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Intra-plant diffusion of new technology: Role of productivity in the study of steel refining furnaces☆

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ABSTRACT

This paper examines intra-plant diffusion of new technology in the Japanese steel industry. The introduction of the basic oxygen furnace (BOF) was the greatest breakthrough in steel refining in the last century. Using unique panel data, the paper estimates total factor productivity by technology type, and associates the estimates with intra-plant diffusion. The paper finds that intra-plant diffusion accounts for about a half of the industry productivity growth. Large plants are likely to adopt the new technology earlier, but retain the old technology longer, than their smaller counterparts.

1. Introduction

Diffusion of new technology has been viewed as the main driving force of economic growth. An important set of questions often raised in the literature concerns what factors determine a firm's decision to adopt a new technology. While this issue of inter-firm technology diffusion has been extensively studied, the adoption of new technology is not in and of itself sufficient for economic growth.[1] For the social benefits of innovation to be realized, the outcome of an innovation must not only be adopted by a firm, but also be extensively utilized in economic activities. Productivity and outputs would not increase in response to the adoption of new technology, if the utilization of the technology remains low. As Mansfield (1963: 356) explains, the accurate measurement of the rate of intra-firm diffusion—the rate at which a particular firm substitutes a new technology for old in its production process—requires firm-level data that identify how capital is utilized by technology type.

Using unique plant-level panel data, this paper analyzes the role of productivity in intra-plant diffusion, which has received little attention in previous empirical examinations. In particular, we focus on the refining furnace technology in the Japanese steel industry. In the 1950s and 1960s, many integrated steel makers updated their technology, shifting from the conventional open-hearth furnace (OHF) to the imported basic oxygen furnace (BOF). The introduction of the BOF was praised as "unquestionably one of the greatest technological breakthroughs in the steel industry during the twentieth century" (Hogan, 1971: 1543). Interestingly, the period of the rapid dissemination of BOF technology coincides with that of the remarkable growth Japan experienced in the wake of the devastation wreaked by World War II. The steel industry expanded its production more than fourfold between 1953 and 1964, making Japan the world's largest steel exporter by 1969. As we discuss in Section 2, intra-plant diffusion played a major role in BOF diffusion, resulting in substantial industry growth in the 1950s and 1960s. Restricting our study to examining refining furnace technology allows us to abstract from market structure effects in our study; virtually all steel plants faced the same market for crude

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[1] Although the data used here refer to plants rather than firms, we use the terms "plant" and "firm" interchangeably, so as to conform to current usage in the literature.

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steel, a homogeneous product manufactured from the refining furnaces. The nature of the market, along with the output data by technology type, allows our analysis to focus on the influence of other determinants of intra-plant technology diffusion. Our unique furnace/plant-level data set covers the inputs and outputs from each furnace type, and the timing and size of new capital installation. The data permit an estimation of the production function based on furnace technology and the measurement of the change in productivity and output growth in the intra-plant diffusion of new technology.

Our estimation results indicate that intra-plant diffusion makes a significant contribution to the industry-level productivity growth, and accounts for more than 70% of the diffusion of the new-technology in terms of industry production capacity. Furthermore, the estimates indicate that differences in the productivities of new and old technologies owned by a plant is negatively correlated with the rate of intra-plant diffusion; if a new technology is more productive than an old one within a plant, the plant will shift its production process from the old to the new technology faster than it would otherwise, so as to minimize the opportunity cost of retaining the old technology. The paper also observes that large plants are likely to adopt the new technology earlier than their smaller counterparts. This finding is consistent with those found in the literature on inter-firm diffusion such as in Rose and Joskow (1990).

In his survey of the literature on new technology diffusion, Geroski (2000) identifies two leading models: the epidemic and probit models. The first model, originally proposed by Mansfield (1963), predicts that the extent of use of a new technology within a plant increases with the number of years since the first adoption. Fig. 1 traces the intra-plant diffusion rate of BOF, i.e., the changes in the share of BOF in a plant's total capacity size, for each of all thirteen plants considered in the paper. Note that they are those that switched from OHF to BOF. Although the BOF share generally increased over the study period, the epidemic model does not fully explain the BOF use observed in Fig. 1; the years elapsed since the first BOF adoption, with the use of a third-order polynomial of the variable, explain about ten percent of the total variability of the BOF output share, a finding similar to that of Battisti and Stoneman (2005). In the empirical implementation on intra-plant diffusion, along with explanatory variables that are considered as proxies for the epidemic effect, we incorporate variables that feature the alternative model—the probit model, which presumes that differences in the diffusion rates reflect differences in firm and technology characteristics. Estimation of the model indicates a difference in the productivity of new and old technologies across plants, an important determinant of the intra-firm diffusion of new technology.

The rest of the paper is organized as follows. Section 2 provides an overview of the Japanese steel market after the Second World War. It describes several important features of the market that have a direct bearing on the formulation of empirical strategies and on the interpretation of quantitative results discussed in the subsequent sections. Section 3 describes our data sources and presents a method for estimating productivity of furnace technologies. The panel feature of our dataset enables us to correct for endogeneity problems when measuring productivity. Using the obtained productivity estimates, the section evaluates the extent to which the intra-plant diffusion contributed to productivity growth. Section 4 quantitatively examines the forces that drive the intra-plant diffusion pattern observed in Fig. 1. The analysis reveals that productivity difference between old and new technologies is an important vehicle in intra-plant diffusion of new technology. Section 5 discusses the relationship between productivity and both inter- and intra-plant diffusion patterns of new technology. Section 6 presents our conclusions, followed by the appendices on the data sources and estimation method used in the paper.

2. Overview of the post-war Japanese steel market

In the early 1950s, most Japanese steel was produced by integrated steel manufacturers. Integrated steel works transform raw materials (iron ore and coking coal) into pig iron in a blast furnace. Pig iron is subsequently transformed into crude steel in a second furnace by removing carbon and other elements. The prevalent technology used in this second or "refining" stage was the OHF, which blows burning fuel gas over the molten pig iron, which provides the heat required to purify the pig iron. In the late 1950s, the OHF began rapidly losing ground to the BOF. This new technology blows oxygen to oxidize the iron, making it possible for steel makers to refine molten iron and scrap charge into steel in approximately 45 min—a sharp decrease from the 6 h that the OHF normally required then. Since molten pig iron is a key input for the BOF and the pig iron is made by blast furnaces, we focus our attention to plants owning blast furnaces as well as OHFs. At the time the BOF was invented, there were thirteen plants owned by nine firms, utilizing blast furnaces as well as OHFs, all of which have shifted their entire steel refining technology from OHF to BOF by early 1970s. Our data set is derived from these thirteen plants.

Invented in Austria, BOF technology was further developed by Japanese steel makers after being imported to Japan. The Japanese have been responsible for the two most important improvements in the BOF hardware: the multi-hole lance and the oxygen converter gas recovery system (OG system) (Lynn, 1982: 34; Odagiri and Goto, 1996: 149). The multi-hole lance reduces splashing in the BOF, thus increasing steel-making yield and improving refractory life. Over the course of our study period, the BOF lance continuously improved its capability for softer blowing at lower velocities while achieving higher production rates. The OG system allows the recovery of gases from the BOF. It controls pollution and helps reduce energy costs, while contributing to steel-making yield. These "user-centered technological improvements" (von Hippel, 2005) associated with the BOF are known to have contributed to the increase in steel-making productivity in Japan. In Section 3, we observe the effects of these user-side technological innovations on the process of intra-plant diffusion. [2]

Fig. 2 illustrates the diffusion of the new technology observed from the dataset. Three BOF diffusion paths are plotted in the figure: overall diffusion is the BOF share in the industry's total capacity size; inter-plant diffusion is defined by the percentage of plants that installed at least one BOF out of the population of 13 plants; and intra-plant diffusion is the annual average across all thirteen intra-plant diffusion patterns shown in Fig. 1. The inter-plant diffusion indicates that all plants represented in the data had adopted the BOF by 1965, at which time within-plant technology penetration had reached approximately 30%, and intra-plant diffusion became the sole driving force of the overall diffusion. Interestingly, it was between 1965 and 1970 that the Japanese steel industry doubled its output. The figure thus illustrates the importance of intra-plant diffusion in the later stages of the diffusion process. This finding has also been observed with regard to other technologies, including computer numerically controlled (CNC) machine tools as reported in Battisti and Stoneman (2004).

Industry circles have recognized that producing steel involves substantial learning from current and previous production. Hogan (1971) and Lynn (1982) both noted that it was only through extensive furnace use that detailed knowledge of furnace operation was gained. Both OHF and BOF refining furnaces cannot be operated without skilled workers. It was the experience and judgment of skilled workers that made it possible for plants to

[2] This paper does not consider the electric furnace (EF), because its share in production was small during our study period.