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PRICE-INDUCED TECHNICAL PROGRESS IN ITALIAN AGRICULTURE

ROBERTO ESPOSTI AND PIERPAOLO PIERANI
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Roberto Esposti[§] and Pierpaolo Pierani[§§]

Abstract

In this paper we aim at investigating the price-induced innovation hypothesis in Italian agriculture. We generalize the framework of analysis proposed by Peeters and Surry (2000). The generalization includes a short-run specification of the dual technology as well as a quadratic spline in a time variable. We argue that the temporary equilibrium setting gives a more realistic representation of how relative prices may steer innovation and variable input bias over time, while the quadratic function has desirable properties with respect the splined variable, i.e., a more flexible treatment of exogenous technical change. Results provide evidence in favour of price-induced innovation in Italian agriculture over the years 1951 to 1991.

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[§] Corresponding author: Department of Economics, Università Politecnica delle Marche, P.le Martelli, 8, 60121 Ancona (Italy). E-mail: r.esposti@univpm.it; website: www.dea.unian.it/esposti.

[§§] Department of Economic Policy, Finance and Development (DEPFID), Università degli Studi di Siena (Italy).

Authors are listed alphabetically and authorship may be attributed as follows: sections 1, 3, 5 and 7 to Pierani; sections 2, 4 and 6 to Esposti. We are grateful to an anonymous referee for some helpful comments on a previous version of the paper.

Contents

1. Introduction

This paper is primarily concerned with the investigation of price-induced innovation on technological change in Italian agriculture. The role of both autonomous technical progress and R&D expenditure in Italian agriculture after WWII has received a significant deal of attention (Esposti, 2000; Esposti and Pierani, 2000, 2003b, 2006; Pierani and Rizzi, 2005; Rizzi and Pierani, 2006). Nonetheless, there is not much evidence on the price inducement hypothesis and the few econometric findings are not clear-cut, perhaps due to the little consensus about the modelling of inherent mechanisms.

Recently, Peeters and Surry (2000) (hereafter PS) have proposed a dual model, which explicitly considers the time required by the innovation process. They cast the induced technical progress within a partial adjustment framework, which involves lagged prices and enters a symmetric generalized McFadden (SGM) multi-output cost function.

In this paper, we depart from them by introducing quasi-fixed inputs and enabling lagged prices to have an influence on variable inputs alone, given the short-run fixity of agricultural capacity. Another extension is that we postulate a quadratic spline in the time variable, which consists in a more flexible specification of the exogenous technical change than is provided by PS. We argue that the temporary equilibrium setting and the generalization with respect the splined variable constitute a more appropriate framework of analysis of the inducement mechanism and permit a comprehensive decomposition of variable input bias into pure substitution, exogenous and price induced technical progress, expansion and utilization effects (Morrison, 1988).

Moreover, the short-run technology, when combined with the lagged price conjecture about inducement mechanism, permits the distinction of short-, medium- and long-run price elasticities, incorporating temporary-equilibrium, price inducement and full-equilibrium attributes, respectively. Once the parameters of the restricted cost function are estimated, the calculation of these price elasticities is relatively straightforward.

The rest of the paper is organised as follows. The second section shortly reviews the price-inducement literature, with some attention to the empirical applications concerning agriculture and recent improvements and developments. The third section presents the short-run SGM cost function used to model Italian agriculture. The study focuses on the role of variable input lagged prices and the measure of price-inducement, thus, the relevant price elasticities and technological biases are detailed in the fourth section. The fifth section shortly describes data and estimation method, while the sixth section discusses the empirical findings. The last section concludes and suggests some possible directions of future research on this topic.

2. Price-induced technical progress in agriculture: an overview

Price-induced and induced technical change are two different concepts, albeit strongly related and sometimes confused. The former deals with how technical change is triggered by prices according to firm profitability considerations; the latter deals with how prices affect the direction of R&D and innovation activities (Caputo and Paris, 2005, p. 262). Both notions can be traced back to the seminal conjecture whereby capital/labour ratio depends on relative prices beyond the pure-substitution effect (Hicks, 1932).

Since Hayami and Ruttan (1970) that explained patterns of agricultural development under different conditions in terms of resource scarcity, the identification of these two effects (substitution and induced technical change) has always been a major empirical task. To that end, Binswanger (1974) used a *two-stage approach*: in the first step, technical change biases are estimated and then they are regressed on relevant prices. Ever since, such a two-stage specification of the inducement mechanism has become popular alias the *induced innovation hypothesis* (Ahmad, 1966; Hayami and Ruttan, 1985; Thirtle, 1985). This hypothesis states that changes in relative prices provide signals to the research community thus affecting the direction of research and innovative activities; these innovations then allow the producers to adopt new techniques where factor proportions, *ceteris paribus*, are now biased against scarce inputs.

In this formulation, technical change inducement is not endogenous to the firm, though it may become endogenous at aggregate level. Prices drive innovations through a complex institutional system, where public and private research, property rights and regulations play a major role. This institutional network can still be represented within the neoclassic (meta)production function scheme by admitting that the research effort can provide the producers with a whole set of possible technologies (the *Innovation Possibilities Frontier*) over which they can choose according to the observed relative prices. The same idea has been formulated also in a dual framework (Clark *et al*., 2003). A number of papers contributed in this respect by focusing on the firms' behaviour in running R&D activities and adopting innovations, thus making price-induced technical change endogenous. These works mainly rely on the neoclassical production and growth framework, but have been also extended to other theoretical paradigms (Ruttan, 1997).

Concerning agriculture, the topic has been tackled from different angles and with mixed results. Some studies attempt to explain how a sequence of technological breakthroughs (mechanical, chemical, biological, biotechnological, etc.) generated remarkable changes in capital/labour and land/labour ratios in the last century (Koppel, 1995; Sunding and Zilberman, 2001). Here, the induced innovation hypothesis is appealing in that it highlights the role played by the complex institutional system (external to farms) delivering agricultural research and innovations within developed and developing countries (the so-called National Agricultural Research Systems, NARS).

Others oppose Hayami and Ruttan conclusions on a historical basis (Olmstead and Rhode, 1994) and shed light on the temporal dimension of the process, which involves a sequence of events comprising relative prices formation, R&D investments and changes in factor proportion according to a well-established causal chain. In this respect, the recent empirical literature can be broken down into two branches.

The first strand generally aims at testing the induced innovation hypothesis by implementing the two-stage sequence implied by Hayami and Ruttan intuition. First it is assessed whether relative prices really affects the direction of agricultural R&D and innovation activities and then whether estimated Hicksian biases in both input use and output supply, are consistent with these price movements. Salem (1998), Thirtle *et al.* (1998; 2002) and Khatri *et al.* (1998) tested the induced innovation hypothesis in different agricultural systems using time series econometrics. In principle, this approach is particularly appropriate for assessing the consistency of the inducement mechanism, but it requires very long time series, which are rarely available for R&D data. Moreover, they use simplified technologies (e.g., Thirtle *et al.*, 2002, use a CES specification), thus imposing unnecessary restrictions on factor substitution. Cointegration analysis is also used by Clark *et al.* (2003) that estimate a flexible specification of Canadian agriculture over the period 1926 to 1985. Here, lack of R&D data is not so detrimental in that the relevance of the inducement mechanism is assessed with no reference to the underlying research activities by testing for a cointegrating relationship between technical change biases and factor prices (Machado, 1995). An awkward limitation of the time-series approach is that it can only check the consistency between data and inducement hypothesis, but not test it *strictu sensu* (Thritle *et al.*, 2002). Such a logical drawback is extensible to Esposti and Pierani (2003b) that use a flexible representation of Italian agriculture to search whether public R&D stock and input prices respond to each other as predicted by the inducement hypothesis.

Using a non-parametric approach, Chavas *et al.* (1997) and Esposti (2000) tackle the problem by linking explicitly technical change biases to lagged input and output prices and past R&D investments. This method is particularly powerful, less data-demanding and quite close to

Hayami-Ruttan explanation. Unfortunately, it is not a statistical approach; therefore no explicit test on the significance of the inducement hypothesis can be carried out.

Despite modelling differences, all these studies try to keep short- and long-run relationships between prices and factor use separate and, thus, to spell out their relevant effects, namely factor substitution and new technology adoption. Accordingly, Fulginiti (1994) discriminates between "market prices" and "normal prices" in order to set two different time horizons over which they may impact on firm's behaviour and technology.

The second group of works privileges a completely different view (alias *price-induced* or *price-conditional technology*), whereby lagged prices (as proxy of the long-term or "normal" prices) enter directly both production technology and derived behavioural equations in a *one-stage approach* (Fulginiti, 1994).

Two papers have especially emphasized that stand, modelling technical change inducement either by explicitly including lagged factor prices as arguments of the production function (Paris and Caputo, 2001) or extending the usual price-taking cost-minimization approach (Caputo and Paris, 2005). According to these micro-foundations, price-induced technology is not just the effect of lagged prices on firms' input use (or output composition) through an external (and exogenous) research and innovation system. Actually, prices themselves make the firm endogenously determine the new technology (through either own R&D-innovation efforts or adoption of external innovations). In this respect, theoretical justifications and empirical findings may significantly diverge from the literature directly inspired by Hayami and Ruttan[1].

A few contributions tested the price-induced innovation hypothesis by including lagged prices (approximating long-run prices) either in a flexible production function (Celikkol and

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[1] Unfortunately, these works leave some open questions, too. The authors suggest that theoretical complications may raise if one wants to introduce flexibility into the representation of how prices endogenously determine innovation formation and/or adoption within firms. Some of these implications are actually disregarded by PS and Celikkol and Stefanou (1999), as well as in the present study.

Stefanou, 1999) or a flexible cost function together with output level, current market prices and the time variable as proxy of exogenous technical change (PS)[2].

In this paper we follow PS. One important aspect on which we contribute is the temporal dimension of the price impact on input use and the representation of the underlying technology. In fact, only some inputs can adjust in the short-run to their optimal level; others can only in a longer period. Therefore, it seems more appropriate to exploit the temporary equilibrium framework to provide more realism and complexity to the interaction between prices and inputs over time. Moreover, the chosen specification allows a comprehensive analysis of price responses and decomposition of input biases by attributing them to both price-innovation inducement and other causes, such as pure substitution, scale economies and capacity utilization (Morrison, 1988).

3. The SGM restricted cost function with price-induced innovation

A pivotal argument of the discussion above is the time span of different price responses. Hence, the modelling of price induced technical progress recommends for a specification with embedded the capability of exploiting such a distinctive feature.

Accordingly, we assume that the objective of Italian farmers is to minimize the cost of producing a given level of output, conditional on input prices, stocks of quasi-fixed inputs and technological level. Under some regularity conditions, duality principles ensure consistency between variable cost and production functions, so that either one will describe farming activity equally well (Paris and Caputo, 1995). A constant returns to scale (CRTS) restricted cost function is given by:

$$G = G^{\circ}(y, p, z, T) = y\, g^{\circ}(p, z / y, T) \qquad (1)$$

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[2] A similar approach to price-inducement, though within a production frontier efficiency analysis, is also applied to Dutch pot-plant firms by Lansink *et al.* (2000).

where G is variable cost, y output, p vector of N current variable input prices, z vector of M fixed input quantities, and T state of technology, which is approximated by two terms. The first term is the time variable t, which is conventionally intended to reflect *autonomous technical change*, i.e. unrelated to price changes as well as farm's behaviour (*type I* technical change, according to PS). The second term involves lagged input prices, which drive farmer's decisions, and thus operates, *ceteris paribus*, as an additional shifter of input-demand equations (*type II* technical change). This element is supposed to represent *price-induced technical change*.

Empirically, we depict G° by means of the SGM form because it is flexible, its curvature properties hold globally (it has a Hessian of constants) and it is invariant to normalization. Our formulation departs from PS, by introducing quasi-fixed inputs. The short-run technology seems appropriate if one postulates that price inducement is a lasting process which is cast within a temporary equilibrium model, where agriculture capacity may not be at its long-run level.

The model estimated is:

$$\begin{aligned} G_t = {} & \frac{1}{2}\left(\frac{p_t^{'}Bp_t}{\theta' p_t}\right)y_t + (b' p_t)y_t + (p_t^{'}A\rho_t)y_t + p_t^{'}Dz_t + (d' p_t)y_t t + \frac{1}{2}(\theta' p_t)\frac{z_t^{'}Cz_t}{y_t} + \\ & (\theta' p_t)(c' z_t)t + \frac{1}{2}(\theta' p_t)b_{tt}t^2 y_t \end{aligned} \qquad (2)$$

where i, j (= 1,…, N) and k, h (= 1,…, M) index variable and quasi-fixed inputs, respectively; ρ is a column vector of N lagged variable input prices; $B = \{b_{ij}\}$ is a $N \times N$ symmetric negative semidefinite matrix of unknown parameters, such that $B' p^* = 0$ with $p^* >> 0$. Since p^* is chosen to be the vector of ones, we have $\sum_j b_{ij} = 0, \forall i$, and the rank of B is (N-1). $C = \{c_{kh}\}, D = \{d_{ik}\}$ and $A = \{a_{ij}\}$ are MxM, NxM and NxN matrices of unknown parameters, respectively. b, c, d are Nx1, Mx1 and Nx1 column vectors of unknown parameters; b_{tt} is an unknown scalar. θ is a column vector of N non-negative (predetermined) constants not all zero.

It can be shown that G is a flexible (linearly homogeneous in p) restricted cost function at any point (y^*,p^*,z^*,t^*) provided that $p^* >> 0$, $\theta' p^* > 0$. Moreover, G is globally concave in p if B is negative semidefinite and globally convex in z if the matrix C is positive semidefinite and $\theta' p^*>0$. For the SGM cost function to be parsimonious, the vector θ need to be exogenously given[3]. If the estimated B matrix does not conform to concavity criteria, negative semidefiniteness can be imposed by reparameterizing it as B=-LL', where L is a lower triangular matrix.[4] Global convexity in quasi-fixed inputs can be stated analogously upon the positive semidefiniteness of the estimated matrix C.

In estimation, we generalize the *type I* technical change by adding a quadratic spline in the time variable, thus permitting a flexible treatment of this exogenous component. The quadratic spline model has the same properties as the linear one but, in addition, each derived equation is continuous and once differentiable at the break points with respect to the time variable (Diewert and Wales, 1992).

The quadratic spline function is defined as follows:

$$\delta^i(t)=\begin{cases} \delta^1 = b_t t + .5 b_{tt} t^2 \\ \delta^2 = \delta^1 + .5(b_{70} - b_{tt})(t - t_{70})^2 \\ \delta^3 = \delta^2 + .5(b_{84} - b_{70})(t - t_{84})^2 \end{cases} \qquad (3)$$

We allow for the possibility of three intervals, with knots set in 1970 and 1984, according to a commonly accepted historical spelling of the Common Agricultural Policy, which has strongly twisted production incentives, and so it may have influenced autonomous technical change, too. The former break point associates a period of strong and increasing price support to the changes of Italian agriculture self-sufficiency and net-exports performance, especially in some key-commodities such as cereals. The latter marks the introduction of milk quota and, more

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[3] The inner product θ′p can be seen as fixed-weight price index. We assume that it has the Laspeyres form with weights given by the mean quantities (Kohli, 1993). In this case, θ′p*>0 and θ >0. For the flexibility proof see Kumbhakar (1989).

[4] In this study, the estimated Hessian matrices have the expected signs.

generally, the progressive implementation of compensatory and supply-reducing measures within CAP.

Type II technical change deals with farmer's response to long-run (or normal) prices, therefore, it has to be modeled as some function of lagged prices. Following PS,[5] price-induced technical change is specified as a geometrically declining lag structure beginning from period t-1 and with a common adjustment parameter λ; namely,

$$\rho_{it} = \sum_{\tau=0}^{\infty} \lambda^{\tau} \frac{p_{i,t-\tau-1}}{\theta' p_{t-\tau-1}} = \sum_{\tau=0}^{\infty} \lambda^{\tau} q_{i,t-\tau-1} = \frac{1}{1-\lambda L} q_{i,t-1} \tag{4}$$

and

$$A_i \rho_t = \sum_{j=1}^{N} \frac{a_{ij}}{1-\lambda L} q_{jt-1} \tag{5}$$

where L denotes the lag operator, A_i is the i-th row of the symmetric negative semidefinite matrix A, and q is the vector of (normalized) lagged variable input prices. It's apparent that the sole inducement mechanism considered here is that affecting variable inputs (and not, for example, marginal cost and/or shadow prices).[6] The matrix A is assumed to have the same homogeneity and symmetry properties as the matrix B (Lasserre and Ouellette, 1991).

This specification deserves some comments. The idea is that it takes some time to prices to affect technology and such an adjustment is only related to technical inducement not to input substitution. In other words, it is postulated that allocative effect operates instantaneously via current prices and subject to a given technology, whereas dynamic adjustment through lagged prices only regards the change of production technology eventually affecting the input substitution possibilities.

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[5] Celikkol and Stefanou (1999, p. 143-144) approximate long-run prices with lagged (or predicted) price moving averages.

[6] This is only a simplifying assumption. We could in principle allow for a more complex interaction between lagged input prices and model variables but this would considerably complicate the empirical specification.

Which kind of process is really operating under this scheme is not completely clear, yet (Celikkol and Stefanou, 1999; PS). If we start from the original idea of induced innovation, lagged prices should actually influence R&D activities mainly carried out outside the farm. In an more extensive interpretation, this model could be interpreted as a sort of “reduced form” of an underlying structure, whereby lagged input prices first affect R&D, which, in turn, generates input-using (saving) innovations; thus, farmers take their optimising input decisions on a given (exogenous) technology.

On the other hand, these equations can be interpreted also as literal description of farms' behaviour, i.e., of how lagged (or expected) input prices are accounted for in generating and adopting new technological combinations. However, in this case the distinction between substitution and price inducement effects is not so clear, particularly because the way these new technologies endogenously emerge within the farm is actually not made explicit.

Nonetheless, the common parameter λ summarizes these unobserved adjustments: λ represents the rate of decline, $(1-\lambda)$ is the speed of adjustment and $\lambda/(1-\lambda)$ the mean lag. The larger is λ the longer the effect of prices. If the lag structure is aimed at mimicking the timing of the underlying R&D investment or innovation adoption, this result would imply a shorter effect of R&D or adoption investments over time; that is, R&D investments more oriented toward applied or development activities rather than basic research.

In any case, whether the Koyck structure is an appropriate description is an empirical question. In principle, letting data decide about the lag structure, rather than imposing it, would be more informative about the real inducement process. However, it must be also considered that, within the adopted approach, the lag structure should also be interpreted in terms of price expectation formation. In fact, the lag structure should proxy the long-term input price, that is the price farms expect and on which they decide to adjust their technology. In this respect, the lagged structure, either imposed ex-ante or estimated, has to be interpreted and justified also in terms of a theoretically consistent representation of expectations formation.

For econometric implementation, a set of cost-minimizing variable input demands can be derived based on Shephard's lemma. Here, optimal input-output coefficients are considered to reduce possible heteroskedasticity:

$$\frac{x_{it}}{y_t} = \left\{ \frac{B_i p_t}{\theta' p_t} - \frac{\theta_i}{2} \frac{p_t' B p_t}{\left(\theta' p_t\right)^2} \right\} + b_i + A_i \rho_t + D_i \frac{z_t}{y_t} + d_i t + \frac{\theta_i}{2} \frac{z_t' C z_t}{y_t^2} + \theta_i \frac{c' z_t}{y_t} t + \frac{1}{2} \theta_i b_{tt} t^2 \tag{6}$$

where, B_i, and D_i indicate the i-th row of the corresponding matrices, respectively. Given the geometrically declining structure, after some algebra we arrive at the following estimable equations:

$$\begin{aligned} \frac{x_{it}}{y_t} = & \left\{ \frac{B_i p_t}{\theta' p_t} - \lambda \frac{B_i p_{t-1}}{\theta' p_{t-1}} \right\} - \frac{1}{2} \theta_i \left\{ \frac{p_t' B p_t}{\left(\theta' p_t\right)^2} - \lambda \frac{p_{t-1}' B p_{t-1}}{\left(\theta' p_{t-1}\right)^2} \right\} + (1-\lambda) b_i + A_i q_{t-1} + \\ & \left\{ \frac{D_i z_t}{y_t} - \lambda \frac{D_i z_{t-1}}{y_{t-1}} \right\} + d_i (t - \lambda (t-1)) + \frac{1}{2} \theta_i \left\{ \frac{z_t' C z_t}{y_t^2} - \lambda \frac{z_{t-1}' C z_{t-1}}{y_{t-1}^2} \right\} + \\ & \theta_i \left\{ \frac{c' z_t}{y_t} t - \lambda \frac{c' z_{t-1}}{y_{t-1}} (t-1) \right\} + \frac{1}{2} \theta_i b_{tt} \left(t^2 - \lambda (t-1)^2 \right) + \lambda \frac{x_{it-1}}{y_{t-1}} \end{aligned} \tag{7}$$

The system of equations (7) is homogeneous of degree zero in current and lagged prices and contains all relevant parameters. However, greater efficiency in estimation can be gained by including additional information with the marginal cost pricing equation, i.e. $\partial G/\partial y = p_y$, where p_y is output price. It can be easily derived from equation (2) as follows:

$$p_{yt} = \frac{1}{2} \left(\frac{p_t' B p_t}{\theta' p_t} \right) + (b' p_t) + (p_t' A \rho_t) + (d' p_t) t - \frac{1}{2} (\theta' p_t) \frac{z_t' C z_t}{y_t^2} + \frac{1}{2} (\theta' p_t) b_{tt} t^2 \tag{8}$$

Equation (8) is homogeneous of degree one in current prices and zero in quantities and lagged prices.[7]

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[7] The assumption of long-run CRTS would allow the inclusion of additional information in model estimation. Under CRTS, it is possible to determine the ex-post returns to quasi-fixed inputs as the gross operating surplus, $p_y y - G = R$, where p_y is output price and R is revenue (Morrison, 1988). However, it must

4. Price elasticities and input biases

The proposed model ascribes a crucial role to relative prices. In the *short-run*, current prices and autonomous technical change affect variable input use through substitution effects and technological biases, respectively. The *medium-run* admits the price-induced adjustment, so it is the time span over which lagged prices fully exert their effect on production technology. In the *long-run* quasi-fixed inputs get at their optimal levels, equalizing relevant rental and shadow prices.

Hence, in comparing the relevant responses, it is practical first to set the definitions down. Current and lagged price elasticities are defined as $\varepsilon_{ij} = \partial \ln x_{it} / \partial \ln p_{jt}$ and $\eta_{ij} = \partial \ln x_{it} / \partial \ln p_{jt-1}$, respectively. The former has the usual meaning the latter represents the partial response, within one period, due to changes in production technology associated with the induced innovation process. The *adjusted* lagged price elasticities are defined as $\gamma_{ij} = \partial \ln x_{it} / \partial \ln \rho_{jt} = \eta_{ij} /(1-\lambda)$; they measure the potential response of variable inputs once technology has fully adjusted to changes in lagged prices. Unlike PS, we refer to the lapse of time needed for such an adjustment as *medium-run*.

The Morishima elasticity of substitution is an exact measure of how the *i*, *j* input ratio responds to a change in the *j-th* price (Celikkol and Stefanou, 1999). We distinguish among different notions of two-factor-one-price elasticity: *short-run* substitution due to scarcity: $\sigma_{ij}^{S} = \varepsilon_{ij} - \varepsilon_{jj} = \partial \ln(x_i / x_j) / \partial \ln p_j$; *short-run* substitution due to innovation $\sigma_{ij}^{I} = \eta_{ij} - \eta_{jj} = \partial \ln(x_i / x_j) / \partial \ln p_{jt-1}$; *medium-run* substitution due to innovation $\sigma_{ij}^{M} = \gamma_{ij} - \gamma_{jj} = \sigma_{ij}^{I} /(1-\lambda)$; *long-run* substitution $\sigma_{ij}^{L} = \partial \ln(x_i^L / x_j^L) / \partial \ln p_j$, which

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be noticed that, whenever $\lambda>0$, the homogeneity properties are analytically lost; consequently, the solution above, relying on linear homogeneity with respect to quantities, is indeed inappropriate.

incorporates both response to scarcity and fully adjusted response to innovation, where x_i^L indicates the equilibrium level of the *i-th* factor.

Based on these definitions, we can decompose relative factor changes in terms of the constituent biases. Pure substitution bias represents the differential change in the *i-th* variable input resulting from a change in the *j-th* current price: $B_{ij} = \partial s_i / \partial \ln p_j = s_i(\varepsilon_{ij} - \varepsilon_{Cj}) = s_i(\varepsilon_{ij} - s_j)$, where s_i is the *i-th* variable input share in total costs. For example, if the two inputs are substitute and ε_{ij} outweighs the positive s_j term, then $B_{ij} > 0$ and an increase of the *j-th* price makes the share of the *i-th* input increase. Induced innovation bias describes the differential change in the *i-th* variable input due to a change in the *j-th* lagged price: $B_{ij}^{t-1} = \partial s_i / \partial \ln p_{jt-1} = s_i(\eta_{ij} - \eta_{Cj})$, where $\eta_{Cj} = \partial \ln C(.) / \partial \ln p_{jt-1}$, and $C(.)$ is total costs. Correcting η_{Cj} indicates the rate of technical change induced by the *j-th* price change (*type II*): $\gamma_{Cj} = \left(\partial \ln C(.) / \partial \ln p_{jt-1}\right) / (1-\lambda) = \eta_{Cj} / (1-\lambda)$. This derivative is expected to be negative.

The rate of autonomous (*type I*) technological progress is defined as the percentage reduction in total costs over time, $\varepsilon_{Ct} = \partial \ln C(.) / \partial t$; this derivative, too, is expected to be negative. Generally, this technical change is non-neutral; such additional bias can be expressed by the rate of change in factor proportions, $B_{it} = \partial s_i / \partial t, \forall$i. Recalling the SGM demand functions, it can easily be seen that $B_{it} = s_i(\varepsilon_{it} - \varepsilon_{Ct})$, where $\varepsilon_{it} = \partial \ln x_i / \partial t$. These semi-elasticities are not independent of one another, as $\varepsilon_{Ct} = \sum_i s_i \varepsilon_{it}$ and, consequently, $\sum_i B_{it} = 0$. Autonomous technological change is defined to be i-th input using (B_{it}>0), saving (B_{it}<0), or neutral (B_{it}=0), depending on whether relative change in i-th input is larger, smaller or equal to the rate of cost reduction, respectively. When $B_{it}=0, \forall i$, overall neutrality is implied.

The output bias can be depicted analogously by determining the relative share change given a *short-run* change in output: $B_{iy} = \partial s_i / \partial \ln y = s_i(\varepsilon_{iy} - \varepsilon_{Cy})$, where $\varepsilon_{Cy} = \partial \ln C / \partial \ln y$ and $\varepsilon_{iy} = \partial \ln x_{it} / \partial \ln y_t$ are the output elasticities of total costs and the *i-th* variable input, respectively.

Finally, the subequilibrium or utilization bias can be defined as $B_{ik} = \partial s_i / \partial \ln z_k = s_i(v_{ik} - \varepsilon_{Ck})$ where $\varepsilon_{Ck} = \partial \ln C / \partial \ln z_k = (p_k - f_k) z_k / C$ and $v_{ik} = \partial \ln x_i / \partial \ln z_k$ are utilization elasticities of total costs and the *i-th* variable input. The dual measure of capacity utilization, *CU_c*, can be derived from these fixed-inputs utilization elasticities as $CU_C = 1 - \sum_k \varepsilon_{Ck}$ (Morrison, 1988). ε_{Ck} will be negative if the stock z_k falls short of its equilibrium level $(p_k < f_k)$, and will be positive if z_k is in excess $(p_k > f_k)$. If shadow and rental prices coincide for each k, then $\varepsilon_{Ck} = 0$, and capacity is fully utilized. Assuming that $\varepsilon_{Ck} < 0$, $B_{ik} < 0$ implies that variable input *i* and stock *k* must be substitute, hence an increase of the quasi-fixed factor *k* is variable input *i* saving. This reasoning is reversed if the two are complements $(v_{ik} > 0)$.[8]

5. Data and estimation procedure

The study covers the years from 1951 to 1991. Throughout this period, Italian agriculture experienced an unprecedented productivity growth (Rizzi and Pierani, 2006); hence, these 40 years seem an appropriate period to endorse the proposed approach.[9] Data are taken from AGRIFIT database of Italian agriculture (Caiumi *et al.*, 1995) and consider one output, three variable inputs and two quasi-fixed stocks. Each variable is arrived at as a superlative Fisher

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[8] To inform about the direction of the *long-run* adjustment process, shadow price elasticities can also be computed, as they indicate whether these quasi-fixed inputs are over or underutilised, thus if their quantities are scarce (or in excess). Due to space limitation, in section 6 we skip these and other long-run results, which are available upon request.

[9] The period under study is stopped at 1991 mainly because the 1992 CAP reform provoked a sharp structural break in terms of both input use and land allocation, thus output supply, in Italian agriculture (Rizzi and Pierani, 2006). Though this does not necessarily reflect in productivity figures, it still strongly affects the estimation of technical change input biases, as well as price-inducement, and would make model estimation and result interpretation over the whole period much more complex.

index. Output aggregates fifty-two products; it does not comprise categories like self-produced inputs while it includes deficiency payments and other production subsidies. Variable inputs are made up by the following categories: purchased feeds (x_1), other intermediate inputs (x_2), and hired labour (x_3). Feed costs amount to outlays on compounds, forages, feed grains and so on. The second group includes mainly fertilizer, pesticides, seed, fuel, energy, veterinary costs, as well as overheads, i.e. the costs of repair and maintenance of capital equipment, insurance and rent.

Quasi-fixed inputs consist of the service flows from capital (z_1) and family labour (z_2). The former aggregates ten broad categories (mainly machinery and equipment, building and structure, breeding livestock, and land). Stocks and their user costs are defined at the beginning of the year. Labor is expressed in equivalent fully employed workers (2200 hrs per year), with the admittedly simplifying assumption of an undifferentiated wage rate between the two types of labor.

Parameter estimates of the SGM restricted cost function are obtained by simultaneously estimating the system of the input demand equations (7) and the marginal cost pricing equation (8). Prior to econometric estimation, additive error terms are appended to each behavioral equation, namely:

$$\begin{aligned}
&\frac{x_{jt}}{y_t} = \frac{1}{y_t}\frac{\partial G_t(.)}{\partial p_{jt}} + u_{jt} \quad j = 1,2,3 \\
&p_{yt} = \frac{\partial G_t(.)}{\partial y} + u_{4t}
\end{aligned} \tag{9}$$

Parameters are estimated using the iterative Zellner technique under the typical assumption that the error terms are jointly normally distributed with zero means and constant but unknown variances and covariances.

6. Results and discussion

6. 1. Production technology: substitution and inducement effects

Since results show modest variation over time, we discuss only mean estimates and focus on short-run elasticities and biases in order to conserve space.[10] Most estimated parameters are statistically significant and R^2 is quite high as it varies between 0.92 for feeds demand equation and 0.99 for the p_y equation.

Table 1 reports selected indicators of Italian agriculture in the period under study. Output more than doubles while dramatic changes in factor proportions can be observed. Both hired and family labor strongly decrease (by more than 50%) while the use of all other factors increased markedly. Apparently, the role played by relative prices in this transformation seems of major relevance, as they counterbalance quantity variations given that the estimated shares do not vary much during the whole period. For example, hired labor share increases by about 4% and family labor share declines by 7,6%. This is mainly explained by the large increase in the relative price of agricultural labor (Pierani and Rizzi, 2005).

Agricultural capacity is, on average, below unity (.86) thus suggesting an excess of the installed capacity. Figure 1 shows that the utilization index is characterized by large variation and crosses the equilibrium line from above around the eighties. The passage from over- to under-utilization underlies some structural adjustment in the production structure and investment strategy. This is confirmed by the long-run/observed ratio of the two stock variables (z^L/z). While capital is, on average, scarce and thus over-utilized, family labor is always in excess, particularly in the second half of the period. Therefore, beyond relative prices movement, both

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[10] Model parameter estimates as well as sub-period estimates are available upon request. In estimation, analytical derivatives for the SGM elasticities and approximated standard errors are obtained through the TSP commands DIFFER and ANALYZ, respectively.

tendencies of family labour and physical capital in Italian agriculture can be interpreted as the adjustment of quasi-fixed inputs to their optimal levels.

A first look at short-run elasticities (table 2) reveals that, on the whole, input use is much more responsive to output than prices. In general, a unit increase in output has a more than proportional effect on variable inputs, with a relatively stronger impact on hired labour (1.64). Hence, short-run changes in factor proportions might be mainly determined by output expansion. Own- and cross-price elasticities indicate that coefficients are accurately estimated and all are smaller than unity, which suggests a rather rigid structure. Direct responses of feeds (-.21) and especially of other inputs (-.07) are comparatively low, whereas the own-price elasticity of hired labour (-.43) shows a relatively higher degree of responsiveness.

Purchased feeds adjust consistently to both fixed inputs, while the signs of other inputs and hired labour adjustments depend upon which stock is changing. In particular, capital is a strong substitute for hired labour (-1.25) and, with a decreasing intensity, for other input (-.42) and purchased feeds (-.26). Finally, family labour substitutes for purchased feeds (-.17) and behaves as complement of the remaining two variable inputs. Most of these adjustments are significant and their absolute values are well above the range of price effects.

Table 3 reports lagged price elasticities, which indicates the effect of induced innovation within one period and in the medium run. Sign and size of lagged responses are consistent with the current price counterparts (table 2), revealing that, according to expectations, the induced technological innovations have added to the current price substitution effects, during the investigation period. In particular, own lagged-price elasticities are always negative, thus corroborating the innovation inducement hypothesis[11], and adjusted elasticities are larger than one-year lag cases, as obvious given the estimated value of λ. Unfortunately, several lagged-

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[11] Chavas (2001) explains the induced innovation hypothesis as follows: “the (induced innovation) hypothesis states that relative scarcity tends to guide technical change toward using additional inputs that are plentiful and inexpensive, while saving on scarce and inexpensive inputs”.

price responses show large standard errors. Hence the discussion of these results has to be taken with some caution.

Tables 4 and 5 collect the relevant Morishima elasticities and provide evidence about the different effects of price changes, namely response to scarcity and to innovation and their composite effect in the long-run. Table 4 indicates that all variable inputs are Morishima substitute. Again, elasticities of substitution involving hired labour are by large the highest. All signs of pure-substitution (σ_{ij}^{S}) are confirmed by the lagged-price elasticities (σ_{ij}^{I} and σ_{ij}^{M}), which can be interpreted as a further validation of the price-inducement hypothesis.

In the long run pure-substitution and price-inducement effects are combined, and the use of quasi-fixed inputs may itself vary. Table 5 shows how these aspects may affect the long-run Morishima elasticities of substitution. Being the combination of the two-effects and their impact moving in the same direction, the long-run elasticities tend to be larger, although the substitution relationship is confirmed in all cases, with the exception of other inputs being complement of feeds in the long run. This greater flexibility of the production technology is also motivated by the possibility to adapt the use of capital and family labour to their equilibrium levels. While capital substitutes for all other inputs, family labour is complement of all production factors and this relation is particularly strong with respect to hired labour (as could be expected) and to other inputs. Long-run elasticities also confirm that farm labour seems to react more intensely to price changes than other factors.

6.2. Technical change

Technical change is here represented by two terms: price-induced technical change (*type II*) is depicted by lagged price impact on input demand; autonomous technical change (*type I*) is represented by the conventional time trend. Table 1 shows that the latter is indeed negligible (0,1% yearly) and not statistically different from zero. This holds in the whole period and, despite the quadratic splines, quite homogenously in all the sub-periods with a maximum, but still not significant, observed in the sixties (1,4%). Since a significant and higher exogenous technical progress has been observed in previous studies on Italian agriculture (Esposti and Pierani, 2000, 2003c; Pierani and Rizzi, 2005; Rizzi and Pierani, 2006), this would suggest that *type II* technical change here takes over most of what was previously attributed to *type I*.

With regard to *type II* technical change it is of particular interest to notice that the estimated Koyck parameter (λ) is positive and significant, thus confirming that the geometrically declining lag structure representing price-inducement is accepted by the data. The estimated value (.540 with standard error of .063) is lower than that reported in PS (.695). This seems relevant in terms of economic interpretation as it suggests a little lower rate of decline and mean lag, that is, R&D investments more oriented toward applied or development activities rather than basic research. This finding supports previous evidence on Italian agriculture (Esposti, 2002; Esposti and Pierani, 2003a).

The role played by this *type II* technical change in Italian agriculture emerges in table 6, which decomposes the input biases into the five effects discussed above. These distortion measures, also adopted by Celikkol and Stefanou (1999) and originally proposed by Binswanger (1974), are particularly appropriate to detect the direction of technical change in a multifactor context. Nonetheless, particular attention has to be paid to the interpretation of these biases. Since they measure the change of share on total cost, variable input biases do not sum up to 0, as usually occurs in the long-run context when all inputs are variable. It follows that the sign and magnitude of the different biases in table 6 have to be interpreted in relative terms, that is comparing different biases among them for the same input, or comparing the same effect (bias) among variable inputs.

Three effects of table 6 are actually not related to technical change. They just measure pure price substitution, the expansion (output) and the utilization biases, the latter being generated by changes of the fixed inputs stock endowment. These biases provide the same qualitative information, though in a different form, already observed in commenting the elasticities above. However, the comparison among non-technological change biases also indicates how the utilization effect is the greatest, in absolute term, for all inputs: for other inputs and hired labour the highest effect is generated by change in the capital stock, while for feeds the major role is played by family labour. This supports the idea that disregarding quasi-fixity of some inputs, and thus the degree of utilization of the installed capacity, may significantly distort results. The adoption of a restricted cost function thus seems appropriate here.

The last two effects reported in table 6 deal with *type I* and *type II* technical change biases, respectively. Results suggest some interesting interpretation on how technical change took form in the last decades in Italian agriculture. First of all, they confirm that *type I* (autonomous) technical change is indeed negligible not only in terms of overall productivity growth but also in terms of input biases. Much more relevant is the role of *type II* (price-induced) technical change in determining input biases, and this confirms the evidence emerged in Celikkol and Stefanou (1999) while contrasts with PS.

Price-inducement is supported by the statistically significant estimates of $\gamma_{Ci} = (\partial \ln C_t / \partial \ln p_{it-1})/(1-\lambda)$: -.287, -.104 and -1.02 for feeds, other inputs and hired labour, respectively. These values not only demonstrate that an increase in price generates, after some years, a cost-reducing technical change, particularly strong in the case of feeds, but comparing them with the rates of *type I* technical change also confirms that price-inducement almost entirely takes over autonomous technical change. In terms of short-run biases (table 6), it must be noticed that for all variable inputs the effect of the own price is the lowest, and this is consistent with the idea that, relatively to other prices, the own price change has the lowest input-using effect. Moreover, change in hired labour price induces feeds-using technical change, as well as change in other input price, whereas change in feeds price induces hired labour using technical change.

7. Some final remarks

This paper investigates the price-induced innovation hypothesis in Italian agriculture. We generalize the framework of analysis proposed by PS. The generalization includes a short-run specification of the dual technology as well as a quadratic spline in a time variable. We argue that the temporary equilibrium setting gives a more realistic representation of how relative prices may steer innovation and variable input bias over time, while the quadratic function has desirable properties with respect the splined variable, i.e., a more flexible treatment of exogenous technical change. The approach is also inspired by the theoretical contributions of Fulginiti (1994), Paris and Caputo (1995 and 2001) and Caputo and Paris (2005), and aims to contribute to the renewed interest in the induced innovation hypothesis emerged in the empirical literature.

Another novelty concerns the sectoral context. Previous works (Celikkol and Stefanou, 1999; PS) did not focus on agriculture, though the inducement hypothesis traditionally finds major attention in the farm sector.

Results generally confirm that method is suitable to testing the price-inducement hypothesis and also to provide a whole set of measures highlighting how inducement takes place and how it interacts with other effects affecting input use proportions. Moreover, they support the hypothesis that technical change price-inducement really occurred in Italian agriculture in the last decades and that its magnitude is of major relevance with respect to the other effects, particularly autonomous technical change and pure substitution.

Nonetheless, despite the empirical potential and tractability, the adopted approach leaves some questions open also in the interpretation of the results, and they could be matter of future research on this subject.

Firstly, as stressed by Paris and Caputo (1995 and 2001) and Caputo and Paris (2005), the theoretical implications of the adopted model with particular reference to the economic interpretation of price-inducement have still to be fully understood and developed, while appear sometime neglected in empirical applications.

Secondly, and more on the empirical ground, the inducement mechanism modelled through an ad hoc specification of the lag structure should be empirically tested, rather than imposed *ex-ante* (the Koyck structure in our application); in addition, the economic interpretation of this lag structure should me more carefully investigated. In fact, it could mimic the usual time pattern over which research activities generate innovations and innovations are adopted; but this pattern can assume quite different and unpredictable forms.

A third improvement could also be achieved extending this representation of production technology with price-inducement by entering the R&D stock as a fixed input. This could allow, in principle, to reconcile the two notions of technical change inducement. Lagged prices take into account endogenous inducement whereas the interaction between the R&D stock and lagged prices may take over the exogenous induced innovation generated by the agricultural research and innovation system.

Finally, some econometric implications can also emerge from the introduction of lagged input prices in the model; these may actually generate endogeneity problems thus requiring appropriate IV, or GMM, estimators. Recent empirical applications do not seem to have paid enough attention to this possible estimation issue.

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Table 1: Selected growth indicators of in Italian agriculture, 1951-1991 (at the sample means – approximated standard errors in parenthesis)

Observed change in output and input use (%)	Y	+111
	x_1	+258
	x_2	+310
	x_3	-50
	z_1	+317
	z_2	-69
Estimated change in total cost shares (%)	x_1	-4.7
	x_2	+.9
	x_3	+4.2
	z_1	+7.2
	z_2	-7.6
Estimated capacity utilization	CUc	.863 (.044)
	z_1^L/z_1	1.66
	z_2^L/z_2	.46
Estimated (type I) technical change rate ($-\varepsilon_{Ct}$)	1951-1991	-.001 (.004)
	1951-1961	-.014 (.013)
	1962-1971	.006 (.008)
	1972-1981	.006 (.005)
	1982-1991	.002 (.003)

Table 2: Variable input short-run elasticities (at the sample means – approximated standard errors in parenthesis)

1951-1991	Feeds p_{1t}	Other inputs p_{2t}	Hired labor p_{3t}	Output y	Capital z_1	Family labor z_2
Feeds	-.214	-.059	.273	1.432	-.257	-.175
(x_1)	(.060)	(.044)	(.077)	(.055)	(.118)	(.104)
Other inputs	-.107	-.072	.179	1.249	-.416	.167
(x_2)	(.080)	(.081)	(.094)	(.097)	(.147)	(.093)
Hired labor	.313	.113	-.426	1.635	-1.254	.620
(x_3)	(.095)	(.060)	(.132)	(.115)	(.145)	(.184)

Table 3: Lagged-price elasticities of variable input (at the sample means – approximated standard errors in parenthesis)

1951-1991	η_{ij}			$\eta_{ij}/(1-\lambda)$		
	Feeds p_{1t-1}	Other inputs p_{2t-1}	Hired labour p_{3t-1}	Feeds ρ_{1t}	Other inputs ρ_{2t}	Hired labour ρ_{3t}
Feeds (x_1)	-.104 (.057)	-.001 (.037)	.105 (.067)	-.226 (.118)	-.002 (.081)	.228 (.145)
Other inputs (x_2)	-.006 (.067)	-.014 (.077)	.020 (.101)	-.013 (.146)	-.031 (.167)	.044 (.219)
Hired labour (x_3)	.107 (.078)	.006 (.064)	-.113 (.121)	.232 (.172)	.013 (.139)	-.245 (.264)

Table 4: Response to scarcity and to innovation (one-year lag and fully adjusted): short and medium run Morishima elasticities of substitution (at the sample means)

1951-1991	σ_{ij}^{S}			σ_{ij}^{I}			σ_{ij}^{M}		
	Feeds	Other inputs	Hired labour	Feeds	Other inputs	Hired labour	Feeds	Other inputs	Hired labour
Feeds	.0	.044	.478	.0	.038	.217	.0	.082	.464
Other inputs	.159	.0	.363	.124	.0	.130	.267	.0	.279
Hired labour	.396	.126	.0	.232	.023	.0	.497	.049	.0

Table 5: Response to both scarcity and innovation: long run Morishima elasticities of substitution σ_{ij}^{L} (at the sample means)

1951-1991	Feeds	Other inputs	Hired labour	Capital	Family labour
Feeds	.0	-.035	.585	.368	-.403
Other inputs	.619	.0	.389	.444	-.937
Hired labour	1.217	.263	.0	.439	-1.403
Capital	.407	.104	.616	.0	-.611
Family labour	.028	-.090	.369	.210	.0

Table 6: Short-run biases of variable inputs (at the sample means)

1951-1991	Feeds (x_1)	Other inputs (x_2)	Hired labour (x_3)
Pure substitution (B_{ij})			
P_1	-.064	-.019	.004
P_2	-.020	-.014	-.005
P_3	.010	-.004	-.070
Expansion (B_{iy})			
y	.069	-.003	.019
Utilization (B_{ik})			
z_1	-.012	-.021	-.078
z_2	-.114	-.005	.006
Exogenous technical change (B_{it})			
t	-.007	.002	.005
Price-induced technical change (B_{ij}^{t-1})			
p_{1t-1}	.020	.022	.055
p_{2t-1}	.022	.007	.016
P_{3t-1}	.042	.014	.007

Figure 1 – Capacity utilization (CUc) over the whole period