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Introduction
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We are pleased to present the ninth volume of the *Annual Review of Resource Economics (ARRE)*. The journal is evolving with new developments in resource economics, and our aim is to provide critical assessment of new discoveries and identify new promising directions for research. Our interpretation of resource economics is broad and includes the economics and management of the environment, agriculture, renewable and non-renewable resources, energy, and development. Our agenda emphasizes current developments and new discoveries while continuing to expand our understanding of core issues. Therefore, we include articles on assessment of and adaptation to climate change, agricultural and research policy, the emerging bioeconomy, inequality and poverty, impact of global trade, environmental policy, and policies and methods to address risk and uncertainty. This current volume combines review of new research methodologies, new discoveries in major subfields, and public policies and political economy analysis. Natural resource economics must by its very nature emphasize multidisciplinary perspectives, where an economic lens integrates knowledge and methods from other disciplines to generate holistic and policy-relevant perspectives on resource management problems. Accordingly, *ARRE* serves as a major bridge between economics and the biophysical and environmental sciences.

Following our tradition, we dedicate the first review to the life and contribution of an eminent economist. This year we feature Emery Neal Castle, who pioneered research on agricultural resources and rural development. Emery grew up on a farm and attended a one-room schoolhouse in Kansas. He left his college to join the air force during WWII, returned to Kansas State University, and then got his PhD from Iowa State University. After graduation, he moved to Oregon State University, developed an educational program on water and resource economics, and spearheaded the emergence of OSU as a leading research and education program on economics of natural resources. He became Dean of his college and then moved to Washington DC to become a transformational president of Resources for the Future, who put the foundation on sound financial footing. Emery was one of the first researchers to quantify the value of outdoor recreation and environmental amenities as well as augmenting benefit-cost analysis to account for these amenities. He pioneered research and education on rural studies, integrating the economic and cultural aspects of rural life. His work incorporates advanced models of decision making under uncertainty with unique features of rural and natural resource systems to produce practical management and decision-making tools.

Following the interview, we present five sections related to agriculture, integrated assessment of resources, environmental economics, energy economics, and development. In the first article in the agriculture section, Sumner reviews and critically analyzes the myriad state and regional policies regulating ownership, investment, and

organization of farms as well as regulation of practices and technologies such as seed selection and animal welfare. These regulations tend to restrict interstate trade, have significant efficiency implications. Though introduced in specific locations, the spillover effects are substantial. Furthermore, many of these policies outlive their usefulness. In the following review, Sheldon analyzes the economics of credence attributes of food. Attributes include the manner in which food is produced or distributed (e.g. organic, Fair Trade), which are unobservable to the consumers. The literature finds that one of the challenges of the establishment of credence goals is the qualifications of the organization that provides the monitoring and diagnosis. So, consumer welfare may be negatively affected because of the uncertainty of both the practices of the producers and the certifiers that monitor them.

In the third article of the section, Clancy and Moschini review the literature on the impact of the increasing reliance on formal intellectual property rights (patents) on biological innovations in agriculture. They explain the different mechanisms to protect breeder rights, emphasizing heterogeneity of the use of plant protection mechanisms across locations and technologies, and analyze their impact on protection of innovators' rights and innovation activities. They find that strengthening of IPR for biological innovations has accelerated the rate of innovation, but impacts vary and depend on the implementation of the IPR. Interestingly, they find that impacts of stronger IPR in biological innovation are no different from their impacts on other innovations. In the next article, Grethe reviews the literature on the economics of farm animal welfare. Defining and measuring animal welfare is challenging. Different perspectives have emerged on animal welfare as outcomes in the market may conflict with outcomes in the voting booth. This leads to a regulatory dilemma that may lead to inconsistent policies. Animal welfare regulations affect production practices and farm costs. Studies reject the hypothesis that small, traditional farms automatically imply higher farm animal welfare. Implementation of animal welfare policies affect competitiveness and trade, and have welfare costs. There are attempts to integrate various animal welfare policies to improve cost effectiveness, but this is an area for continued research. In the last review of the agriculture section, Stephenson and Shabman analyze studies on the role of water quality trading in addressing a major non-point source pollution from agriculture, namely nutrient pollutants. They find that, despite the predictions of conceptual studies that trading will reduce nutrient pollutants, evidence shows that current and proposed water quality trading programs will have a minimal impact on nutrient pollution. As a result, the authors suggest new policies that take into account behavioral economic considerations.

Our second section contains four reviews on integrated assessment models to analyze and understand major environmental and resource management issues. These models are multidisciplinary and frequently integrate models of different systems within an economic or policy decision-making framework. In the first review of this section, Lemoine and Rudik present recently developed recursive integrated assessment models of climate change that have become a major tool to study the uncertainties about modeling climate change and analyze their policy implications. The literature identifies several sources of uncertainty and mechanisms to quantify it. They argue that

clever design of new recursive numerical simulations may become very effective in reducing uncertainty regarding impact of climate change. In the next article, Kling et al. review integrated assessment models of the food, energy and water nexus in the context of climate change. They show that modeling the components of this system need to be incorporated in a coordinated manner, otherwise advancement in some sectors may comprise the system overall. They find that the big challenges are integrating models of different systems, and in particular, integrating economic and biophysical models as well as improved model validation. Next, Muller and Keiser review the status of integrated assessment of air and water pollution in terms of policy design. In particular, optimal outcomes occur when marginal damages from pollution are equal to the marginal cost of damage reduction. However, monetization of these two aspects and integrating them to the overall national account is a major challenge that may be met with better modeling and computational tools. In the last review of this section, Bretschger develops an integrated baseline model to investigate the tradeoff between natural environment and economic growth. The analysis separates the impact of consumption and capital accumulation on economic welfare and environmental quality, and argues that the assessment of tradeoffs depends on the number of sectors considered as well as functional forms. The analysis emphasizes that key inputs can play a major role both to manage pollution externalities and to conserve resources. A key challenge in designing policies that balance growth and environmental sustainability is the challenge of remaining on the optimal path.

The third section of this volume addresses specific environmental economics research studies. In the first article of this section, Fankhauser reviews the economic and analytical challenges of adaptation to climate change under conditions of risk and uncertainty. There is growing evidence of widespread human adaptation to climatic changes. Adaptation requires knowledge, planning, coordination, and foresight. Policies to enhance adaptation have to address behavioral barriers and market failures. The intensity of adaptation should vary across locations over time. Priority should be given to areas where delay might lock in future vulnerability. Adaptation policies and efforts are interlinked to economic development, and thus the planning of industrial expansion and urban development needs to consider adaptation and resilience to climate change. Adaptation strategies are limited by financial constraints, and there are gains to be captured from coordinating adaptation and mitigation policies. One mechanism to foster adaptation is through innovation, and in the next article, Lambertini reviews the factors that determine firms' green R&D efforts. In particular, the literature shows that market power and policy stimuli contribute to such efforts as well as consumer willingness to pay for green products. At best, the author finds that there is mixed evidence of the Porter hypothesis, where environmental regulation induces innovation and efficiency.

The economics of green industrial policies in developing countries is investigated in the following review by Harrison, Martin, and Nataraj. These policies promote industries that produce green technologies and encourage traditional industries to produce goods and services with a greener focus. The authors report findings on the performance of voluntary programs to reduce pollution and contrast China's successful policy to promote solar photovoltaic industry with that of India. They compare the relative efficiency of promoting deployment of green technologies versus R&D. They find

inconsistent policies such as continued subsidization of fossil fuels that may harm adoption of renewable energy sources. Some effective strategies include hybrid policies that combine regulatory standards directed at major polluters' intensive margin versus financial incentives directed towards others. They find that trade policies that reduce barriers to foreign direct investments and dismantle tariffs can contribute significantly to environmental quality improvement. Wesseler and von Braun analyze the economics and policies of a major green sector: the bioeconomy, which uses new developments in biological resources to produce a wide variety of products. The bioeconomy is driven by advances in microbiology and has the potential to increase resource use efficiency and reduce greenhouse gases. The modern bioeconomy is in its infancy but is growing fast, and its rate of growth is largely affected by regulation and future R&D investments, whether public or private.

Measurement of impact of environmental programs is a major challenge. Pfaff and Robalino analyze literature measuring the spillover effects of conservation programs. For example, adoption of water conservation technologies may lead to reduce water prices and a secondary increase in water use. Their review reveals evidence of how conservation programs might affect outcomes beyond their borders. They identify five major channels by which spillovers can arise: (1) input reallocation; (2) market prices; (3) learning; (4) nonpecuniary motivations; and (5) ecological-physical links. In the final article of the section, Whittington, Adamowicz, and Lloyd-Smith review literature on the challenges of eliciting demand for environmental goods. They argue that in many stated preference studies, willingness to accept questions is more appropriate than willingness to pay, and they provide guidelines under which condition each valuation approach is preferred. Finally, they show how to design surveys that reliability elicit willingness to accept measures for both public and private goods.

The fourth section is dedicated to energy economics. Harding and Sexton review the literature on time-varying electricity prices. In principle, time-varying prices can increase efficiency in energy markets but are rarely used. There are, however, a number of experiments conducted to assess consumer responses to such pricing schemes. Evaluation of these experiments suggests that outcomes are consistent with theory, and that introduction of time-varying pricing increases efficiency and reduces energy generation costs. In the second article of this section, Rajagopal, Vanderghem, and MacLean review life cycle assessment techniques used by economists. These techniques quantify inputs and emissions associated with the life cycle of a product, from raw materials extraction through the product's ultimate consumption or use. The review identifies situations that merit a product life cycle approach in environmental regulation and then discusses the use of LCA as an aid to implementation of different types of policy instruments. The authors discuss methodological and implementation-related challenges of using LCA in the evaluation of public sector regulations.

The final section presents four reviews in development economics. Wuepper and Lybbert focus on behavioral development economics and the critical role of perceived self-efficacy (PSE) – individuals' perception of their domain specific capabilities – in making economic decisions, especially concerning technology adoption. The literature

argues that individuals with low PSE are less likely to take initiative and emphasizes PSE's important role in understanding poverty and economic development. In the next review, Christiaensen and Kanbur explore whether a shift in public investment toward secondary towns from big cities will improve poverty reduction performance. This review investigates the sources of difference among secondary towns and big cities, the economic mechanisms for differential contributions, and how policies affect them. The authors present early evidence that such investment shifts may alleviate poverty.

Carter et al. investigate the potential of index insurance to reduce risk and enhance investment, productivity growth, and poverty reduction among smallholder agriculture. They find a disappointingly low adoption rate of existing index-based insurance for risk mitigation and explore opportunities for revised contract designs, improved marketing and policy support. Furthermore, they recommend that such instruments be combined with stress tolerant seed varieties and new risk-oriented savings and credit products that advance the complementarities between what can be offered by index insurance and other instruments structured to cope with unanticipated shocks. The final article of this section, by Pingali and Sunder, reviews the literature on transition towards nutrition-sensitive food systems in developing countries that emphasize consumption of micronutrient-rich nonstaples. Nutrition sensitive approaches target individual needs and choices and investigate intra-household equity and access to nutrients as well as food safety and security. Agricultural systems and policies affect nutrition and a critical challenge is to identify and implement food and nutrition policies that are appropriate to the particular stage of structural transformation in the country being analyzed.

The *ARRE* is a dialogue between our authors and you, our readers. We are continuously looking for your input and response as we strive to take advantage of new developments and make our publication more interactive and transparent. We extend our gratitude to all those who have contributed to the growth of our journal and those who work behind the scenes to contribute to the generation of an exciting new publication. We thank our authors for their insights, their ingenuity, and their hard work to be clear, up to date, and responsive to the review process. Our editorial committee selects the topics and the authors and oversees a rigorous peer-review approval process. The authors are encouraged to provide diverse and original perspectives on the frontiers of resource economics. As Editors, we appreciate readers' feedback and advice on how we can develop this venue, in which leading scholars advance and interpret the further cutting-edge developments emerging from our field.