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An intertemporal microeconomic theory of disembodied and price-induced technical progress

Michael R. Caputo [a,*], Quirino Paris [b]

[a] Department of Economics, University of Central Florida, P.O. Box 161400, Orlando, FL 32816-1400, United States
[b] Department of Agricultural and Resource Economics, University of California, One Shields Avenue, Davis, CA 95616, United States

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ABSTRACT

A theory of a wealth maximizing, capital accumulating, price taking firm facing adjustment costs and operating in the presence of disembodied and price-induced technical progress is developed. The testable implications of the extended theory are derived under mild assumptions and are thus intrinsic to the theory, not to mention observable, thereby permitting empirical scrutiny of them. The comparative dynamics properties are given in the preferred form of a symmetric and semidefinite matrix. The testable implications are contrasted with their archetypal counterparts from the adjustment cost theory. The comparison shows how (i) the introduction of disembodied and price-induced technical progress into the adjustment cost theory destroys all of its testable properties, and (ii) the disembodied and price-induced technical progress theory nests the adjustment cost theory as a special case.

1. Introduction

The idea that the market prices of goods affect the preferences of a consumer dates back to at least Samuelson (1947, p. 119), when he introduced money balances and the prices of goods in a consumer's direct utility function for the purpose of deriving a demand function for liquidity. Over the next several decades more than a few authors attempted, albeit unsuccessfully, to derive the observable and refutable comparative statics of this so-called price-dependent-preferences utility maximization model. Despite the negative intonation of the paper's title, it was Samuelson and Sato (1984) who provided the first complete qualitative characterization of the aforesaid model. Their work was later generalized by Paris and Caputo (2002).

On the theory-of-the-firm front, it appears that Hicks (1932) was the first to suggest that the market prices of a firm's inputs and output might influence the technology of a firm and thus be included as explicit arguments of its production function, by way of what we call his price-induced technical progress (TP) hypothesis. This is evident in the ensuing passage in Hicks (1932, p. 120):

> We may now proceed to examine more closely the things upon which the elasticity of substitution depends. Substitution, in the sense in which we are using it, may take any of three forms:
>
> 1. The change in the relative prices of the factors may lead simply to a shift over from the production of things requiring little of the increasing factor to things requiring more. If capital increases, the commodities in whose production capital had already been used to an extent above the average will become cheaper relatively to others, and presumably, therefore, more of them will be made.
> 2. Methods of production already known, but which did not pay previously, may come into use. This form will include, possibly as its most important case, the mere extension of the use of instruments and methods of production from firms where they were previously employed to firms which could not previously afford them.
> 3. The changed relative prices will stimulate the search for new methods of production which will use more of the now cheaper factor and less of the expensive one.

The above quote is clear in conveying Hicks' (1932) belief that the elasticity of substitution, and hence the production function from which it was derived, depends on the prices of the factors of production. Observe that the first form of substitution described above is the prototypical substitution effect among factors towards the relatively cheaper one. The second is just another way of saying that changes in relative prices may lead firms to adopt different technologies extant. And the third is nothing more than the assertion that changes in relative prices will led to research and development that favors the use of the less expensive factors of production.

* Corresponding author. Tel.: +1 407 823 1405; fax: +1 407 823 3269.
E-mail addresses: mcaputo@bus.ucf.edu (M.R. Caputo), paris@primal.ucdavis.edu (Q. Paris).

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In the years that followed, other prominent economists also argued that prices could explicitly enter a firm's production function for a variety of reasons, such as " … commitments to fixed plant and equipment inputs, and contracts to purchase inputs (e.g. labor services) or supply outputs" (McFadden, 1978, p. 6). Indeed, contracts to purchase inputs and supply outputs imply knowledge of, and decisions based on, the corresponding input and output prices. Moreover, commitments to fixed plant and quasi-fixed capital equipment necessarily depend on current, past, and future expected input and output prices.

The literature on TP also contains claims regarding the role of profits in influencing the choice of production technique. For example, Griliches (1957, p. 519) emphasized the dependence of TP in the cultivation of hybrid corn upon profitability. One of his fifteen such assertions states that "… our results do suggest that a substantial proportion of the variation in the rate of acceptance of hybrid corn is explainable by differences in the profitability of the shift to hybrids in different parts of the country." Similarly, Arrow (1969, p. 29) wrote: "From studies of Griliches (1957) and Mansfield (1968, part IV) we know that the diffusion of technological knowledge, at least within a given economy, is partly governed by profitability considerations." Continuing the citation of economists who advanced the conjecture that TP may depend on profitability considerations, Hirsch (1969, p. 38) stated that "And although the formal neoclassical models of the firm do not explicitly show the intertemporal trade-offs, the engineer–manager is assumed to choose the most profitable techniques of production from among all possible production functions." Because profit depends fundamentally on prices—think of a firm's maximum profit function—the above assertions are simply more evidence that economists have recognized for some time that TP is influenced by prices.

We opened by citing Samuelson (1947, p. 119), who introduced money balances and the prices of goods in a consumer's direct utility function for the purpose of deriving a demand function for liquidity. Taking only Samuelson's (1947, p. 119) work into account, and recognizing that the theory-of-the-firm counterpart to a consumer's preferences is a firm's technology, it is a small but natural step to insert market prices in a firm's production function. This generalization embeds the traditional adjustment cost theory of a firm within the broader framework of an intertemporal theory in which a firm's TP is influenced by factor prices and the price of output. By doing so, we achieve a unification of the theory that is fundamental to a deeper understanding of it. On an even more basic level, it seems rather implausible that economists would believe that relative prices do not play a significant role in influencing TP on a microeconomic scale.

Despite the aforesaid literature, it was not until the 21st century that the price-induced TP hypothesis was formalized by Paris and Caputo (2001), wherein they derived a complete qualitative characterization of a profit-maximizing model of a firm operating under the influence of price-induced TP. Several years later Caputo and Paris (2005) extended the theory by deriving the exhaustive qualitative properties of a cost-minimizing price-induced TP model of a firm. In the latter paper, the authors also presented convincing statistical evidence in favor of the theory.

Newell et al. (1999) developed an econometric model of induced technical change by regressing the total cost of producing room air conditioners, central air conditioners, and water heaters on their characteristics, such as energy flow, cooling capacity, and heating capacity. They introduced induced technical change in their model by specifying the parameters of the cost equation as functions of energy efficiency standards and relative energy prices. Their most relevant conclusion for our paper in which they found statistical support, was that energy price changes induced changes in the subset of technically feasible models that were offered for sale. In other words, they found empirical evidence that TP was influenced by prices, thereby providing support for the idea of including prices in a firm's production function.

The surveyed literature shows that for more than 55 years, various economists contemplated the idea that prices can and do affect TP and thereby a firm's technology. Not surprisingly, we believe that Hicks' (1932) priced-induced TP hypothesis is worthy of further development. Indeed, our paper takes the Hicks (1932) price-induced TP hypothesis one step further by introducing it in an intertemporal framework. As a result, it represents a natural and logical extension of the atemporal work of Paris and Caputo (2001) and Caputo and Paris (2005).

The basic framework contemplated here is that of the price-taking adjustment cost model of the firm. We develop an extended version of this canonical model by introducing three important modifications in order to account for disembodied and price-induced TP. First, and in line with Paris and Caputo (2001) and Caputo and Paris (2005), we explicitly introduce the time-varying and market-determined input and output prices faced by a firm in its production function in order to capture price-induced TP. Ostensibly an uncomplicated extension of the basic adjustment cost model, such a construction implies a double role for the prices, to wit, that of their traditional role as indicators of resource scarcity, and the novel role as shifters of the technology. This complication was apparent to Hicks (1932, p. 120) when he wrote "Partly, therefore, substitution takes place by a change in the proportions in which productive resources are distributed among existing types of production. But partly it takes place by affording a stimulus to the invention of new types."

Second, we also include the time rate-of-change of the input and output prices in the firm's production function. As shown in Section 2, this implies that in addition to the current set of market prices, all past and future-expected prices influence the firm's choice of technology. This means that we model not only the capital accumulation process as dynamic, but also the choice of technology because of the implied forward-looking behavior.

Third, in order to allow for disembodied TP, as distinct from price-induced TP, we assume that the production function is an explicit function of calendar time. This characterization permits TP to take place even if no changes in the prices occur. One could also make the case that for the theory to be empirically viable, this modification of the canonical model is necessary. Solow (1957) pioneered the theory of disembodied TP by assuming that it took the special form of a total factor productivity time-varying parameter unrelated to the marginal rate of substitution between factors of production, and provided empirical evidence as to the validity of the assumption. He did not refer to it as disembodied TP, but rather as neutral technical change—the terminology of Hicks—and provided time-series estimates of it. In our model, we allow for calendar time to affect technology in a general manner, thereby permitting the effects of disembodied TP to be neutral or non-neutral with respect to the shape of the production function.

The most important implication of the dual role postulated for the prices is that it destroys all of the refutable qualitative properties of the archetypal adjustment cost model. The main contribution of the paper, therefore, is the derivation of the complete set of testable and observable qualitative properties of the adjustment cost model of the firm in the presence of disembodied and priced-induced TP. A major result of our analysis is the derivation of the refutable comparative dynamics properties of the feedback factor demand functions in the form of a symmetric and negative semidefinite matrix. Because they are observable, the aforesaid refutable implications of the disembodied and priced-induced TP hypothesis can be subjected to a statistical test of their veracity, a key element of any newly proposed theory. The above results are derived by making use of the Hamilton–Jacobi–Bellman equation associated with the firm's underlying optimal control problem. This permits the derivation of its intrinsic qualitative properties in a straightforward and succinct manner. It furthermore allows the direct comparison of the results contained here with those extant for the prototypical adjustment cost model, and thereby permits a simple demonstration of the fact that the latter is a special case of, i.e., is embedded within, the disembodied and price-induced TP model contemplated here.