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Introduction

This dissertation argues to be the product of original research pertaining to sustainable development. Which begs the question: what constitutes such research? The question is not trivial, and there seems to be no guideline, let alone consensus, of what such research consists of. A Ph.D. student in economics, inheriting the history of an academic discipline recognized for at least 150 years and with it a common understanding of what *research in economics* is, does not face this conundrum and can simply provide three chapters — there would be no need for this introduction. Sustainable development is not a traditional discipline, and as such has no history defining or framing it, nor does it have its own large community of scholars identifying themselves as such, whose work to look towards for guidance.

To demonstrate my production of research pertaining to sustainable development, the first step ought to be understanding what this entails. By lack of an agreed upon definition, this introduction starts by proposing a brief one,[1] and then presents how its three chapters provide such scholarship.

In theory

The present section attempts not to define sustainable development but to frame *research pertaining to* sustainable development. However, the former being a prerequisite to the latter, it does beg a brief characterization. My conceptualization departs slightly from the widely accepted definition by Brundtland (1987) of a "development that meets the needs of the present without compromising the

[1] Alumni of this Ph.D. program have argued that it may be partly the program's job to define it. So did the Dean of the School offering it: "The School of International and Public Affairs is committed to continue to support the program as it evolves, advances, and defines the science of sustainable development" (SIPA, 2014).

ability of future generations to meet their own needs." First, the positive characteristic *sustainable* refers to the ability to be maintained over time; yet this intertemporal concern need not be reduced to intergenerational considerations, and may be extended to shorter timescales. The second notion, *development*, is fundamentally more contentious. Making it explicit and expanding from a focus on needs, I follow Sen (2003)'s conceptualization of development as the expansion of the capability to "function", and consider development as either exploring or increasing the capability to function.[2]

Sustainable development is a goal, not a discipline.[3] The anthropocentric goal in question is to be on a sustainable development path, i.e., for humanity to explore and expand its functioning in such a way that it is not reducing its capacity to do so in the future. At a minimum, this means maintaining the Earth and human organization into societies as a human-habitable and desirable place. We note that as what is desirable is inherently political, and there are probably many possible sustainable paths, this field of research goes beyond a technocratic approach of planetary management. The main argument here is that since sustainable development is a goal, research pertaining to sustainable development is simply research on or for this goal: from dissecting the goal itself (e.g., what constitutes a sustainable development path and its limits) to analyzing where a society is positioned with respect to it and how to reach it.

The first implication is semantic: research *in* sustainable development is less apt than *on* — when analyzing the goal itself — or *for* — when studying how to reach it. The three chapters of this dissertation fall within the area of research *for* sustainable development. The second implication concerns the ambition required of research questions to produce such scholarship. Addressing a topical environmental or development issue does not suffice to generate knowledge for sustainable development, though it might be a stepping stone. For instance, estimating the capitalization of ecosystem amenities into property values, or the causal impact of heat on virtually any outcome of interest, does not by itself tell us how to get closer to a sustainable development path, and thus falls

[2]This highlights the distinction with *sustainability* research, which, though prone to studying the same objects ("Sustainability research studies the dynamics and prospects of co-evolving human and ecological systems, a subject of inherent complexity" (Raskin, 2008, p. 461) — the analytic unit that is the complex socio-ecological system is addressed later in this section), does not stipulate what ought to be sustainable and loses the progress dimension of *development*. The economic notions of weak and strong sustainability, which are concerned with the maintenance of capital stocks, are similarly devoid of the notion of expansion (Costanza and Daly, 1992).

[3]Simple parallels of this distinction can be drawn from those disciplines often leveraged for related research: ecology is a discipline, conservation is a goal; economics is a discipline, maximizing welfare is a goal.

short of such scholarship, unless for example the relationship is explored in a way that introduces some *agency*,[4] or the analysis sheds light on factors impeding sustainability that can be intervened upon. Defining what a field of research consists of is much harder than identifying what it excludes. Here, I have only addressed the latter; still, this provides, if not some perfect orientation, at least a filter for the type of research questions which may pertain to sustainable development.

What about the relevant *unit(s) of analysis*? Existing definitions offer some guidance. Sachs (2015) defines sustainable development as "a science of complex systems",[5] namely the main complex interacting systems that are the global economy, society and the Earth's physical environment. This science aims to explain and predict the interlinkages, specifically the "complex and nonlinear interactions" of these human and natural systems. Similarly, Wiesmann and Hurni (2011) explicitly identifies the relevant analytical units for research for sustainable development as "strongly coupled human-environment systems," also referred to as socio-ecological systems.

In practice

Interdisciplinarity The sustainable development objective of maintaining — if not improving — the habitability and desirability of Earth and societies directly involves both social and natural sciences, and thereby calls for interdisciplinarity. How is a researcher to produce interdisciplinary work? One scholar cannot reasonably be an expert in multiple disciplines, let alone all those relevant to study a socio-ecological system. Instead, the scholar's contribution may be to bring them together. One pragmatic approach to interdisciplinarity is therefore understanding the core concepts and approaches of, to then find junctions between, the various relevant academic disciplines. Economics occupies a privileged place in interdisciplinary grounding for sustainable development

[4] Some agency in the heat-outcome relationship can be introduced by exploring ways to act upon either the causal variable considered, or its relationship to the outcome of interest. In the case of extreme heat, the panel of actions on the causal variable is largely known: mitigation, adaptation, or migration. Agency in the relationship, however, can be explored in various ways. For example, in estimating the impact of extreme weather on conflict, by investigating the mechanism underlying the relationship; in estimating the impact of extreme heat on food production, by analyzing the effect's heterogeneity across a third variable. In chapter 2, we first estimate the effect of extreme temperature on milk production in Israel, and then study how this relationship varies with the cooling technologies adopted.

[5] Sachs (2015) considers multiple dimensions of sustainable development, e.g., a practice, an ethical framework, or an analytical field of study. The latter conceptualization is the one referred to here.

and provides a useful framework for research questions in this field,[6] but remains at best a partial bridge between the social and natural sciences. In empirical work, one common toolbox is applied statistics. The statistical practices of different disciplines vary in name and focus, but share the same overall agenda of learning from data by dealing with uncertainty. Finding possible junctions in order to connect (or to show the points of disagreement to ultimately facilitate the connection of) the methods and concerns of the relevant disciplines, makes it possible to bring together the various research communities required to address questions *on* or *for* sustainable development.[7]

Approaches to study systems We saw that at the core of all research questions pertaining to sustainable development are interactions within and between socio-ecological systems. Does this require a systems-based approach? Meadows (2008) argues that the "systems way of seeing" is not better than the "reductionist way of thinking", but rather "complementary, and therefore revealing." The lens of systems theory are not necessary to produce knowledge about sustainable development. However, whichever the approach and the set of methods used, sustainable development research stands out by its focus on questions about *systems*, and its leveraging the strengths of the methods from core disciplines to apply them to a systems context. When the object under discussion is a system, reductionist approaches will generate system-level knowledge *if* they invite the systems way of thinking by showing where the analyses are placed within that framework, i.e., on which parts of the system new knowledge has been acquired, and interpreting the results in the context of this larger system.

This dissertation falls within the simple framework proposed in this introduction through three

[6] The high position of economics stands to reason on multiple grounds, notably its providing one way of connecting social and ecological parts of the system directly, as the study of how individuals and societies choose to allocate and use scarce resources (Case et al., 2012).

[7] One seemingly fundamental divide, but arguably reconcilable, between modeling communities, is the distinction between explanatory and predictive modeling. Their different stated aims lead to different statistical approaches — forward causal inference for the first, which hence focuses on identification assumptions; prediction for the second, which thus evaluates and chooses functional forms based on predictive power (Shmueli, 2010). Yet these goals are arguably not opposing but rather complementary: the results of a (true or quasi) experiment are of general interest to the extent that the observed treatment assignments are representative of a population of future assignments (Rubin, 1974), i.e., that the causal relationship has a certain predictive ability. Prediction accuracy can also support causal inference by providing an additional check of — or reducing the reliance upon — prior theory to dictate the model, especially in social sciences where the statistical assumptions about the data generating process are largely unverifiable (Freedman, 1991). Prediction and causal inference are complementary, and can be pursued jointly in interdisciplinary work, while bolstering inferences by combining the expertise of each community.

chapters. Chapters 1 and 2 focus on the animal farming system. In chapter 1, I leverage two different identification strategies to estimate the impact of animal feeding operations on surface water quality in the top two swine producing states in the U.S. I provide causal estimates of the externality, that suggest the exceedance of the carrying capacity of the ecosystem and thereby have implications on the depth of the changes that would be required at the system level to address the pollution, namely, reducing the concentration of farm animals in space. In the first part of chapter 2, I estimate the non-linear response of daily cow milk production to humid heat, and the potential of adaptation technologies adopted in already hot regions to alleviate the highest negative impacts. The second part of chapter 2 and chapter 3 address how assumptions in the "climate-economy" literature limit the external validity of findings, and thereby the production of knowledge for sustainable development. In chapter 2, I provide evidence against the assumption of time separability of the effects of temperature in agricultural production, and suggest how misleading insights can result. In chapter 3, I show how the simple best linear approximation to the conditional expectation function, obtained by the typical linear reduced form model, can generate highly misleading insights in the climate-conflict literature, and suggest an alternative model for inference.