Abstract. This paper addresses the normative relationship between changes in technology and technical efficiency and the exploitation of common renewable resources. These changes can exacerbate the commons problem and deepen the externality. Their impact depends on the rate and nature of change, levels of effort and resource stock, and state of property rights. The paper develops an augmented fundamental equation of renewable resource economics with a modified marginal stock effect and a new marginal technology effect term that account for changes in technology and technical efficiency. Neglecting these changes generates misleading policy advice. An empirical application illustrates the results.

Key words: Technical change, common renewable resources, fundamental equation of renewable resources, economic efficiency

JEL Codes. O13, O33, Q22, Q28

Acknowledgements. The authors are grateful to David Au, John Childers, Paul Crone, and Pat Tomlinson for providing the biological parameters, advice on the population dynamics, and the U.S. catch and effort time series data used, to Jenny Sun and Ben Gilbert for econometric advice, to the American Fishermen’s Research Foundation and the U.S. albacore troll industry for collecting the panel data, and John Holmes of the Department of Fisheries and Oceans Canada for the Canadian vessel data. The authors are grateful to workshop participants in Helsingor, Denmark, to seminar participants at Australian National University, La Trobe University, and University of Queensland, and to participants at the Vietnam meeting of the International Institute for Fisheries Economics and Trade (IIFET) for comments. The authors remain responsible for any errors. Squires is grateful to the University of Southern Denmark for support during a sabbatical. The results are not necessarily those of the U.S. National Marine Fisheries Service.
1. Introduction

Technical progress and gains in economic efficiency are generally viewed as favorably contributing to economic growth and welfare, but does this normative conclusion hold for industries exploiting common renewable resources? What are their effects on the paradox between the individual firm’s private economic efficiency and economic efficiency and social costs at the level of society with common renewable resources (Gordon 1954)? In short, what is the relationship between technical change and a broad notion of efficiency with the “Tragedy of the Commons” and the optimum exploitation of common renewable resources?

The normative economics literature on common renewable resources has largely overlooked technical change and its effects, instead focusing on steady-state levels of effort or capital stock, resource stock, yield, and their dynamic approaches under constant technology.1 Smith (1972), an exception, examined induced technological change and common renewable resources, finding that an unpriced common resource induces technical change in favor of increased utilization of the unpriced resource and that the competitive pressures of the race to fish can compel firms to adopt process innovations. Dasgupta (2008) recently reiterated these points and further discussed the relationship between technical change (and economic growth) and the shadow price of common renewable resources and other forms of natural capital and the role of property rights. Smith and Krutilla (1982) observed that technical change under open access accelerates the dissipation of resource rent and depletes resource stocks that are already overexploited.2 McAusland (2005) considered technical progress that directly affects the intrinsic growth rate of the resource stock but not the production technology, and was not concerned with direct normative economic optimization of resource exploitation. Murray (2007) introduced
exogenous and disembodied technical progress into a static Gordon-Schaefer model of a fishery to show that not accounting for technological change can lead to overestimated natural growth of the resource stock and that inputs must be removed from the fishery at the rate of technological change to sustain the harvest target, and simulated the probability of resource stock collapse. In short, the normative literature has yet to formally analyze the impact of technical progress upon optimum exploitation of common renewable resources within a formal normative framework.

This literature has considered non-autonomous models, but focused on exogenous price shocks (Clark 1990). This normative literature has similarly overlooked the notion of economic efficiency developed by Debreu (1951) and Farrell (1957), to instead concentrate solely on the efficient scale of production, i.e. on the optimum level of effort.³

In contrast, the normative exhaustible resource and sustainable growth literature has paid considerably more attention to technical progress and to substitution possibilities between the resource stock and inputs in discussions of natural resource scarcity, limits to growth, and backstop technologies (Arrow et al. 2004, Simpson et al. 2005). Farzin (1995), Berck (1995), and d’Autume and Schubert (2008) summarized the literature on technical progress and exhaustible resources and focused upon the impact of technical change on measures of resource scarcity. Climate change and the need to reduce fossil fuel and carbon emissions are focusing considerable attention upon induced technical change, with recent surveys by Jaffe, Newell, and Stavins (2003) and Pizer and Popp (2007).

This paper contributes to the normative economic literatures on technical change, efficiency, and optimum exploitation of renewable resources by introducing both output-oriented Debreu-Farrell technical inefficiency and technical progress into normative static and dynamic models of an industry exploiting a common renewable resource and examining the economic and
policy ramifications. The paper develops the bioeconomic stages of production and clarifies that normative renewable resource models focus solely on scale efficiency and overlook technical and allocative efficiency. The most important contribution is an augmented fundamental equation of renewable resource economics that incorporates changes in technology and technical inefficiency into a new term, the marginal technology effect, and modifies the existing marginal stock effect. The results show that lower costs from technology generally outweigh lower costs from a higher resource stock and that resource stock levels can decline far below the steady-state equilibrium with static technology. The renewable resource model is developed for a fishery using the classic Gordon-Schaefer specification (Schaefer 1957, Gordon 1954), which lies at the heart of this literature and allows direct and analytic development of the modified Golden Rule. The technical change specified is disembodied, exogenous, and learning-by-doing and -using.

Overlooking technical progress and technical efficiency in common renewable resource industries in a normative framework has profound policy consequences through exacerbating the commons problem under open access or potentially generating misleading policy advice in terms of economic optimum levels of the resource stock, yield, effort (input use), and economic welfare. In fishing industries, for example, once fish could no longer hide from vessels that are increasingly more technologically advanced, the stage was set for the current overfishing crisis in many of the world’s fisheries. In fact, perhaps the single greatest pressure on global fisheries is technical progress, now that fishing fleets’ capital stocks have built up to an overcapitalized state, but policy advice that remains focused solely on reducing capital stocks, fishing effort, or subsidies overlooks the ongoing march of technology that allows even reduced capital stock or effort to be more effective at finding and harvesting fish. Similarly, technical progress contributed mightily to the decimation of many of the great whale stocks (Davis et al. 1987).
Section 2 develops a stochastic stock-flow production frontier incorporating technical change and technical inefficiency. Section 3 introduces this production frontier into the simple static Schaefer model that forms the basis of Section 4’s static Gordon-Schaefer bioeconomic model, the workhorse of renewable resource economics, examining the Nash equilibrium of open access. Section 5 extends the Gordon-Schaefer rent frontier to the static steady-state Pareto optimum, i.e. the sole owner of Scott (1955). Section 6 develops the backward bending supply curve with technical progress and inefficiency based on the static Gordon-Schaefer rent frontier. Section 7 develops a simple normative dynamic model of the economic optimum incorporating technical inefficiency and technical change, culminating with an augmented Golden Rule or fundamental equation of renewable resources incorporating the new marginal technology effect term and a modified marginal stock effect. Section 8 considers several policies. Section 9 introduces the empirical application. The unavailability of detailed capital and investment data for the empirical example precludes an empirical analysis of embodied technical change. Section 10 provides the empirical results. Section 11 provides concluding remarks. The main static results are summarized in Table 1 for conditions with and without technical change or technical efficiency. Table 2 summarizes the main dynamic model results. All derivations in the paper are available in a separate Appendix from the authors.

2. Fishery Production Frontier

The stock-flow production function in time $t$ relates catch, $Y_t$, to the fish stock, $S_t$, and fishing effort, $E_t$ (Schaefer 1957): $Y_t = f(q_t, E_t, S_t)$. Catch is the output or flow from the resource stock, and the resource stock and fishing effort are specified as aggregate inputs. Effort is typically considered as the first stage in a two-stage production process and implicitly assumes