Price-induced technical progress in Italian agriculture

Roberto Esposti, Pierpaolo Pierani***

* Corresponding author: Department of Economics, Università Politecnica delle Marche, Piazza Martelli, 8, 60121 Ancona, Italy
e-mail: r.esposti@univpm.it

** Department of Economic Policy, Finance and Development (DEPFID), University of Siena (Italy)

Summary *– 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). This 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. The quadratic function has desirable properties with respect to the splined variable,* i.e., *a more flexible treatment of exogenous technical change. Results provide evidence in favour of the price-induced innovation in Italian agriculture from 1951 to 1991.*

Keywords: *induced innovation, Italian agriculture, SGM Restricted Cost Function*

Progrès technique induit par les prix dans l'agriculture italienne

Résumé – Ce travail vise à étudier l'hypothèse de l'innovation induite par les prix dans l'agriculture italienne en généralisant le cadre d'analyse proposé par Peeters et Surry (2000). Cette généralisation comprend une spécification à court terme de la technologie ainsi qu'une spline quadratique dans la dimension temporelle. Nous montrons que le modèle avec équilibre temporaire donne une représentation plus réaliste sur la manière dont les prix relatifs induisent l'innovation et les biais sur les inputs variables dans le temps. La fonction quadratique a des propriétés désirables concernant la variable temporelle, c'est-à-dire un traitement plus flexible du changement technologique exogène. Les résultats suggèrent l'existence d'une innovation induite par les prix dans l'agriculture italienne entre 1951 et 1991.

Mots-clés : innovation induite, agriculture italienne, fonction de coût restreint SGM

Descripteurs JEL : Q16, O30

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.

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 and Pierani, 2003b, 2006 ; Pierani and Rizzi, 2005). 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 empirical modeling of the underlying inducement process.

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.

This paper departs 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 of a more flexible specification of the exogenous technical change than the one provided by PS. We argue that the temporary equilibrium setting and 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, 1988a).

Moreover, short-run technology, when combined with the lagged price conjecture on the 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.

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

Price-induced and induced technical change are two different concepts, albeit strongly related. 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 of Hicks (1957).

In their influential work, Hayami and Ruttan (1970) explained patterns of agricultural development under different conditions in terms of resource scarcity. Their contribution also makes clear that the identification of the two effects underlying changes in input use (substitution and induced technical change) represents a major empirical task. To that end, Binswanger (1974) used a two-stage approach, whereby technical change biases are first estimated and then regressed on relevant prices. Such a sequential formulation of the inducement mechanism has become popular as the induced innovation hypothesis (Ahmad, 1966 ; Hayami and Ruttan, 1985 ; Thirtle, 1985).

In this specification, technical change inducement is not endogenous to the firm, though it may become endogenous at the 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 a neoclassic (meta)production function by admitting that the research effort can provide 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 also been formulated in a dual framework (Clark *et al.*, 2003). A number of papers have contributed in this respect focusing on the firms' behaviour in running R&D activities and adopting innovations, thus making price-induced technical change endogenous.

In relation to agriculture, some studies try to explain how a sequence of technological breakthroughs (mechanical, chemical, biological, etc.) generated remarkable changes in capital/labor and land/labor ratios in the last century (Koppel, 1994 ; Sunding and Zilberman, 2001). Here, the induced innovation hypothesis is appealing in that it highlights the role of the so-called National Agricultural Research Systems (NARS), that are external to the farms and deliver agricultural research and innovations within developed and developing countries. Others oppose Hayami and Ruttan's conclusions on a historical basis (Olmstead and Rhode, 1993) and shed light on the temporal dimension of the process which involves a sequence of events comprising relative price 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's intuition. First, it is assessed whether relative prices really affect 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. Within a primal representation of technology and in accordance with Hayami and Ruttan (1970) spirit, some papers (Kawagoe *et al.*, 1986 ; Karagiannis and Furtan, 1990) test the Hicksian hypothesis of induced innovation by using the two-level CES production function with factor-augmenting coefficients, allowing factor substitution to be separated from technological change. The model was applied to the historical data of US and Japanese agricultural development, two distinctly different regions of Canada, and South African commercial agriculture, respectively. The results were consistent with the hypothesis that different patterns of technical change were induced by differences in the levels and the movements in relative factor prices.

Following analogous frameworks, Shaik (1998), Thirtle *et al.* (1998 ; 2002) and Khatri *et al.* (1998) tested the induced innovation hypothesis in different agricultural systems using time series econometrics. Unfortunately, this approach requires very long time series of R&D variable which is rarely available. Moreover, they use simplified technologies, thus imposing unnecessary restrictions on factor substitution. Cointegration analysis is also used by Clark *et al.* (2003) who estimate a flexible specification of Canadian agriculture over the period from 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 consistency between data and inducement hypothesis, but not test it *strictu sensu* (Thirtle *et al.*, 2002). Such a logical drawback is extensible to Esposti and Pierani (2003b) who use a flexible representation of Italian agriculture to determine whether public R&D and input prices respond to each other.

Using a non-parametric approach, Chavas *et al.* (1997) tackle the problem by explicitly linking technical change biases to lagged input and output prices and past R&D investments. This method demands less data and is quite close to Hayami and Ruttan's explanation. Unfortunately, it is not a statistical approach. Therefore, no explicit test of the significance of the inducement hypothesis can be carried out.

Despite modeling differences, all these studies try to keep short- and long-run relationships between factor prices and 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 takes a completely different view (alias price-induced or price-conditional technology), whereby prices enter directly both production technology and derived behavioural equations in a one-stage approach. Two papers have especially emphasized that standpoint, modeling technical change inducement either within the production function framework (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 prices on firms' input use (or output composition) through an exogenous research system. Actually, prices themselves make the firm endogenously determine new technology (either through its own R&D efforts or the adoption of external innovations). In this respect, theoretical justifications and empirical findings may significantly diverge from the literature directly inspired by Hayami and Ruttan. Unfortunately, these works leave some open questions, too. Caputo and Paris (2005) suggest that theoretical complications may arise 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 omitted by PS and Celikkol and Stefanou (1999), as well as in the present study.

A few contributions tested the price-induced innovation hypothesis by including lagged prices (as proxy of the long-term or "normal" prices) either in a flexible production function (Celikkol and Stefanou, 1999) or a flexible cost function (PS). The present paper follows the PS approach but also aims at introducing a major conceptual and methodological novelty. It concerns the representation of agricultural technology and the consequent temporal dimension of price impact. While PS assumes a total (full-equilibrium) cost function, where all inputs instantaneously react to relative price changes and adjust to their long-run equilibrium levels, here a variable (or short-run) cost function is adopted. Particularly in agriculture (*e.g.*, land, family labor, etc.), in fact, only some inputs can adjust in the short-term to their optimal level and if we accept that "technical change is a process that requires time" (PS, p. 53), this may be true for factor substitution, as well.

The temporary equilibrium framework brings about new opportunities as well as new issues in modeling induced innovation. This paper aims at emphasizing the new insight the proposed model can provide, while it leaves the open issues to further research improvements [1]. On the former aspect, it must be noticed that the short-run specification is not only more realistic (especially for agricultural production) but also returns a richer and more comprehensive analysis of price responses and biases by attributing them to price-induced innovation and to other causes, beside pure substitution, such as scale economies and capacity utilization (Morrison, 1988a). On the latter aspect, however, it should be also recognized that, within such representation, the PS clear-cut distinction between price substitution and inducement remains valid only for variable inputs. For quasi-fixed inputs, although price inducement can still be investigated, in principle, *via* shadow prices and capacity utilization, this can not be achieved by simply distinguishing between short-run and long-run movements.

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

An essential aspect of the discussion above concerns the distinctive timing of different responses to price changes, as well as the differences occurring among production factors in this respect. Hence, the modeling of price induced technical progress recommends for a specification with embedded the capability of exploiting such distinctive features.

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 both will describe farming activity equally well (Paris and Caputo, 1995). A constant returns to scale (CRTS) restricted cost function [2] is given by:

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

where G is variable cost, y is output, p is the vector of N current variable input prices, z is the vector of M fixed input quantities, and T is the state of technology, which is approximated by two terms. The first term is the time variable t, which is

[1] In particular, the appropriate theoretical derivation of the adopted specification and the endogenous determination of lags remain open issues. Some of these issues, however, are fully present in the PS framework, as well. On them, as mentioned, some theoretical and empirical contributions have recently provided significant steps forward (Celikkol and Stefanou, 1999 ; Paris and Caputo, 2001 ; Caputo and Paris, 2005).

[2] Long run constant returns to scale means that all long run output elasticities equal one (Morrison, 1988a).

conventionally intended to reflect autonomous technical change, *i.e.* unrelated to price changes as well as to 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 (Pierani and Rizzi, 2003). 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:

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

where ρ is a column vector of N lagged variable input prices. $B = \{b_{ij}\}$ is an $N \times N$ symmetric negative semidefinite matrix of unknown parameters, such that $B'\, p^* = 0$ with $p^* >> 0$, where i, j (= 1,..., N) are variable input indices. 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 $M \times M$, $N \times M$ and $N \times N$ matrices of unknown parameters, respectively, where k, h (= 1,..., M) index quasi-fixed inputs. b, c, d are $N \times 1$, $M \times 1$ and $N \times 1$ 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 $\theta' p^* > 0$. The inner product $\theta' p$ can be seen as a fixed-weight price index. We assume that it has the Laspeyres form with weights given by mean quantities (Kohli, 1993). In this case, $\theta' p^* > 0$ and $\theta > 0$ [3]. For the SGM cost function to be parsimonious, vector θ needs to be exogenously given. 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].

[3] For the proof of flexibility see Kumbhakar (1989).

[4] Following PS and Lasserre and Oulette (1991), matrix A is assumed to have the same homogeneity and symmetry properties as matrix B. This is essentially motivated by the fact that in a long-run equilibrium any biased technical change should be of purely exogenous nature. Hence, one should have homogeneity in both current and lagged prices.

In estimation, we generalize 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 break points with respect to the time variable (Diewert and Wales, 1992).

The quadratic spline function is defined as follows:

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

We allow for the possibility of three intervals, with knots set in 1970 and 1984, according to a commonly accepted interpretation of the Common Agricultural Policy (CAP)'s historical evolution, 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 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, which can be modeled as some function of lagged prices. Following PS, 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 is apparent that the sole inducement mechanism considered here is that affecting variable inputs (and not, for example, marginal cost and/or shadow prices). This is only a simplifying assumption. Within an analogous temporary equilibrium framework, Esposti and Pierani (2003b) analyse induced innovation on quasi-fixed inputs through shadow price elasticities and changes in capacity utilization. Such further analysis is also possible here as, in principle, the adopted framework allows for a more complex interaction between lagged input prices and model variables. Nevertheless, this extension would considerably complicate the empirical specification; thus, it is omitted in the present application and left to future developments of the model.

As our focus remain on variables input use, we want to show how changes in variable input use can be decomposed in a set of effects, including long-run disequilibrium, and not just in "pure" factor substitution and price inducement. We also maintain the PS assumption that there is a different timing of price affecting input use between substitution and inducement. This assumption, however, deserves some comments. The idea is that it takes some time for 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, for variable inputs, the allocative effect operates instantaneously *via* current prices and subject to a given technology, whereas dynamic adjustment, through lagged prices, only relates to the change of production technology eventually affecting input substitution possibilities.

What kind of process is really operating under this scheme is not completely clear, yet. If we start from the original idea of induced innovation (Hayami and Ruttan, 1970 and 1985), we should acknowledge that lagged prices actually operate by firstly influencing R&D activities mainly carried out outside the farm. Then, such R&D activities make new technological solutions available to the farm. Within the adopted modeling framework, however, this first R&D stage is not represented as it is entirely external to farm optimising behaviour. In a more extensive perspective, therefore, such 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. While input substitution is entirely decided within the farm and, thus, can be assumed instantaneous, at least for variable inputs, time lags are needed to represent price-induced technical change just to make explicit this unobserved and external R&D stage.

On the other hand, these equations can also be interpreted 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, $(1\text{-}\lambda)$ is the speed of adjustment and $\lambda/(1\text{-}\lambda)$ the mean lag. The larger λ is 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. This means that R&D investments are 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 also be 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:

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

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:

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

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 py is the 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.

In principle, the assumption of long-run CRTS would allow the inclusion of additional information in model estimation. Under CRTS, in fact, it is possible to determine the *ex-post* returns to quasi-fixed inputs as the gross operating surplus, $p_y y - G = R$, where R indicates the revenue (Morrison, 1988a). However, it must be noticed that, whenever $\lambda > 0$, the homogeneity properties of (2) and (7) with respect to both prices and quantities are analytically lost. Consequently, the use of relation $p_y y - G = R$, relying on linear homogeneity with respect to quantities, would indeed be inappropriate in this case.

4. Cost elasticities and biases

As discussed in section 2, most empirical literature on induced innovation aims at separating two effects of price changes, that is, input substitution and price-induced technical change, by distinguishing how such changes occur over time. The PS approach here followed fully embraces this idea. The present temporary equilibrium specification, however, makes the separation of these effects more complex, as we now have three different time horizons over which price changes may generate their effects on input use. The first two only concern variable inputs, while the last one involves all production inputs.

In the short-run, current prices and autonomous technical change affect variable input use (along the short-run isoquant) 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 and movement occurs around the innovation possibility frontier rather than the isoquant. In the long-run quasi-fixed inputs are at their optimal levels, equalizing respective rental and shadow prices, and all inputs can fully adjust moving along the long-run isoquant. Medium-run and long-run effects, thus, differ not for the different time they take but for the fact the former still involves only variable inputs, albeit through lagged prices, while the latter concerns all and fully-adjusted production factors. The present approach allows separately identifying these three different movements in response to price changes.

Hence, in comparing the relevant responses, it is practical, first, to set some definitions. Current, lagged, and adjusted price elasticities are defined as $\varepsilon_{ij} = \partial \ln x_{it} / \partial \ln p_{jt}$, $\eta_{ij} = \partial \ln x_{it} / \partial \ln p_{jt-1}$, $\gamma_{ij} = \partial \ln x_{it} / \partial \ln \rho_{jt} = \eta_{ij} / (1 - \lambda)$, respectively. The first has the usual meaning, the second represents the partial response within one period due to changes associated with the induced innovation process, while the third measures the potential response once technology has fully adjusted to changes in lagged prices. Unlike PS, we refer to the 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. We distinguish among different notions: short-run substitution due to scarcity: $\sigma^{s}_{ij} = \varepsilon_{ij} - \varepsilon_{jj} = \partial \ln(x_i / x_j) / \partial \ln p_j$; short-run substitution due to innovation $\sigma^{I}_{ij} = \eta_{ij} - \eta_{jj} = \partial \ln(x_i / x_j) / \partial \ln p_{jt-1}$; medium-run substitution due to innovation $\sigma^{M}_{ij} = \gamma_{ij} - \gamma_{jj} = \sigma^{I}_{ij} / (1 - \lambda)$; long-run substitution $\sigma^{L}_{ij} = \partial \ln(x^L_i / x^L_j) / \partial \ln p_j$, which incorporates both response to scarcity and fully adjusted response to innovation, where x^L_i indicates the equilibrium level of the i-th factor. These elasticities all depend on the extent of fixity of inputs.

Using those definitions, we can decompose relative factor changes in terms of constituent biases. Biases are computed as second derivatives of the short run total cost function, or, equivalently, derivatives of cost elasticities (Mergos and Karagiannis, 1997). The temporary equilibrium total cost function in terms of (1) is defined as $C = G^{\circ}(y, p, z, T) + \sum_k p_k z_k$. The substitution bias, for example, reflects the change in demand for variable input i resulting from a change in the j-th current price. For the dual cost framework it can be shown that this definition is based on the relative factor share change allowing for substitution effects (Morrison, 1988b): $B_{ij} = \partial s_i / \partial \ln p_j = s_i (\varepsilon_{ij} - \varepsilon_{Cj}) = s_i (\varepsilon_{ij} - s_j)$, where $s_i = x_i p_i / C = \varepsilon_{Ci}$ is the short run share of variable input i in total costs. For example, if the two inputs are substitute and ε_{ij} outweighs the positive s_j term, then $B_{ij} > 0$, thus an increase in the j-th price makes the share of the i-th input increase. Analogously, induced innovation bias describes differential changes in variable input use resulting from lagged price changes: $B_{ij}^{t-1} = \partial s_i / \partial \ln p_{jt-1} = s_i (\eta_{ij} - \eta_{Cj})$, where $\eta_{Cj} = \partial \ln C / \partial \ln p_i$. The rate of technical change induced by the j-th price change (type II) is given by: $\gamma_{Cj} = \eta_{Cj} / (1 - \lambda)$.

The rate of autonomous (type I) technological progress is defined as the percentage reduction in total costs over time, $\varepsilon_{Ct} = \partial \ln C / \partial t$. Generally, this technical change is non-neutral. A corresponding bias definition is based on the relative factor share change allowing for substitution effects: $B_{it} = \partial s_i / \partial t = s_i (\varepsilon_{it} - \varepsilon_{Ct})$, 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 on individual inputs can be depicted analogously, by determining the change in the share given a short-run change in output demand: $B_{iy} = \partial s_i / \partial \ln y = s_i (\varepsilon_{iy} - \varepsilon_{Cy})$, where $\varepsilon_{Cy} = \partial \ln C / \partial \ln y$ and $\varepsilon_{iy} = \partial \ln x_{it} / \partial \ln y_i$. This bias reflects a short run change and thus does not represent true scale but instead returns to the variable inputs [5].

Finally, a subequilibrium or utilization bias can also 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, CUc, can be derived from these fixed-input utilization elasticities as $CU_C = 1 - \sum_k \varepsilon_{Ck}$ (Morrison, 1988b). ε_{Ck} will be negative if 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. If $\varepsilon_{Ck} < 0$, for example, $B_{ik} < 0$ 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 ($v_{ik} > 0$) [6].

[5] For the decomposition of biased technological change in the nonhomothetic full equilibrium model, see Antle and Capalbo (1988) and Karagiannis and Furtan (1993).

[6] 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 showing whether their quantities are scarce or in excess. Due to space limitation, in section 6 we have skipped them as well as other long-run results. They are available upon request.

5. Empirical implementation

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:

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

Model 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.

Model estimation covers the years from 1951 to 1991. Throughout this period, Italian agriculture experienced an unprecedented productivity growth. Hence, these 40 years seem an appropriate period to endorse the proposed approach. Though it remains true that the adopted approach is able to take into account structural breaks (in particular, through the spline specification of the type I technical change), it is still difficult to separate those effects on productivity figures that can be fully attributed to technical change from those that are generated by institutional change. Other important institutional changes occurred over this period and their influence on technical change patterns cannot be excluded [7].

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

Quasi-fixed inputs consist of the service flows from capital (z_1) and family labor (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 (2 200 hrs per year), with the admittedly simplifying assumption of an undifferentiated wage rate between the two types of labor.

[7] For instance, we can mention the end of the sharecropping system, which was formerly prevalent in some parts of Italy. Its conversion was enforced in the early eighties but actually occurred quite gradually in the seventies. Thus, the effect of this institutional change on productivity figures, though probably significant, did not take place abruptly.

Within the adopted framework, such aggregation and definition of input categories is particularly critical because, as mentioned, once variable and quasi-fixed inputs are settled this also affects how the model represents price inducement[8]. Therefore, input aggregation is expected to emphasize those factors on which most literature on induced innovation concentrates the attention, in particular the use of agricultural land and labor, at least in the historical experience of largely studied countries (for instance, USA and Japan) (Olmstead and Rhode, 1993 ; Hayami and Ruttan, 1985).

At the same time, however, the emphasis on such inputs should not overlook the fact that, according to the adopted temporary equilibrium framework, selection and aggregation of variable and quasi-fixed inputs has to take into account the real agricultural production structure and factor fixity in the short-run, thus assuming as quasi-fixed those production factors whose response to relative price changes (due to technical, economic or even social reasons) does require time.

Empirical literature is quite unanimous in this respect. When two conventional quasi-fixed inputs are admitted[9], they are very often capital stock and labor (rather than their service flows). Limiting our attention to Italian agriculture, we can mention Esposti and Pierani (2003b) and Pierani and Rizzi (2003, 2005). More generally, these are typical factors on which literature on dynamic factor demand and adjustment costs focuses on (Fulginiti and Onofri, 2008). Alternatively, when a single conventional quasi-fixed factor is specified, it usually concerns agricultural capital (Esposti and Pierani, 2003c, 2006) or family (or unpaid) labor (Huffmann *et al.*, 2002). To be consistent with these prevalent input aggregations, here labor and capital are assumed quasi-fixed.

As discussed in previous sections, this inevitably prevents from fully assessing price-inducement on these factors and may appear a major limit of the empirical exercise here presented. It does not mean, however, that the adopted approach is not suitable to support the test of induced innovation hypothesis. Eventually, it prevents from testing some of its typical variants, particularly dealing with substitution of non-reproducible production inputs with reproducible substitutes, only because of the empirical specification we adopt. By changing specification or extending the model toward the already mentioned interaction between price lags and quasi-fixed inputs (*via* shadow price), it is possible to test the hypothesis also on other input aggregates.

Two further clarifications on this point, however, are needed. The first concerns labor. By looking at results provided by Esposti (2000) using a non-parametric technique, it clearly emerges that induced innovation on agricultural hired labor behaves quite differently from family labor. Therefore, they are included as separate

[8] The following discussion on the proper model specification and input aggregation has been stimulated by helpful comments raised by an anonymous referee. We want to acknowledge, here, his contribution as well as to emphasize that further discussion and developments are welcome in future research on this topic.

[9] In several papers, in fact, non-conventional inputs, (public R&D, infrastructure, etc.) are also included among quasi-fixed factors (Huffmann *et al.*, 2002 ; Esposti and Pierani, 2003b, 2006).

inputs, here, as also done by Huffmann et al. (2002), Esposti and Pierani (2003b) and Pierani and Rizzi (2003, 2005) where only the latter is, in fact, often considered as a fixed input. Breaking down labor input into two categories (hired and family labor), and distinguishing them in terms of short-run fixity, is also helpful to achieve further insight into the relation between technical change and agricultural labor use. In particular, the assumption of family labor as quasi-fixed factor may affect the substitution between capital and labor as intended in the classical literature regarding technical change. First of all, in the short-run, substitution is only possible between capital (which might also change in quality through time by incorporating technical change) and hired labor. Secondly, in the long run, a labor saving technology does not only save hired labor, but family labor as well. This feature also implies that technical change may thus affect the organizational nature of the farm by transforming it towards a more commercial based structure.

The second clarification concerns agricultural land. Here, land input is included in the capital aggregate (z_1), though most classical literature (Olmstead and Rhode, 1993 ; Hayami and Ruttan, 1985) underlines the different impact of technological change on land (as not reproducible input) and capital (as reproducible factor) use, especially in those countries where land is scarce. Nonetheless, it must be noticed that in Esposti (2000) there is no clear evidence about induced innovation on land use. Thus, aggregating land and capital in a single input would not necessarily mix up opposite behaviours.

In practice, there is no real better alternative specification of land in the present approach. Including land, or its service flow, as a variable input would evidently conflict with the fact that its use varies very little over time and its response to price changes does take time. On the contrary, we could argue that land is not a capital item and should enter the model as a physical quantity, that is, as an exogenous shifter. This would ignore that land is neither fixed (it varies over time) nor exogenous (its use depends on relative price changes) and such solution would thus incur model misspecification. For instance, over the period under investigation here (1951-1991) agricultural land in Italy declined, on average, by 0.4 % per year.

Finally, land could be separated from capital and included as a further quasi-fixed input, as done by Mergos and Karagiannis (1997). A specification with three quasi-fixed inputs, however, would significantly increase the number of parameters to be estimated and model complexity (Esposti and Pierani, 2003b) without necessarily providing better statistical results. Separating land from capital is, in fact, not an easy task as several components of capital (new plantings, irrigation works, land improvement investments, etc.) are strictly embodied in land and affect its quality. Measuring the value and thus the price of mere land is, consequently, a complex issue and, at least in the Italian case, may generate series with poor quality (Rizzi and Pierani, 2006). In any case, separating land from capital either as an exogenous shifter or as an additional quasi-fixed factor would not allow price-inducement to be fully tested on land use.

For these major reasons, we eventually maintain here the specification adopted in several analogous empirical studies (among others, Esposti and Pierani, 2003c ; Pierani and Rizzi, 2003 and 2005 ; Fulginiti and Onofri, 2008), also concerning the induced innovation (Esposti and Pierani, 2003b), where capital and land are aggregated in a single quasi-fixed factor.

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. Moreover, the estimated Hessian matrices have the expected signs suggesting that all underlying curvature conditions hold globally over the period under study.

Table 1 reports selected indicators of Italian agriculture during the investigation period. Output more than doubles while dramatic changes in factor proportions can be observed. Both hired and family labor strongly decreased (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).

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

1951/91 change (%)	Feeds	Other inputs	Hired labor	Output	Capital	Family labor
Level [a]	+ 258	+ 310	− 50	+ 111	+ 317	− 69
Total cost share [b]	− 4.7	+ .9	+ 4.2		+ 7.2	− 7.6

[a]: observed ; [b]: estimated

	1951/91	1951/61	1962/71	1972/81	1982/91
Type I technical change (rate) [b]	-.001 (.004)	-.014 (.013)	.006 (.008)	.006 (.005)	.002 (.003)
Capacity utilization [b]	.863 (.044)				
z_1^L / z_1	1.66				
z_2^L / z_2	.46				

[a]: observed ; [b]: estimated

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

Average utilization is below unity (.86), suggesting an excess of the installed capacity. Figure 1 shows that the dual index is characterized by large variation and crosses the equilibrium line from above around the eighties. This shift from over- to under-utilization underlies some structural adjustment, which is confirmed by the long-run/observed ratio of the two stock variables (z^L/z). While capital is, on average, scarce family labor is always in excess, particularly in the second half of the period. Therefore, beyond relative price movement, both tendencies of family labor 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 labor (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. As properly outlined by an anonymous referee, this latter result should not surprise as obtained over an highly aggregated technology and sector, and it is also confirmed by previous studies on Italian agriculture (Pierani and Rizzi, 2005). Direct responses of feeds (-.21) and especially of other inputs (-.07) are comparatively low, whereas the own-price elasticity of hired labor (-.43) shows a relatively higher degree of responsiveness.

Purchased feeds adjust consistently to both fixed inputs, while the signs of other inputs and hired labor adjustments depend upon which stock is changing. In particular, capital is a strong substitute for hired labor (-1.25) and, with a decreasing intensity, for other input (-.42) and purchased feeds (-.26). Finally, family labor substitutes for purchased feeds (-.17) and behaves as complement of the remaining two

Figure 1. **Capacity utilization (*CUc*) over the whole period**

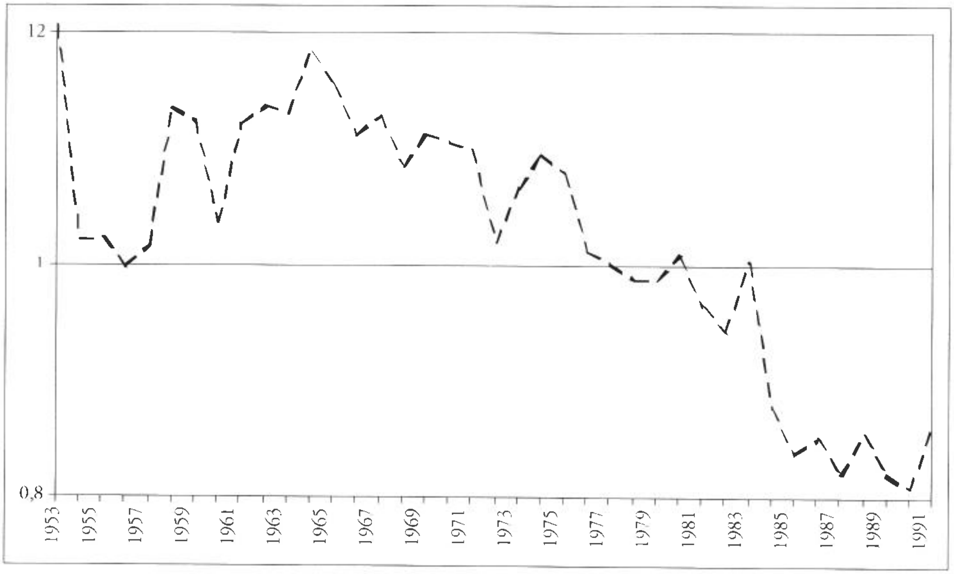

Tableau 2. **Variable input short-run elasticities (at the sample means – approximated standard errors in parenthesis)**

1951/91	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)

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 indicate 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, and this could be interpreted as support of the innovation inducement hypothesis according to the definition of Chavas (2001) [11]. In addition, adjusted elasticities are larger than one-year lag cases, as expected, given the estimated value of λ. Unfortunately, several lagged-price responses show large standard errors, hence these results have 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 substitutes. Again, elasticities of substitution involving

Tableau 3. **Lagged-price elasticities of variable inputs (at the sample means – approximated standard errors in parenthesis)**

1951/91	η_{ij}			$\eta_{ij}/(1-\lambda)$		
	Feeds ($p_{1t-1\ t}$)	Other inputs ($p_{2t-1\ t}$)	Hired labor ($p_{3t-1\ t}$)	Feeds ($\rho_{1t\ t}$)	Other inputs ($\rho_{2t\ t}$)	Hired labor (ρ_{3t})
Feeds	-.104	-.001	.105	-.226	-.002	.228
(x_1)	(.057)	(.037)	(.067)	(.118)	(.081)	(.145)
Other inputs	-.006	-.014	.020	-.013	-.031	.044
(x_2)	(.067)	(.077)	(.101)	(.146)	(.167)	(.219)
Hired labor	.107	.006	-.113	.232	.013	-.245
(x_3)	(.078)	(.064)	(.121)	(.172)	(.139)	(.264)

[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*".

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

1951/91	σ^S_{ij}			σ^S_{ij}			σ^M_{ij}		
	Feeds	Other inputs	Hired labor	Feeds	Other inputs	Hired labor	Feeds	Other inputs	Hired labor
Feeds	.0	.044	.478	.0	.038	.217	.0	.082	.464
Other inputs	.159	.0	.363	.124	.0	.130	.267	.0	.279
Hired labor	.396	.126	.0	.232	.023	.0	.497	.049	.0

Tableau 5. **Response to both scarcity and innovation: Long run Morishima elasticities of substitution σ^L_{ij} (at the sample means)**

1951/91	Feeds	Other inputs	Hired labor	Capital	Family labor
Feeds	.0	-.035	.585	.368	-.403
Other inputs	.619	.0	.389	.444	-.937
Hired labor	1.217	.263	.0	.439	-1.403
Capital	.407	.104	.616	.0	-.611
Family labor	.028	-.090	.369	.210	.0

hired labor are clearly the highest. All signs of pure-substitution (σ^S_{ij}) are confirmed by the lagged-price elasticities (σ^I_{ij} and σ^M_{ij}).

In the long run pure-substitution and price-inducement effects are combined, and the use of quasi-fixed inputs may 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, 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 labor to their equilibrium levels. While capital substitutes for all other inputs, family labor is complementary to all production factors and this relation is particularly strong with respect to hired labor (as could be expected) and to other inputs. Long-run elasticities also confirm that farm labor seems to react more intensely to price changes than other factors.

6.2. Technical change

Technical change here is 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 does not statistically differ from zero. This holds in the whole period and, despite 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, 2003b and 2006 ; Pierani and Rizzi, 2005), this would suggest that type II technical change here takes over most of what was previously attributed to type I.

As regards 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 is relevant as it suggests a lower rate of decline and mean lag, *i.e.*, R&D investments are more oriented toward applied or development activities rather than basic research. This finding supports previous evidence on Italian agriculture (Esposti and Pierani, 2003a).

The results in table 6 are meant to provide additional information with respect to previous short-run elasticities. This information is summarised by biases with respect to changes in exogenous variables which distinguish input specific effects from the overall effect (Morrison, 1988b). The impact of each change is looked at on its own and assessed from the biases without summing up the specific components. They reflect changes in demand for a variable input with a change in the exogenous variables relative to other input responses, and thus indicate their relative contributions to cost changes. The first three effects in table 6 capture price substitution, output and utilization biases, respectively. These figures show that among non-technological biases the utilization effect is the strongest, in absolute terms. For other inputs and hired labor the highest effect is generated by a change in capital stock, while for feeds a major role is played by family labor. This supports the idea that disregarding the fixity of some inputs in the short-run, and thus the degree of utilization of the installed capacity, may result in ambiguous results.

Tableau 6. **Short-run biases of variable inputs (at the sample means)**

1951/91	Feeds (x_1)	Other inputs (x_2)	Hired labor (x_3)
Pure substitution (B_{ij})			
p_1	-.064	-.019	.004
p_2	.020	-.014	-.005
p_3	.010	-.004	-.070
Expansion (B_{iy})	.069	-.003	.019
Utilization (B_{ik})			
z_1	-.012	-.021	-.078
z_2	-.114	-.005	.006
Exogenous t.c. (B_{it})	-.007	.002	.005
Price-induced t.c. (B_{ij}^{t-1})			
p_{1t-1}	.020	.022	.055
p_{2t-1}	.022	.007	.016
P_{3t-1}	.042	.014	.007

The last two biases in table 6 deal with autonomous and price-induced technical change, respectively. These biases suggest some interesting interpretation on how technical change materialized during the investigation period in Italian agriculture. It is confirmed that type I technical change is negligible both in terms of productivity gains and input biases. These biases show that autonomous technical change tends to be relatively feeds saving and other input and hired labor using. More relevant is the role of type II technical change in determining input biases, which confirms the evidence in Celikkol and Stefanou (1999) but contrasts with PS.

Price inducement is supported by the statistically significant estimates of γ_{Ci}: -.287, -.104 and -1.02 for feeds, other inputs and hired labor, respectively [12]. These values show that a price increase, generates, after some years, a cost-reducing technical change, particularly strong for feeds; moreover, comparing them with the rates of autonomous technical change 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, with respect to other prices, the own price change has the lowest input-using effect.

Looking at the cross-price effects, the largest impact concerns hired labor and feeds. An increase in the hired labor price induces feeds-using technical change, whereas an increase in feeds price induces hired labor using technical change. This means that an increase in hired labor price does not only intensify feeds use immediately (and *vice versa*), as they behave as substitutes, but the same effect holds even with some lags, as price increase induces a feeds using technology. These two effects move in the same direction and, thus, we can say that the medium-run effect of a price change is reinforced with respect to the short-run effect. On the contrary, we may notice that a price increase of "other inputs" behaves differently. Table 6 still shows that it induces hired labor, as well as feeds, using technical change but this effect is lower in magnitude and, above all, moves in the opposite direction with respect to the contemporaneous price effects. In this case, eventually, pure substitution (short-run) and price-induced (medium-run) technical change biases almost reciprocally offset.

7. Some final remarks

This paper investigates the price-induced innovation hypothesis in Italian agriculture. We generalize the framework of the analysis proposed by PS. Our 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 to 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 that has emerged in the empirical literature.

[12] Where $\gamma_{Cj} = \eta_{Cj} / (1 - \lambda)$; see section 4.

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 the proposed method is suitable for testing the price-inducement hypothesis and also for providing 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, in particular, 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.

First of all, Paris and Caputo (1995 and 2001) and Caputo and Paris (2005) analyse in detail the major theoretical implications of the adopted model with particular reference to the economic interpretation of price inducement. These implications, however, must still be fully implemented in empirical studies, such as Celikkol and Stefanou (1999) and PS, as well as in the present application.

Secondly, the inducement mechanism modeled 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 be 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 (Esposti and Pierani, 2003a).

A third improvement could also be made by extending this representation of production technology to price inducement by entering R&D stock as a fixed input (Esposti and Pierani, 2003b). This could reconcile, in principle, the two notions of technical change inducement. Lagged prices take into account endogenous inducement whereas the interaction between R&D stock and lagged prices may take over the exogenous induced innovation generated by agricultural research and innovation system.

References

Ahmad S. (1966) On the theory of induced innovation, *Economic Journal* 76, 344-357.

Antle J.M., Capalbo S.M. (1988) An introduction to recent developments in production theory and productivity measurement, *in* : *Agricultural Productivity: Measurement and Explanation*, Capalbo S.M., Antle J.M. (eds), Washington, DC, Resources for the Future, 17-95.

Binswanger H. (1974) The measurement of technical change biases with many factors of production, *American Economic Review* 64, 964-976.

Caiumi A., Pierani P., Rizzi P.L. and Rossi N. (1995) *AGRIFIT: una banca dati del settore agricolo (1951-1991)*, Milano, Franco Angeli, 80 p.

Caputo M.R., Paris Q. (2005) An atemporal microeconomic theory and an empirical test of price-induced technical progress, *Journal of Productivity Analysis* 24, 259-281.

Celikkol P., Stefanou S.E. (1999) Measuring the impact of price induced innovation on technological progress: Application to the US food processing and distribution sector, *Journal of Productivity Analysis* 12, 135-151.

Chavas J.P. (2001) Structural change in agricultural production: Economics, technology and policy, *in*: *Handbook of Agricultural Economics*, vol. 1A, Gardner-Rausser (eds), Amsterdam, North-Holland, 263-285.

Chavas J.P., Aliber M. and Cox T.L. (1997) An analysis of the source and nature of technical change: The case of US agriculture, *Review of Economics and Statistics* 79, 482-492.

Clark S.J., Klein K.K. and Kerr W.A. (2003) Fundamental and induced biases in technological change in Central Canadian agriculture, Paper presented at the XXV IAAE Conference, Durban, August.

Diewert W.E., Wales T.J. (1992) Quadratic spline models for producer's supply and demand functions, *International Economic Review* 33, 705-22.

Esposti R. (2000) The impact of public R&D and extension expenditure on Italian agriculture. An application of a mixed parametric/nonparametric approach, *European Review of Agricultural Economics* 27(3), 365-384.

Esposti R., Pierani P. (2006) Price, private demand and optimal provision of public R&D investment: An application to Italian agriculture, 1960-1995, *Empirical Economics* 31, 699-715.

Esposti R., Pierani P. (2003a) Building the knowledge stock: Lags, depreciation, and uncertainty in R&D investment and productivity growth, *Journal of Productivity Analysis* 19, 33-58.

Esposti R., Pierani P. (2003b) Public R&D investment and cost structure in Italian agriculture, 1960-1995, *European Review of Agricultural Economics* 30, 509-537.

Esposti R., Pierani P. (2003c) R&D, technology and productivity growth in Italian agriculture, 1963-1991, *Cahiers d'économie et sociologie rurales* 67, 5-27.

Fulginiti L.E. (1994) Price-conditional technology, *Journal of Agricultural and Resource Economics* 19, 161-172.

Fulginiti L.E., Onofri A. (2008) Public inputs and dynamic producer behavior: Endogenous growth in US agriculture, *Journal of Productivity Analysis* 30, 13-48.

Hayami Y., Ruttan V.W. (1985) *Agricultural Development. An International Perspective*, Baltimore, Johns Hopkins University Press, 512 p.

Hayami Y., Ruttan V.W. (1970) Factor prices and technical change in agricultural development: The United States and Japan, 1880-1960, *Journal of Political Economy* 78, 1115-1141.

Hicks J.R. (1957) *The Theory of Wages*, Gloucester, Smith, 247 p.

Huffmann W.E., Ball V.E., Gopinath M. and Somwaru A. (2002) Public R&D and infrastructure policies: Effects on cost of Midwestern agriculture, *in*: *Agricultural Productivity: Measurement of Sources of Growth*, Ball V.E., Norton G.W. (eds), Boston, Kluwer Academic Publishers, 167-183.

Karagiannis G., Furtan W.H. (1993) Production structure and decomposition of biased technical change: An example from Canadian agriculture, *Review of Agricultural Economics* 15(1), 21-37.

Karagiannis G., Furtan W.H. (1990) Induced innovation in Canadian agriculture : 1926-87, *Canadian Journal of Agricultural Economics* 38, 1-21.

Kawagoe T., Otsuka K. and Hayami Y. (1986) Induced bias of technical change in agriculture: The United States and Japan, 1880-1980,*Journal of Political Economy* 94(3), 523-544.

Khatri Y., Thirtle C. and Townsend R. (1998) Testing the induced innovation hypothesis: An application to UK agriculture, 1953-90, *Economics of Innovation and New Technology* 6, 1-28.

Kohli U. (1993) A symmetric normalized quadratic GNP function and the US demand for imports and supply of exports, *International Economic Review* 34, 243-255.

Koppel B.M. (1994) *Induced Innovation Theory and International Agricultural Development : A Reassessment*, Baltimore, Johns Hopkins University Press, 200 p.

Kumbhakar S.C. (1989) Estimation of technical efficiency using flexible functional form and panel data,*Journal of Business and Economics Statistics* 7, 253-258.

Lasserre P., Ouellette P. (1991) The measurement of productivity and scarcity rents : The case of Asbestos in Canada,*Journal of Econometrics* 48, 287-312.

Machado F.S. (1995) Testing the induced innovation hypothesis using cointegration analysis,*Journal of Agricultural Economics* 46, 349-360.

Mergos G., Karagiannis G. (1997) Sources of productivity change under temporary equilibrium framework and application to Greek agriculture, *Journal of Agricultural Economics* 48, 313-329.

Morrison C.J. (1988a) Quasi-fixed inputs in US and Japanese manufacturing: A generalized Leontief restricted cost function approach, *Review of Economics and Statistics* 70, 275-287.

Morrison C.J. (1988b) Subequilibrium in the North American steel industries: A study of short run biases from regulation and utilisation fluctations, *Economics Journal* 98, 390-411.

Olmstead A.L., Rhode P. (1993) Induced innovation in American agriculture: A reconsideration,*Journal of Political Economy* 101, 100-118.

Paris Q., Caputo M.R. (2001) Price-induced technical progress and comparative statics, *Economics Bulletin* 15, 1-8.

Paris Q., Caputo M.R. (1995) The rhetoric of duality, *Journal of Agricultural and Resource Economics* 20, 195-214.

Peeters L., Surry Y. (2000) Incorporating price-induced innovation in a symmetric generalised McFadden cost function with several outputs, *Journal of Productivity Analysis* 14, 53-70.

Pierani P., Rizzi P.L. (2005) Utilizzazione della capacità e crescita della produttività totale nell'agricoltura italiana (1952-1991), *in*: *Cambiamenti strutturali e convergenza economica nelle regioni dell'Unione europea*, Brasili C. (ed.), Bologna, CLUEB, 432 p.

Pierani P., Rizzi P.L. (2003) Technology and efficiency in a panel of Italian dairy farms: An SGM restricted cost function approach, *Agricultural Economics* 29, 195-209.

Rizzi P.L., Pierani P. (2006) *AGREFIT. Ricavi, costi e produttività dei fattori nell'agricoltura delle regioni italiane (1951-2002)*, Milano, Franco Angeli, 65 p.

Ruttan V.W. (1997) Induced innovation, evolutionary theory and path dependence: Sources of technical change, *Economic Journal* 107, 1520-1529.

Shaik S. (1998) Causality between TFP, R&D and prices: Unconditional and conditional linear feedback, Paper presented at the AAEA Meeting, Nashville (Tennessee), August.

Sunding D., Zilberman D. (2001) The agricultural innovation process: Research and technology adoption in a changing agricultural sector, *in*: *Handbook of Agricultural Economics*, vol. 1a, Gardner B.L., Rausser G.C. (eds), Amsterdam, North-Holland, 207-261.

Thirtle C. (1985) The microeconomic approach to induced innovation: A reformulation of the Hayami and Ruttan model, *Manchester School of Economic and Social Studies* 53, 263-279.

Thirtle C., Schimmelpfennig D.E. and Townsend R. (2002) Induced innovation in United States agriculture, 1880-1990: Time series tests and an error correction model, *American Journal of Agricultural Economics* 84, 598-614.

Thirtle C., Townsend R. and van Zyl J. (1998) Testing the induced innovation hypothesis: An error correction model of South African agriculture, *Agricultural Economics* 19, 145-157.