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Technology adoption and diffusion with uncertainty in a commons

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HIGHLIGHTS

- We model technology adoption in a commons with uncertainty in the resource stock.
- Firms use their own resource extraction to update priors on the value of technology.
- Initial adoption and diffusion rates are greater when the resource stock is larger.
- Diffusion is faster when competition for the resource is stronger.

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ABSTRACT

We model adoption and diffusion in a commons under uncertainty about a technology's value. Technological resource stock externalities make technology less valuable with depleted stocks, but transmit information about a new technology's value, causing faster adoption of high-value technologies.

1. Introduction and motivation

Do firms have different incentives to adopt resource extraction technologies when the resource is held in common? Zero steady state rents would suggest the value of technology adoption is limited, yet adoption of new technology may increase one's share of the resource. Several empirical studies have documented rapid adoption in open access fisheries and an emerging literature examines the impact of technological change on renewable resource abundance and welfare (Squires, 1992; Hannesson et al., 2010; Fissel and Gilbert, 2010; Gordon and Hannesson, 2011; Murray, 2012; Squires and Vestergaard, forthcoming). To this end, Squires and Vestergaard (forthcoming) find a normative relationship between technological change specific to the commons. The consequences for common resources may be large; Murray (2012) shows that ignoring technical change when assessing resource stock size can lead to sudden collapse of the resource and the industry, and Fissel and Gilbert (2010) show that technical change can cause boom and bust cycles and exacerbate excess entry. This literature has not studied adoption and diffusion incentives. The problem is important for other common pool resources such as forests and groundwater.

A new technology's productivity is typically uncertain to market participants. The potential profitability and the spread of information about the new technology are two key determinants of adoption and diffusion (Sunding and Zilberman, 2001). In resource extraction industries in particular, uncertain harvest conditions

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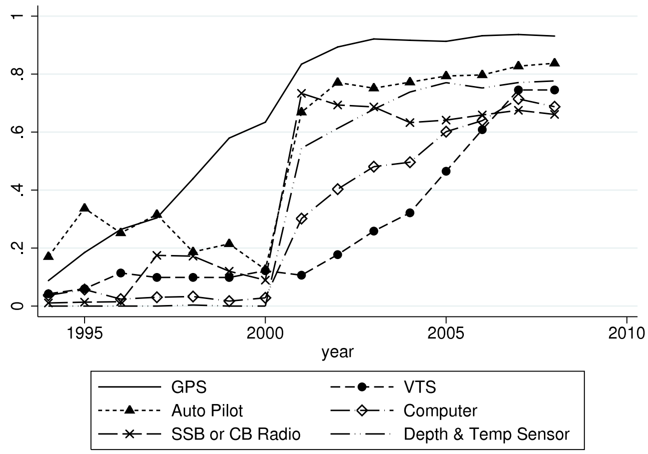

Fig. 1. Technology diffusion for various electronics in the NEGF.

make identification of the marginal effect of a new technology on productivity difficult. In this paper we develop a simple model of technology adoption specific to the commons. In the model, the quality of a new technology is uncertain. The contribution of this paper is to identify how uncertainty over the quality of the new technology manifests in a common pool resource.

As motivation, consider the New England groundfish fishery (NEGF), a multispecies, multi-gear fishery targeting cod, haddock, pollock, hake, and flounder. After being essentially open access through 1999, the NEGF underwent two important management changes in 2000 and 2004. Regulations in 2000 created new definitions of overfishing resulting in tighter caps, more closures within seasons, and a limited number of firms participating. One way of interpreting these changes is that the fishery went from a de facto open access fishery to one managed with an annual cap on time and total harvest.

In 2004 the fishery underwent another change. The Northeast Fisheries Management Council (NEFMC) further tightened limits on fishing time and implemented a formal quota sharing agreement with Canada with annual harvest caps for each country and monitoring of US catch. It is possible that the restrictions imposed in 2000 and 2004 increased harvest competition within fishing seasons. However, resource stocks did not markedly recover.

Fig. 1 shows diffusion rates for a variety of equipment for individual vessels surveyed between 1994 and 2008. The data presented are from individual surveys of vessels given by federal on-board observers. The figure shows a distinct increase in the uptake of new technologies in 2000 as the fishery went from open access to a more constrained form of a common pool in which externalities between boats within a season may have been greater.[1] These graphs are shown for motivation of the model in the next section and caution should be taken in drawing any strong conclusions considering the short time period and lack of a comparison group.

2. The model

We model adoption in the context of resource stock uncertainty when the productivity of the new technology is also not known. Consider a group of fishing vessels or firms supplying unit effort E inelastically (we consider a vessel to be a firm and will use the terms interchangeably) such that the relationship between effort and harvest is entirely determined by the resource stock size X, the stock elasticity α (assumed to be one[2]) and the level of technology θ: $y = \theta X^{\alpha} E = \theta X$. Assume that a new technology is available for a fixed cost F that could be a high productivity technology (θ_H) or a low productivity technology (θ_L) such that $\theta_H > \theta_L \geq \theta$. This formulation of the production function constrains signals of the technology's productivity to the resource stock. Thus, the harvests of other firms carry information about the technology's productivity through the resource stock. Note that this is true even if the harvests and profits of other firms are not directly observable.

Firms are homogeneous except in their initial belief $\tau_{i0} \in (0, 1)$ about the probability that the technology is of type θ_H. An alternative model could have heterogeneous initial productivity θ_i so the value of the marginal increase in θ_i is different across firms. Note, though, that the results of this model of idiosyncratic beliefs about the productivity of the new technology would not change if firms have heterogeneous productivity.[3]

Non-adopting firms receive signals about the productivity of the new technology through the stock's effect on their own harvest. Information accrues according to the following process within each period: There is a stock or level of escapement that is carried over from the previous period, X_{t-1}. At the beginning of the period, recruitment to the stock (or growth) occurs as an unobserved draw from a time independent distribution[4] $\epsilon_t \sim U[\underline{\epsilon}, \overline{\epsilon}]$. For notational simplicity define the expected recruitment as $E[\epsilon] = \mu$. Fishing occurs by all vessels simultaneously and every firm observes its harvest y_{it}. Beliefs are then updated according to Bayes Rule. Adoption decisions are then made at time t before the start of the next time period.

First, consider the initial decision of a firm to adopt the technology as a function of some initial belief τ_{i0} that the technology is of type θ_H. For simplicity, assume that there are two ex ante homogeneous vessels each with full knowledge of the previous period's escapement, X_{t-1}. The expected yields from adopting the new technology assuming the other vessel does not adopt are:

$$\begin{aligned} E(y_{it}|\tau_{i0}) &= \tau_{i0}\,[\theta_H(X_{t-1} + \mu - k\theta(X_{t-1} + \mu))] \\ &\quad + (1 - \tau_{i0})\,[\theta_L(X_{t-1} + \mu - k\theta(X_{t-1} + \mu))] \\ &= \tau_{i0}\theta_H(1 - k\theta)(X_{t-1} + \mu) \\ &\quad + (1 - \tau_{i0})\theta_L(1 - k\theta)(X_{t-1} + \mu). \end{aligned} \tag{1}$$

Here k can be thought of as the average effect of other firms' harvest on a firm's own harvest within a season. By withdrawing from the same stock, all other vessels leave a smaller effective stock $(1 - k\theta)(X_{t-1} + \mu)$ available for an individual vessel to harvest in that season. Assume $k < 1$ and $k\theta < 1$ so that k represents the intensity of the externality between firms in the common pool within a given time period.[5]

Given the form of Eq. (1), the expected benefit of adopting the new technology is the difference between expected profits with

[1] The composition of sampled vessel types changed somewhat during the sample period, but the diffusion patterns shown are consistent within each category of vessel size and gear type.

[2] We assume $\alpha = 1$ for simplicity. This assumption does not change the qualitative results although $\alpha < 1$ would reduce the magnitude of the effects found in Propositions 1 and 2 because harvest would be less sensitive to available stock and convey less information about technology. $\alpha < 1$ is typically true in fish that swim in schools, although even in these cases $\alpha > 0$.

[3] Without heterogeneous θ, this model informs the initial adoptions rates as opposed to the initial adoption levels. Changes in initial adoption levels could be layered onto this model.

[4] The uniform distribution is assumed for clarity but all results hold for a more general distribution. This includes density dependent innovations or growth under mild assumptions. More critical is the assumption that innovations to the stock must be observable, perhaps with error.

[5] A more precise model would perhaps look like $\int_0^T \theta(X + \epsilon - \theta_{-i}(X + \epsilon)s)sds$. However, Eq. (1) is a good first approximation.