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Emergence of controversy in technology transitions: Green Revolution and Bt cotton in India

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ABSTRACT

Technology transitions following radical technological breakthroughs are often marked by controversies and the transitions to Green Revolution (GR) and Genetically Modified (GM) seeds in India were no exceptions to this rule. Controversies can trigger social dilemmas, but in economics we do not yet have a clear understanding of how they emerge in the wake of major technological transitions. In order to provide insight, we develop a novel conceptual framework of technology transition integrating 'Nature' as a non-economic actor in the innovation system. Then this framework is applied to analyze India's GR and GM transitions in cereals and cotton respectively, using the methods of historical reconstruction, meta-analysis of impact literature and a farmer survey. We show that the trigger points of controversies were different in the two cases, and in general can emerge in any stage of a technology transition. In particular, in the agricultural innovation system, the ecological outcomes rather than economic outcomes are likely to be stronger focal points of controversy. Controversies are also likely to increase as the innovation system becomes complex. High immediate payoffs can override concerns founded on scientific uncertainty in the adoption of new technologies.

1. Introduction

Technological transitions, or paradigm shifts ushered in by radical innovations, are marked by uncertainty or a lack of complete and perfect information about possible outcomes. As a consequence, economic actors in the innovation system may not rank the different outcomes associated with a technology transition as they would in the absence of such informational constraints. At a macro level, in addition to preferences, informational constraints can lead to differences of opinion that escalate into prolonged public disagreements over technology choice. They may even become controversies posing a social dilemma, if there is a risk of misallocation of resources in promoting one option over another or if resources have to be channeled into consensus building in order to make a more informed choice. Hence, management of technology transitions without controversies are a challenge for policy makers, who have to spur economic growth through innovation generation while maximizing societal welfare. However, in economics, we do not yet have a clear understanding of how controversies emerge in the wake of radical technological breakthroughs and the paradigm shifts that follow.[1] Thus, the present paper aims to contribute to closing this gap through a detailed study of two recent technology transitions in the Indian agriculture sector.

In agriculture, once a plant type gains popularity, it is adopted widely and planted in multiple cropping seasons and suitable regions. Over a span of years, it becomes vulnerable to new pests and pathogens and eventually the yield of that variety comes down. This reality calls for continual investments in seed technology research to sustain agriculture productivity (Swanson, 2002; Peng et al., 1999; Peng et al., 2010). However, even if an innovation in the form of new plant variety offers a potential solution to improving productivity, it may not enjoy commercial success, unless it is accepted by key stakeholders in the innovation system. This could be due to controversies, which arise whenever there is a major conflict between the maintenance of 'land productivity', 'farmer livelihoods' and 'environmental preservation'. For governments, it is important to steer technology transitions in agriculture towards all three objectives, and for this, an understanding of controversies is essential.

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[1] A standard bibliometric search which was carried out in Scopus – Economics – citation database using the boolean string ('controversy') AND ('technology' OR 'technology transition' OR 'paradigm shift') in title, keywords and abstracts. The results yielded no journal articles that proposed theoretical frameworks to address the subject from an innovation systems perspective.

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The role of controversies in shaping technology transitions is an understudied topic, though it is widely acknowledged in innovation studies that it is not only the intrinsic technology characteristics that determine the scale of diffusion, but also the strategic positioning of key stakeholders vis-à-vis the innovation. In other words, while the 'why' of controversies in technology transitions can be explained as being due to mutually conflicting beliefs, the 'how' requires further examination. Thus, the objective of the present paper is to study how controversies emerge and influence technology transitions. For this purpose, a theoretical construct is formulated and thereafter validated through application to two technology transitions that have deeply marked Indian agriculture, namely the Green Revolution in cereals and genetically modified cotton.

The Green Revolution (henceforth GR) in Indian agriculture is widely acknowledged to have been responsible for chasing away the specter of famine which haunted India during the 1960s. As a technology package involving improved quality seeds, also termed 'modern variety' seeds, controlled irrigation and measured doses of fertilizers, GR was introduced in India through cooperation between international public agencies and Indian research laboratories. However, while GR technologies heralded a veritable increase in yields with respect to cereals, it left in its wake environmental concerns. Today, GR itself is felt to be yellowing and in its place, rejuvenation of the agriculture sector is being promised by a new technology paradigm, namely genetically modified plant varieties. Transgenic or genetically modified (henceforth GM) crops[2] were developed by the application of modern biotechnology to agriculture. As in GR modern varieties, GM plant varieties were also introduced through technology collaboration with foreign organizations. Only this time, the transfer took place entirely between private sector entities. Genetic engineering of plants, according to its protagonists, promises even greater advantages than GR technology, but according to its opponents, presents even greater ecological risks.

Examining the above context, the present paper makes two types of contributions to the economics of innovation literature. First, it offers a conceptual framework for studying technological transitions in agriculture combining the innovation systems perspective with a game theoretic approach. In particular, it includes Nature or ecology as an actor in the innovation system — a novelty with respect to standard innovation studies. Second, it provides new insights on how major controversies can arise by applying the conceptual framework to analyze GR and GM transitions in Indian agriculture. In the case of emerging technologies shrouded in uncertainty, our case studies illustrate that the confrontation of scientific uncertainty and perceived uncertainty lies at the foundation of controversies. Further, in agriculture, controversies are triggered by concerns about ecology rather than profits. At the same time, controversial technologies can enjoy success with adopters, if they are associated with immediate higher payoffs. The likelihood of controversy is determined by the characteristics of the innovation system in which it is embedded and our case studies indicate that as an innovation system gets more complex, the likelihood of controversy increases.

The remainder of our paper is organized as follows. Section 2 outlines the methodology. Section 3 introduces our conceptual framework. Section 4 contains three types of validation of our theoretical construct. Finally, Section 5 concludes with a discussion of our results and policy recommendations.

[2] "Genetically modified (GM) crops are those that have been genetically enhanced using modern biotechnology to carry one or more beneficial new traits. Modern biotechnology as defined by the Cartagena Protocol on Biosafety as a means the application of: (a.) In vitro nucleic acid techniques, including recombinant deoxyribonucleic acid (DNA) and direct injection of nucleic acid into cells or organelles, or (b.) Fusion of cells beyond the taxonomic family, - that overcome natural physiological reproductive or recombination barriers and that are not techniques used in traditional breeding and selection" (Biotechnology, in, International Seed Federation) Biotechnology, in, International Seed Federation.

2. Methodology

We apply a mixed methodology to answer our central questions of how controversies emerge and influence technology transitions. A theoretical construct of technology transitions in agriculture is first developed. Then it is validated using qualitative research methods. A three stage procedure comprising historical reconstruction of GR and GM transitions in India, analysis of impact literature and survey of Bt cotton farmers is applied. At each stage, results are inferred, and then in the final section, they are combined together to provide a broader analytical insight for the management of controversies in other sectors as well. Multiple sources of data, both primary and secondary, are used to construct our arguments. This multipronged research strategy provides a strong empirical base for the validation of our framework and to arrive at results that constitute a grounded theory (Glaser and Strauss, 2009).

The theoretical construct developed in this paper draws upon the evolutionary economics literature on technology transitions. Using this framework, the history of the introduction of the two radical technological innovations in Indian agriculture is reconstructed in order to understand the role of the different actors, their strategies and the outcomes of their strategies. The case study method is applied, because it is suitable for identifying the 'how' of phenomena (Yin, 2002; Eisenhardt, 1989).

A second validation is carried out through a meta-analysis of the socio-economic impact of GR and GM. The corpus is constructed by looking into the economics literature as well as Government and NGO reports. The focus of the meta-analysis is to identify if there are any differences in findings about the ecological and economic impacts of GR and GM transitions.

A third application of our framework consists of a survey of Bt cotton farmers to discern impact perceptions. Given that controversies on Bt cotton are centered on economic and ecological outcomes, the farmer survey provides us the necessary critical complementary insights. The survey applies a semi-structured questionnaire designed to yield information on personal experiences with Bt cotton.

At this juncture, some limitations of our methodology and approach are acknowledged. An axiomatic theoretical construct can only serve to illustrate a phenomenon or a theory, but does not constitute a theory in itself. Similarly, while case studies are useful to understand processes, they can only give indicators of cause and effect. These important points have been kept in mind while drawing inferences. With respect to a comparison of GR and GM in India, a variety of crops were improved and commercialized under GR as opposed to only cotton under GM. Furthermore, cotton is a cash crop and resistance to a class of pests via transgenes is only one technological solution among the many offered by the emerging GM paradigm. Despite these differences, the dynamics of their diffusion have been compared as they yield valuable insight on our research query. On another note, the primary data used to validate our model is based on a survey of 127 farmers who have adopted GM cotton in India. While this sample is not representative of the thousands of Indian farmers growing GM cotton, we do believe that it is adequate for testing the conceptual framework developed in the present paper.

3. A theoretical construct

3.1. Innovation system and characteristics of agricultural production

In economics, technology is given by efficient input-output combinations, where efficiency signifies that the set of inputs represents the minimum amount of each input (in that combination) required to produce the associated output. Technologies emerge and evolve within the national and sectoral systems of innovation. A national system of innovation refers to the structure and functioning of a system comprising economic actors who are responsible for the creation, development, diffusion and adoption of innovations within a country (Lundvall,