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The adjustment-cost model of the firm: Duality and productive efficiency

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ABSTRACT

We present the theoretical foundation for an adjustment cost technology that supports the intertemporal production decision making behavior using the directional distance function. Dynamic input efficiency measures are developed that can separate out the impact of variable and dynamic factors inefficiency levels. An approach to implement this theory in a nonparametric fashion is developed and applied to an unbalanced panel of Dutch glasshouse firms. The application finds overuse of all variable inputs and overcapitalization of installations, the overall dynamic efficiency gain of 16% remains possible, with allocative inefficiencies indicating underinvestment in structures and installations. A comparison of static and dynamic efficiency measures finds that the static overall cost inefficiency is overestimated with technical inefficiency being overstated and allocative inefficiency being understated.

1. Introduction

The adjustment-cost model of the firm is an intertemporal (dynamic) approach to the theory of the firm where adjustment costs associated with changes in the level of the quasi-fixed factors are the source of the time interdependence of the firm's production decisions (e.g., Lucas, 1967; Treadway, 1969, 1970; Rothschild, 1971; Mortensen, 1973). Hamermesh and Pfann (1996) present an interesting survey of the literature on adjustment costs. The adjustment-cost model of the firm has been widely used in empirical work (e.g., Luh and Stefanou, 1993, 1996; Nielsen and Schiantarelli, 2003; Letterie and Pfann, 2007; Letterie et al., 2010). However, primal and dual analytical foundations of the production theory with adjustment costs have not yet been explored as in the static theory of production.

Several primal representations of the production technology are defined and characterized axiomatically in the static theory of production, namely the production sets and the Shephard's distance functions (e.g., Shephard, 1970; Debreu, 1959; McFadden, 1978; Färe and Primont, 1995). Several generalizations of Shephard's distance functions have emerged in the production literature allowing extensions of the Farrell efficiency measures in the static context (e.g., Färe et al.,1985, Chapters 5–7; 1994, Chapter 8; Briec, 1997; Bogetoft and Hougaard, 1998; Chambers et al., 1996, 1998; Färe and Grosskopf, 2000a, 2000b; Chavas and Cox, 1999; Halme et al., 1999). Specifically, the directional distance functions approach has guided recently much of the development in efficiency and productivity analysis (e.g., Chambers, 2002, 2008; Ball et al., 2002a, 2002b; Färe et al., 2005).

In contrast, primal representations of the production technology in the context of the adjustment-cost theory of the firm have not yet been explored. The production function has been used, in general, as the primal representation of the adjustment-cost production technology (e.g., Epstein, 1981; Lasserre and Ouellette, 1999; Ouellette and Vigeant, 2001). Recently, other primal representations of the adjustment-cost production technology have emerged in the literature allowing for the possibility of multiple outputs. Sengupta (1999) addresses adjustment costs in an optimal control framework with a specification leading to a closed form solution of controls. Silva and Stefanou (2003) show that an adjustment-cost production technology can be represented by a family of input requirement sets satisfying some regularity conditions. A hyperbolic input distance function is defined in Silva and Stefanou (2007) to represent a production technology with adjustment costs and develop dynamic measures of production efficiency.

In this paper, a directional input distance function is defined and characterized to represent an adjustment-cost production technology. The adjustment-cost (dynamic) directional input distance function generalizes the directional input distance function developed by Chambers et al. (1996) in the static context. We further develop the theoretical foundations of dynamic production

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decision making behavior via duality relationships and an approach to implement this theory in a nonparametric fashion. Using this foundation for the adjustment-cost technology, measurement of dynamic efficiency using the directional input distance function and intertemporal duality are developed. The dynamic directional input distance function provides difference measures of relative efficiency as opposed to radial measures (e.g., Lin et al., 2010; Lin and Chiang, 2011; Nemoto and Goto, 2003; Ouellette and Yan, 2008; Wibe, 2008) or hyperbolic measures as in Silva and Stefanou (2007).

Static duality is well established in the production theory: duality between production sets and optimal value functions (e.g., Shephard, 1970; McFadden, 1978; Färe and Primont, 1995); duality between Shephard's distance functions and optimal value functions (e.g., Shephard, 1970; Färe and Primont, 1995); duality between directional distance functions and optimal value functions (Chambers et al., 1996, 1998; Färe and Primont, 2006). In contrast, intertemporal (dynamic) duality has been focused on the dual relation between the production function and the optimal value function of an intertemporal optimization problem (e.g., Epstein, 1981; Lasserre and Ouellette, 1999; Ouellette and Vigeant, 2001), and duality between the optimal value function and the instantaneous variable profit function (McLaren and Cooper, 1980). In the context of intertemporal cost minimization, this paper establishes duality between the adjustment-cost directional input distance function and the current value of the optimal value function.

This paper is structured as follows. In the next section, a directional input distance function is defined and characterized in the context of the adjustment-cost model of the firm. The dynamics are introduced in the production technology specification as an adjustment cost in the form of the properties of the directional input distance function with respect to the dynamic factors (or the change in the quasi-fixed factors). Section 3 establishes, in the context of intertemporal cost minimization, duality between the adjustment-cost directional input distance function and the current value of the optimal value function. Dynamic input-based efficiency measurement is discussed in Section 4. Dynamic input inefficiency measures are generated from the adjustment-cost directional input distance function and duality between this function and the current value of the optimal value function. The empirical implementation of these inefficiency measures is illustrated using DEA techniques and some of these measures are applied to panel data of Dutch glasshouse horticulture firms in the period 1997–1999. The discussion of the DEA models is presented in Section 5; the description of the data and the discussion of the empirical results are presented in Section 6. The final section concludes.

2. Dynamic directional input distance function

The adjustment-cost production technology at time t is represented by a family of input requirement sets. The input requirement set is defined as (Silva and Stefanou, 2003)

$$V(y(t)|K(t)) = \{(x(t), I(t)) : (x(t), I(t)) \text{ can produce } y(t) \text{ given } K(t)\}, \quad (1)$$

where $y(t) \in \Re^M_{++}$ is the vector of outputs, $x(t) \in \Re^N_+$ is the vector of variable inputs, $K(t) \in \Re^F_{++}$ is the capital stock vector and $I(t) \in \Re^F_+$ is the vector of gross investments (dynamic factors).

Including gross investment in the definition of $V(y(t)|K(t))$ implies maximum output levels not only depend on variable and quasi-fixed factors but also on the magnitude of the dynamic factors (change in the level of the quasi-fixed factors). Internal adjustment costs are incorporated in $V(y(t)|K(t))$ in the form of the properties of these sets with respect to the change in the quasi-fixed factors (see Silva and Stefanou, 2003).

Properties of V:

V.1 $V(y(t)|K(t)) \subset \Re^{N+F}_+$ is a closed and nonempty set.
V.2 $V(y(t)|K(t))$ has a lower bound.
V.3 $(x(t), I(t)) \in V(0_M|K(t))$ yet $(0_N, 0_F) \notin V(y(t)|K(t))$, $y(t) \geq 0_M, y(t) \neq 0_M$.
V.4 $(x(t), 0_F) \in V(y(t)|K(t))$.
V.5 If $(x(t), I(t)) \in V(y(t)|K(t))$ and $x(t)' \geq x(t)$, then $(x(t)', I(t)) \in V(y(t)|K(t))$.
V.6 If $(x(t), I(t)) \in V(y(t)|K(t))$ and $I(t)' \leq I(t)$, then $(x(t), I(t)') \in V(y(t)|K(t))$.
V.7 $V(y(t)|K(t))$ is a strictly convex set in $(x(t), I(t))$.
V.8 $K(t)' \geq K(t) \Rightarrow V(y(t)|K(t)) \subset V(y(t)|K(t)')$.
V.9 $y(t) \geq y(t)' \Rightarrow V(y(t)|K(t)) \subset V(y(t)'|K(t))$.

Some of these properties are the usual properties of input requirement sets in the static model of the firm: V.1 – V.3, V.5 and V.9. Properties V.4 and V.6 – V.8 are crucial to define the input requirement set in the context of the adjustment-cost model of the firm (Silva and Stefanou, 2003). Property V.4 postulates that it is possible to produce without making investment in the quasi-fixed factors. This property is consistent with infrequent adjustments in the quasi-fixed factors revealed by micro data (e.g., Ramey, 1991; Bresnahan and Ramey, 1994; Caballero et al., 1995; Caballero, 1997; Nielsen and Schiantarelli, 2003). Property V.6 states that V is negative monotonic in I, implying the marginal product of the dynamic factors is negative. In other words, this property implies there is a positive cost associated with investment in quasi-fixed factors, reflecting the presence of internal adjustment costs associated with gross investment. Property V.8 establishes that output levels are increasing in the stock of capital, implying the marginal product of the quasi-fixed factors is positive. Properties V.6 and V.8 together imply a trade-off between current production and future production: current changes in the dynamic factors decrease current levels of outputs but increase output levels in the future by increasing the future stocks of capital. Strict convexity in (x, I) (property V.7) implies, as shown below, the dynamic directional input distance function is strictly concave in (x, I).

Definition 1. The dynamic directional input distance function $\vec{D}$: $\Re^M_{++} \times \Re^F_{++} \times \Re^N_+ \times \Re^F_+ \times \Re^N_{++} \times \Re^F_{++} \to \Re$ is defined as follows:

$\vec{D}(y(t), K(t), x(t), I(t); g_x, g_I) = \max\{\beta \in \Re : (x(t) - \beta g_x, I(t) + \beta g_I) \in V(y(t)|K(t))\}$, if $(x(t) - \beta g_x, I(t) + \beta g_I) \in V(y(t)|K(t))$ for some β and $-\infty$ otherwise.

The vector $(g_x, g_I) \in \Re^N_{++} \times \Re^F_{++}$ is a nonzero vector determining the direction in which $\vec{D}$ is defined. This function measures the distance of $(x(t), I(t))$ to the boundary of $V(y(t)|K(t))$ in a predefined direction $(g_x, g_I) \neq 0_{N+F}$. Given that βg_x is subtracted from $x(t)$ and βg_I is added to $I(t)$, this function is defined by simultaneously contracting variable inputs and expanding dynamic factors. Properties V.1 and V.2 assure the maximization operation in Definition 1 is well-defined.

Fig. 1 illustrates the dynamic directional input distance function assuming one variable input and one dynamic factor. The input vector $(x(t), I(t))$ is projected onto the isoquant of $V(y(t)|K(t))$ at a point $(x(t) - \vec{D}(.)g_x, I(t) + \vec{D}(.)g_I) \in V(y(t)|K(t))$, $(g_x, g_I) \neq 0_{N+F}$. Fig. 1 shows three possible projections of the input vector $(x(t), I(t))$ associated with three directions: g^0, g^1 and g^2.

Using Definition 1, the following relationship can be established:

$$\vec{D}(y(t), K(t), x(t), I(t); g_x, g_I) \geq 0 \Leftrightarrow (x(t), I(t)) \in V(y(t)|K(t)), \quad (2)$$

$(g_x, g_I) \in \Re^N_{++} \times \Re^F_{++}$. This relationship means that the dynamic