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Disruption costs, learning by doing, and technology adoption☆

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ABSTRACT

We study technology adoption in a dynamic model of price competition. Adoption involves disruption costs and learning by doing. Because of disruption costs, the adopting firm begins in a market disadvantage, which may persist if its rival captures the customers that the adopting firm needs to learn the technology. The prospect of future rents by the rival results in: (i) a failure to adopt socially efficient technologies; (ii) an equilibrium preference for technologies that are learned faster but have lower social value; and (iii) more technologies being adopted if more firms enter the market.

1. Introduction

The adoption of new technologies is the leading force behind productivity growth in many industries. Still, when a new technology is adopted things often go wrong in the beginning. Adopting firms face mayor adaptation problems and become temporarily less productive than non-adopters. Such problems, known as switchover disruption costs, may be overcome through learning by doing as firms accumulate experience using the new technology. In fact, the idea that productivity growth first falls and later rises after the adoption of a new technology is supported by the micro-evidence according to Huggett and Ospina (2001).

The relevance of disruption costs is well-known in the management literature. Christensen (1997) provides ample evidence of disruptive technologies that result in worse product performance in the near-term. Tyre and Hauptman (1992) list as sources of disruption costs the novelty of technical features, the low applicability of previous knowledge, and the incompatibility of current organizational practices with the arriving innovation. In the economics literature, Holmes et al. (2012) provide an excellent discussion of the importance of disruption costs in a number of innovation episodes. Likewise, the business strategy consulting industry has found extensive empirical evidence of experience curves (Henderson, 1968). Economists have also studied the empirical evidence on, and the theoretical implications of, learning by doing since the seminal works of Wright (1936) and Arrow (1962a).[2]

The interplay between disruption costs and learning by doing in strategic settings has been mostly overlooked in the literature. This is unfortunate because many industrial innovations take place in oligopolistic environments where strategic issues play a leading role. In this article we develop a simple model to study technology adoption in a strategic setting with disruption costs and learning by doing.

Our main observation is that non-adopting firms have incentives to undercut prices to prevent the learning of the new technology because this makes the adopting firm a weaker future competitor. The prospect of future rents by non-adopting firms places a pecuniary cost on the adopting firm that, in some cases, renders the adoption of Pareto superior technologies unprofitable. That is, as 'stealing' current customers

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[2] Thompson (2010) reviews both strands of the literature.

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from the adopting firm creates future rents without adding any social value, the know-how needed to learn the new technology becomes an artificially overpriced 'asset' in the market.

The idea of firms sweeping away competition through dynamic pricing relates to the literature on exclusionary contracting with multiple customers (see Rasmusen et al., 1991, 2000; Segal and Whinston, 2000). In these papers a buyer accepts a personalized and exclusive discount by the incumbent, disregarding the fact that his decision may make the (socially desirable) entry of a competitor unprofitable and reduce the surplus of other (possibly future) buyers who are not offered the discount. A similar externality prevents the adoption of Pareto superior technologies in our model: when a costumer buys from a non-adopting firm, future customers face a less competitive industry with higher prices.[3]

We study these issues in a dynamic duopoly model of Bertrand competition in which the adopting firm has a limited amount of time to learn the new technology. This time limit may come from the threat of imitation and the expiration of a patent. In the model firms offer potentially differentiated products to a sequence of short-lived customers with unit demand. The main advantage of this setting with respect to others, e.g., a Cournot model of competition, is that it isolates the dynamics of adoption by assuming away static equilibrium distortions.

Within this framework, we obtain three main results. First, we confirm that, in some cases, the adopting firm prefers to stick to an old technology rather than to switch to a better one. Second, we show that, for the cases of interest, between two technologies with the same social value, the adopting firm prefers the technology whose flow payoffs are received earlier. This equilibrium bias towards technologies with larger early rewards is called the impatience property. As a corollary, we prove that the bias embedded in the impatience property favors the adoption of technologies that are learned faster but may have lower social welfare. Third, we show that adoption is made easier if more firms enter the market. More precisely, we prove that adding non-adopting firms to our model enlarges the set of (efficient) technologies that are adopted in equilibrium. Taken together, our results should warn regulators of keeping an eye on industries either with few competitors or where technological improvements take longer to settle. In our view, these are the industries in which disruption costs and learning by doing raise a strategic barrier to efficient adoption and productivity growth.

Holmes et al. (2012) also study adoption in the presence of switchover disruptions. Using an Arrow-type model, they show that a more competitive environment favors adoption as the cost of adopting a technology is the forgone profits during the disruption period.[4] Our insight is different as we stress that disruption costs open a future profit opportunity to competing firms. In line with a large body of evidence (see Holmes and Schmitz, 2010) we also show that additional competition may promote adoption. But while in HLS's article competition is beneficial because it reduces the forgone profits of the adopting firm, in our case it is so because it limits the spurious rents of non-adopters. Our mechanism thus offers a novel channel through which extra competition facilitates the adoption of a new technology.

Schivardi and Schneider (2008) study a dynamic investment game of disruptive change. In their model an incumbent decides when to adopt a design of unknown potential that a startup firm already uses. They show that the incumbent may delay adoption to learn the value of the new design, exploiting an informational externality from the startup. In our model the adopting firm learns on its own rather than from others, and about the very production process rather than about its potential. Besides, Schivardi and Schneider (2008) do not assess the impact of disruptions and learning on market power and adoption incentives.

In the industrial organization literature, dynamic price competition and learning by doing have been explored by Cabral and Riordan (1994) and, more recently, by Besanko et al. (2010, 2014). The goal of these articles is to understand how learning by doing, jointly with organizational forgetting in Besanko et al. (2010), determines pricing and market dominance in a duopolistic setting. We complement their analyses by showing that the interplay between learning and disruptions drives a wedge between private and social rewards that may result in inefficient technology adoption.

Our work is also related to a list of macro articles in which learning and disruption costs are at the center of the stage. In price-taking environments, Chari and Hopenhayn (1991) and Parente (1994) examine adoption when the implementation of a technology entails losing previously acquired knowledge. Jovanovic and Nyarko (1996) add to this literature by studying the full dynamics of technology adoption in a one-agent Bayesian model of learning by doing. Klenow (1998) examines a firm's decision of when to update a process technology. In contrast to these articles, we consider an oligopolistic setting and show how the ability of non-adopting firms to manipulate prices raises a barrier to technology adoption. This is the key distinctive feature of our work.

The remainder of this article is organized as follows. Section 2 presents the model. Section 3 provides a stripped-down, illustrative example of an adoption breakdown. Sections 4 and 5 introduce some useful concepts and preliminary findings. Section 6 presents our main results. Section 7 concludes. Proofs are collected in the Appendix A.

2. The model

We present a simple, canonical model of learning by doing and technology adoption in the spirit of Cabral and Riordan (1994) and Besanko et al. (2010, 2014).

2.1. The industry

Consider an industry with two firms denoted by $i \in \{1, 2\}$ and a finite number of $T + 1$ customers with unit demand. Sales take place over time: at each period only one customer is available to buy from the firms. Time is denoted by $t \in \mathrm{T} := \{0, \dots, T\}$ and, without loss of generality, firms do not discount the future. Firms start with a baseline technology that allows them to produce at a cost c_0 a unit of a product that customers value at v_0.[5] With s_0:$v_0 - c_0$ we denote the constant, positive flow (per-period) surplus that is created every time a firm sells to a customer using the baseline technology.

2.2. Technology adoption

To ease the exposition, we assume that only firm 1 can adopt a new technology. The new technology may bring either product quality improvements or cost savings, and it is described by the flow surplus it creates at each sale by firm 1. This flow surplus, in turn, depends on the state of the technology via the formula

$$s(x_t) = v(x_t) - c(x_t),$$

where x_t is the stock of know-how (cumulative experience) in using the technology at the beginning of period t, and v and c are the new technology's value and cost. By making a sale, firm 1 adds to its stock of know-how. Hence, the evolution of firm 1's stock of know-how is controlled by the law of motion

$$x_{t+1} = x_t + y_t, \quad x_0 \geq 0 \quad \text{given},$$

[3] We thank co-editor G. Calzolari for pointing out this connection.

[4] Arrow (1962b) was the first to compare adoption incentives under perfect competition and monopoly. However, in Arrow's article and in the literature that follows, for example Gilbert and Newbery (1982), there is neither learning by doing nor disruption costs.

[5] Our results also hold true for asymmetric values and costs.