few states for aluminum. (Roy et al., 2000)

In collaboration with counterparts in India, South Korea, Mexico, Brazil, and Indonesia, we have compiled a substantial database on inputs and output as well as price data for energy-intensive industries of these countries. The data originates from national sources, mostly from industrial surveys that were conducted on a regular basis. It is available from the authors and will be made publicly accessible on the internet in the near future.

This work demonstrates the feasibility and utility of the approaches (growth accounting, and econometric time series and panel data analysis) that we are proposing to extend to other sectors. We now have the experience to successfully conduct this type of research as well as the appropriate staffing and facilities. Additionally, our existing contacts with developing country agencies and researchers (see below) are a unique asset.[5]

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[5] In our current work on the Indian manufacturing sectors, we have also been studying industry-specific features such as structural composition, production, technologies, energy consumption within processes, environmental impacts, sector-specific policies, etc (Schumacher and Sathaye, 1998, 1999a-d). Understanding such features provides a broader context within which the econometric results can be more fully evaluated. We are not proposing to extend this ancillary effort to the additional sectors discussed in the present proposal, primarily due to our uncertainty regarding data availability. Such additional efforts, however, may be appropriate for future research.

3. Research Design and Methods

The proposed research will extend our current work to two additional sectors, agriculture and electric power, in selected developing countries (India, Korea, and two of four other potential countries, Mexico, Indonesia, Brazil or South Africa). As with the current work, the project will have two primary components: a) identifying, collecting, and organizing data on selected developing countries' agriculture and electric power sectors, and putting these data into electronic formats appropriate for statistical and econometric analysis (see below for a preliminary survey of data availability); b) applying these data to conduct statistical and econometric studies of productivity, energy and other input uses, and technological change in these sectors. Our goal is to closely replicate for these additional sectors the LBNL work done to-date on the energy-intensive manufacturing sectors in five developing countries. In the event that full time-series data necessary for this are unavailable, we will alternatively use a panel data approach. (This would also apply in the event of insurmountable problems with data quality or reliability, which we have encountered in previous work; see Mongia and Sathaye, 1995).

The sectors indicated above were selected in order to achieve a comprehensive representation of economic sectors in those countries and correspond to the level of disaggregation prevalent or emerging in most IA models. We have thus far identified the following data and sources for these sectors in India, Korea, Mexico and Indonesia.. Additional data and information on individual countries will be accessed through contacts with research groups in these countries. For S. Korea, the key institutions will be the Korea Energy Economics Institute (KEEI), Seoul National University, and The Council on Energy and Environment, for Mexico, the National University of Mexico (UNAM), for Indonesia, BPPT Teknologi, the agency for the assessment and application of technology, and the Bogor Agricultural University, and for South Africa, the Department of Statistics as well as the University of Cape Town.

India: For the electric power sector, data on natural gas, raw coal and petroleum product inputs as well as electricity output along with their price indices are available from the Central Statistical Office's energy sector data source for 1970 to 1998. We have this data in electronic form. Information on capital and labor input is available from the Central Electricity Authority, CEA, for the same range of years. In addition, the Annual Survey of Industries provides all relevant data in a slightly more aggregated form for the period 1973 to 1994.

For the agricultural sector, we have electricity consumption data in electronic version from the Central Statistical Office. Capital, labor, land, fertilizer and price data for a wide range of years (1970s to present) are available from the Ministry of Labor (Quarterly Employment Review), from the Fertilizer Association of India (Fertilizer Statistics), from the Centre of Monitoring the Indian Economy (India's Agricultural Sector: A Compendium of Statistics and Basic Statistics Relating to the India Economy), and from the Ministry of Agriculture (Agricultural Census).

Korea: State-level and national data on inputs (capital, labor, energy, materials) and outputs for electric power generation are available on a quinquennial basis (starting in 1955) in the Industrial Census of the National Statistical Office. In addition, the needed data can be found in the electrical power statistics by the Korea Electric Power Corporation. Corresponding price data is available from the Bank of Korea's annual Producer Prices Survey.

Agricultural input (KLEM) and output data is available from the National Statistical Office's annual Agricultural Production Cost Survey, Basic Agricultural Statistical Survey and the quinquennial Agricultural Census from the early 1960s on. Price data for the agricultural sector can be found in the Bank of Korea's Producer Prices Survey as well as in publications on price surveys by the National Agricultural Cooperative Federation.

Indonesia: The Indonesian Biro Pusat Statistik collects data on inputs (KLEM), value of output and prices for agriculture (Annual Survey of Agriculture) and electric power (Annual Survey of State Electricity Companies). The annual survey of electricity companies began in 1976 and continues to date. The annual agricultural survey encompasses the period 1972 to date. Publications for several years are available at the UC Berkeley library, the remaining are available from Biro Pusat Statistik.

Mexico: Required input and output data for the electric power sector can be found in several annual statistical publications by the National Commission of Electricity (Comision Federal de Electricidad) as well as by the National Institute of Statistics (Instituto Nacional de Estadistica, Geografia e Informatica – INEGI). The publications comprise a time range from about 1980 to date. Price data for the electricity sector have already been provided in electronic format by our collaborators at the National University of Mexico.

Data on agriculture is published (monthly and annually) by the statistics section of the Department of Agriculture, Government of Mexico (Secretaria de Agricultura y Recursos Hidraulicos). Several issues of these publications are available at the UC Berkeley library, the remaining issues are available from the Department of Agriculture.

To a lesser extent, we will examine ways to extend our methodology to account for different capital structures. We will analyze the effects of different components of the capital stock on productivity growth and technological change by a) distinguishing flexible or malleable components of the capital stock (putty) from rigid ones (clay) and b) by dividing the capital stock into domestic and imported capital components. The first approach is based on the understanding that the effective contribution of capital to productivity changes varies according to the composition of capital. The capital service derived from the rigid (clay) part of the capital stock maybe lower than the service derived from the newer capital (putty) components. Berndt-Wood (1984, 1987), for example, found that the quality-adjustment of the capital stock had a large empirical impact on productivity growth indexes for U.S. manufacturing (see also Morrison Paul, 1999). To date, only few IA models (e.g. MIT-EPPA) take this into account. The second approach relates to the issue of technology diffusion. Decomposing the effects of domestic and imported capital on productivity trends and technological change will help us understand whether technological change is implicitly imported with capital or whether it occurs domestically through investment in the domestic capital stock. Due to intensive data requirements, we propose to examine these issues for Indian manufacturing first where we have both good data availability and extensive expertise.

The deliverables for this project will be a) a mid-term and final report; b) four working papers describing the analysis for each country; c) final versions of these papers submitted to refereed journals. The timeline will be as follows. Although not explicitly noted in the time-line, this project will include ongoing contact with other IA researchers and participation in selected IA-related events, such as meetings of the Energy Modeling Forum. The principal investigator presented preliminary results on the Indian sectors and discussed the general nature and goals for this research in the summer 1997 Snowmass, Colorado IA meeting. Alan Sanstad presented our recent results at the scoping meeting for EMF19 in Washington, DC in March 2000. We expect to participate in the 2000 Snowmass meeting on integrated assessment and in the ongoing EMF19 meetings.

We are in contact with several researchers from the EMF19 meeting. For the MERGE model, for example, we are currently conducting a decomposition analysis of the AEEI factor, looking at two components the energy efficiency improvement due to pure (or technical) energy efficiency gains and the improvement due to structural changes in the composition of the economy. With regards to the SGM model, we are planning to adjust our model setup in way that the results yield an immediate comparison to the SGM production structure. We plan to initiate a similar collaboration with other IA modelers in the course of this project.

Tasks and Timeline

Project start date: October 1, 2000

Task 1: Gathering and inputting of KLEM, price, and other data for the agricultural sector in South Korea and India. Exploring data availability for two additional countries (potentially Indonesia and Mexico) (October 1, 2000- January 31, 2001).

Task 2: Analysis for India and South Korea, beginning preparation of draft papers, reporting results (one set for each country). Gathering and inputting data for the additional countries' agricultural sector. (February 1, 2001- July 31, 2001).

Task 3: Completion of analysis for India and South Korea, completion and circulation of final draft papers. Preparation of mid-term report and submission of mid-term report (August 1, 2001 - September 30, 2001).

Task 4: Gathering and inputting data for the electric power sector in India and South Korea, and the additional countries (potentially Indonesia and Mexico); revision of Indian and South Korean papers on the agriculture sector. (October 1, 2001 - January 31, 2002).

Task 5: Analysis for the electric power sector in India and South Korea and the two additional countries, preparation of draft papers. (February 1, 2002 - July 31, 2002).

Task 6: Circulation, revision, and submission of India and South Korea paper, preparation and submission of final report (August 1, 2002 - September 30, 2002).

4. Institutional Capability

Vitae of the principal investigators of the proposed work are attached to the proposal. The major thrusts of this work involves (1) statistical analysis of the electric power and agricultural output data, (2) econometric estimation of total factor productivity for the specified sectors for India, S. Korea, and potentially Mexico and Indonesia. The investigators provide expertise in all these areas. The investigators have worked on an identical study for the manufacturing sector and have developed the methods for conducting the aforementioned analyses. Dr. Jayant Sathaye, the principal investigator has extensive experience in the analysis of energy use in developing countries, and has long-term contacts with relevant institutions in the proposed countries. Dr. Joyashree Roy is a professor of economics and expert at econometric analysis. She developed the econometric methods for use in the manufacturing sector studies. Ms. Katja Schumacher received her graduate degree in Economics from the University of Bonn, Germany, and has also studied in the Department of Economics at the University of California at Berkeley. Over the course of the current and previous project she has accumulated invaluable experience in the analysis of productivity trends and technological change in developing countries' economies. Dr. Alan Sanstad's current research is also focused on IA modeling with particular emphasis on the mathematics of infinite-horizon optimization, the theory of endogenous technological change, and the economics and policy analysis of energy efficiency.

This project will be conducted primarily at the Lawrence Berkeley National Laboratory (LBNL) in Berkeley, California. LBNL has extensive data sources for the developing countries, computer resources and modeling expertise. In addition to the expertise at LBNL, the resources of the Berkeley campus of the University of California are readily available. Those resources include access to the state of the art computer systems and one of the finest research library systems in the country. We have been in close contact with the faculty of the Department of Agriculture and Resources Economics both at the University of California at Berkeley and Davis. In particular, Prof. Zilberman and Prof. De Janvry at UC Berkeley have conducted a broad range of empirical research in the area of agricultural and environmental resources economics including the economics of technological change in agriculture and electric power sectors (Zilberman et al., 1997; Carlson, Zilberman et al., 1993; De Janvry, 1985, 1986). Prof. Morrison Paul at UC Davis specializes in cost structures and measurement of economic performance with emphasis on capital and its effects on technological change (Morrison, 1992, 1994, 1999).

The project will benefit from extensive collaboration with researchers in the above mentioned research groups. The following contacts have considerable experience in the field of energy and economics.

Brazil
Prof. Gilberto De M. Jannuzzi and Maximo Pompermayer, Universidade Estadual de Campinas, Escritorio de Transferencia de Tecnologia –ETT.

India
Prof. Puran Mongia, Delhi School of Economics, Delhi University, Delhi.
Prof. Joyashree Roy, Department of Economics, Jadavpur University, Calcutta.

Indonesia
Prof. Rizaldi Boer, Bogor Agricultural University, Bogor.
Iwan Hermanto, Badan Pusat Statistik, National Statistical Office, Jakarta.
Agus Adi, BPPT, Jakarta.

Korea
Prof. Hoesung Lee, President Council on Energy and Environment, Korea.
Prof. Jeong-Dong Lee, Techno-Economics and Policy Program, University of Seoul.

Mexico
Prof. Claudia Sheinbaum and Leticia Ozawa Meida, Ingenieria Energetica, Division de Estudios de Posgrado, Facultad de Ingeniera, UNAM, Ciudad Universitaria.

South Africa
Ria Louw, Statistics South Africa, Department of Statistics, Pretoria.
Prof. Randall Spalding-Fecher and Martine Visser, Energy & Development Research Centre, University of Cape Town.

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