Induced Innovation in Italy: an Error Correction Model for the Period 1968-2002

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Abstract

In this work we utilise CES approach where factor ratios (mechanical power/labour and fertilizer/land) are regressed on price ratios and efficiency parameters (public and private R&D) to obtain a direct test of the induced innovation in Italian case for the period 1968-2002. Provided that inducement hypothesis implies a long run relationship an error correction model (ECM) is estimated to separate long-run effect, that is technological innovation, from short-run effects, that is factors substitution. The results corroborate the induced innovation hypothesis and underline the importance of private R&D in Italian agriculture.

Keywords: induced innovation, ECM, Italian agriculture
JEL: Q16

1. Innovation, technological progress and development of Italian agriculture

The prospect of a radical change in agricultural policies (particularly the proposed reduction in the support the EU's common agricultural policy offers to agricultural production mainly through the price mechanism) raises two orders of reflection. On the one hand, it presents European (and therefore also Italian) farmers problems of reviewing their production mix on the basis of maximising the revenues obtainable from the market and the new subsidies decoupled to production volumes; on the other, it requires an analysis of production models aimed at identifying the most suitable growth mechanisms for confronting the new agricultural situation.

Over the course of the last 40 years or so (i.e. since the introduction of the CAP), Italian agriculture has undergone unprecedented growth. In comparison with the 1960s, production has quadrupled, more intensive production processes have been developed as a result of the introduction of technology, the used arable land has decreased by just over 20%, and agricultural employment has fallen by about 60%. It is therefore clear that, throughout this period, there has been a significant increase in productivity as assessed in terms of output per unit of production factor.

However, a result of this kind must be carefully analysed in an attempt to understand the individual weight of the various mechanisms involved in bringing it about. In particular, we though it would be interesting to examine the role of induced innovation in enhancing the effects of the rationalisation of the Italian agricultural production system due to the consequent choices and adaptations made by Italian farmers during the same period, in which there has been considerable competition between the agricultural and other economic sectors aimed at procuring the resources necessary to feed their respective growth processes. It must be forgotten that, particularly during the first decade, the Italian economic system as a whole was characterised by very high rates of development that continued until the monetary crises of the 1970s and the second oil crisis occurring at the end of the same decade. In this context, there was an intense flow of labour from the agricultural sector to the rest of the economy, and this has continued until today despite the resulting increase in wages. Consequently, agricultural labour has become an increasingly rare and costly resource, and this has induced its substitution by, for example, capital. During the same period, population growth, combined with a high demand for land for residential, industrial and commercial purposes, as well as for local infrastructures, contributed to making land itself a rare and increasingly expensive good, above all because of its obviously limited and non-reproducible nature. This last factor is particularly important because scientific and technological progress made available innovative mechanical and chemical products (such as fertilisers, insecticides and pesticides) whose price tends to be relatively lower than that of land and labour. These capital-related factors are widely available, and therefore could be drawn upon as substitutes.

In the case of Italy, innovation in terms of fertilisers and machinery has been substantially capital intensive and land or labour saving. However, in addition to the changes to which these solutions sought a response based on induced innovation, it is important to try to identify the functional relationships in Italian agricultural between the use of traditional production factors and the technical progress incorporated in the factors themselves, particularly capital.

In order to evaluate this last element, we used the number of patents as *proxy* of the innovation associated with private R&D financing, and the public financing aimed at R&D deducible from the related public expenditure.

2. Modelling induced innovation theory

This paper describes the pathways of the growth of Italian agriculture from the point of view of "induced" innovation (Hayami and Ruttan 1985), which refers to the technological changes stimulated by precise economic forces. In particular, it concerns the innovations that facilitate the replacement of abundant and consequently cheap production factors by those that are scarce and therefore expensive. It follows that a negative correlation between the ratios of factor prices and quantities should arise as a result of technological improvements and not just substitution effects. Induced innovation is more likely to emerge over the long term during which a sort of mechanism of equilibrium smoothes out the deviations that may occur over the short term. The theory therefore analyses the causal connection between factor prices, expected prices, and the research and development priorities of new technologies. In particular, Hayami and Ruttan hypothesise that, during the period following a change in the relative prices of the various factors at a given level of technology, farmers seek to replace the most expensive with the cheapest. If these price changes alter the farmers' expectations concerning future prices, there will be an increase in their demand for the new technologies that allow them to reduce their use of the more expensive factors. Public and private research should satisfy this demand by making the required technologies available, albeit with a certain difference in timing.

The concept of induced innovation has been econometrically modelled in various studies in different ways that have evolved over time (Hayami and Ruttan, 1985; Antle, 1984; Machado, 1995), but models allowing its direct estimate have only recently been introduced (Frisvold, 1991; Katri et al., 1998; Thirtle et al. 1998; Thirtle et al., 2002).

In Italy, the hypothesis of induced innovation has been mainly analysed by Esposti (Esposti, 2000a; Esposti and Pierani, 2002; Esposti and Pierani, 2003), although it has never been fully demonstrated. A first study highlighted the presence of induced innovation on the output side, but it appears dubious in terms of inputs; another study underlined the hypothesis with short-run evidence not supported by a consequent long-run R&D investment behaviour; and yet another rejected the hypothesis due to the nature of Italian public research, which seems to be driven more by specific social and political objectives (such as keeping workers in agriculture) than by market forces.

The model utilized by Thirtle et al. (2002) who combine two approaches developed by de Janvry et al. (1989) and Frisvold (1991) is considered in this work. The starting point is a two-level constant elasticity of substitution (CES) production function which are included efficiency parameters that are functions of research activities.

From the first order conditions of a profit maximization problem, the optimal factor ratios can be expressed in the following form:

$$\ln\left(\frac{Q_M}{Q_L}\right) = \sigma_1 \ln\left(\frac{1-\beta}{\beta}\right) + (\sigma_1 - 1)\ln E_M - \sigma_1 \ln\left(\frac{P_M}{P_L}\right) \quad (1)$$

$$\ln\left(\frac{Q_F}{Q_{LAND}}\right)=\sigma_2\ln\left(\frac{1-\alpha}{\alpha}\right)+(\sigma_2-1)\ln E_F-\sigma_2\ln\left(\frac{P_F}{P_{LAND}}\right) \quad (2)$$

where Q_M is machinery, Q_L is labour input, Q_F is fertilizer, Q_{LAND} is land and P_M, P_L, P_F, P_{LAND} are the price of inputs. E_M and E_F are efficiency parameters functions of public and private research and development activities and could result from exogenous changes in scientific knowledge or technological spillovers from other industries (Binswanger, 1974).

Hence this approach provide a theoretical basis for direct tests of inducement hypothesis, since the factor ratios are functions of the price ratios and government and private research.

3. Data

Different sources are be utilized in the application for the period 1968-2002. Annual data for quantity and price concern:

- $\mathbf{Q_M}$: mechanical power in HP (Unacoma);
- $\mathbf{P_m}$: Indexes of agricultural machinery prices bought from farmers (Istat, Producer prices);
- $\mathbf{Q_L}$: number of agricultural hired labourers (Istat, National Account);
- $\mathbf{P_L}$: wages of agricultural hired labourers in lire/labourer ((Istat, National Account);
- $\mathbf{Q_{LAND}}$: Land quantity: agricultural land in ha (INEA);
- $\mathbf{P_{LAND}}$: agricultural land price in lire/ha (INEA);
- $\mathbf{Q_F}$: fertilizer utilized in tonn (FAO);
- $\mathbf{P_F}$: Indexes of fertilizer prices bought from farmers (Istat, Producer prices);
- **R&D**: Public research and development (INEA) deflated by GDP deflator;
- **PT**: patent data (European Patent Office).

Some comments need to made concerning the patent data.

Although sometimes criticised (Schankerman and Pakes, 1986), patent data seem to be suitable economic indicators of the technological activity of a sector, and their relevance has been supported by a number of authoritative economists (Griliches, 1990). For this study, we used information about patents with Italian priority taken from the *Esp@cenet* database on the basis of the year of deposit according to IPC code A01 (agriculture, sylviculture, breeding, hunting and fishing). However, it must be borne in mind that the IPC is strictly technological and may be of little use for economic analysis. In particular, Italian agriculture typically makes use of a technology in which process innovations are mainly product innovations relating to other sectors (Esposti, 2000b). It is therefore useful to estimate in some way the number of patents deposited by following the IPC but which, regardless of the code itself, have an impact on the agricultural system. To this end, we used the Yale Technology Concordance (YTC), which was conceived in Canada by Evenson and Johnson (1997) as a means of translating the IPC codes into codes based on a patent's sector of origin (IOM) and sector of use (SOU). The YTC is based on the probability of a patent with a given IPC classification being attributed an IOM and SOU code which, once known, can be used in every spatial and temporal reality. For the purposes of this study, we took the series of conditioned probabilities relating to patents in the IPC classifications which, in terms of their destined use (SOU), have to do with the agricultural sector, and used to estimate the number of patents destined for agricultural use originating from the other principal sectors. In addition to the variable relating to the patents classified as IPC A01 ($\mathbf{PT_{AGR}}$), the following application made use of two other variables (see Baldi, 2005, for details): a) the number of A01 patents plus the estimated number of patents originating from all other sectors but destined for agricultural use ($\mathbf{PT_{YTC}}$); and b) the number of A01 patents plus the estimated number of patents deposited in the chemical sector that had agricultural implications ($\mathbf{PT_{CH}}$).

The following graphs show the inter-relationships of factor variables, the simple trend of which is enough to provide a first indication of the presence of the induced innovation hypothesis. In particular, analysis of the relationship between mechanical means and agricultural labour in both quantitative and price terms (Fig. 1) shows that it considerably increased up to the beginning of the 1980s, declined in a highly oscillating manner over the next ten years, and then resumed a trend of constant growth. The relationship between labour costs and machinery prices paralleled that of quantities except for the period 1991-99, when there was a weak correlation between the two series.

Albeit with considerable oscillations, the quantitative and price ratios between fertilisers and land generally increased and, with the exception of a few years, there was a close correlation between the two, once again highlighting the behaviours predicted by induced innovation.

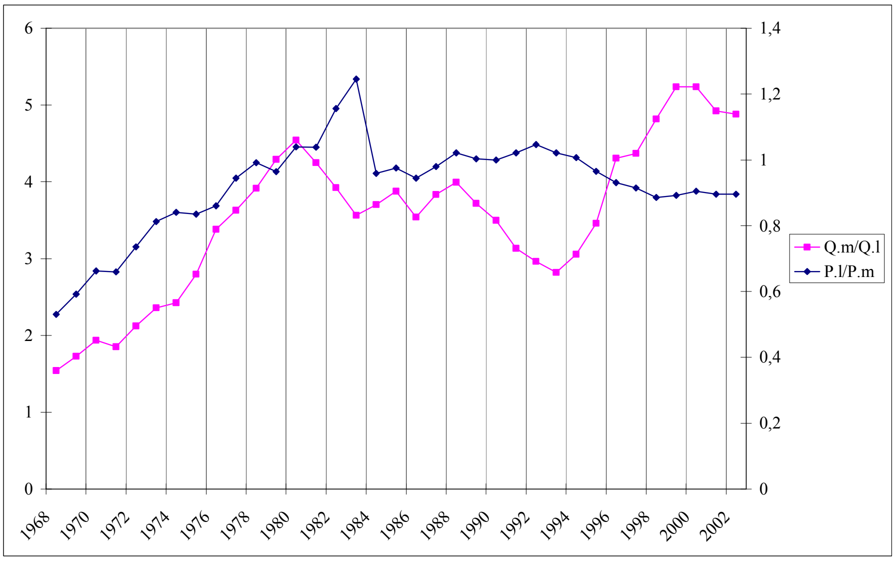

Figure 1. Mechanical power/labour factor ratio and labour/machinery price ratio.

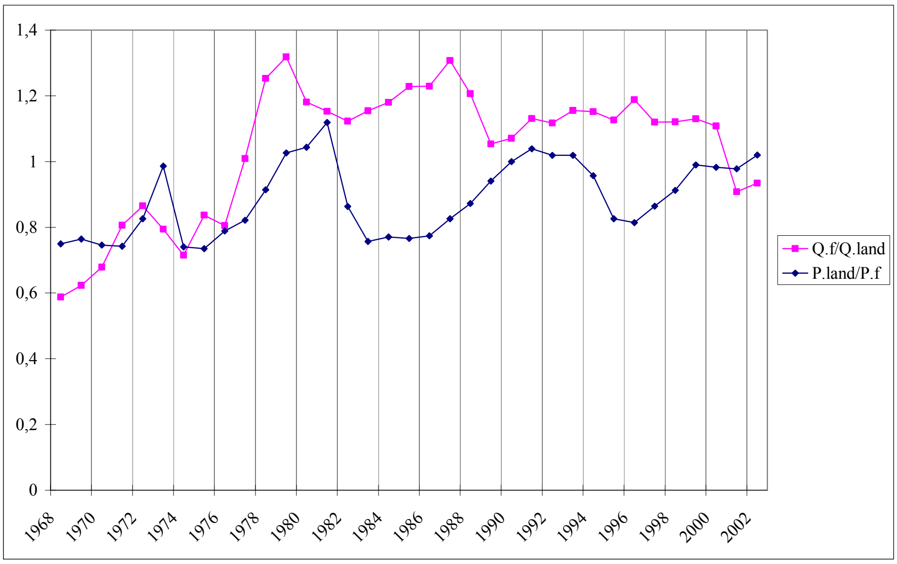

Figure 2. Fertilizer/land ratio and land/fertilizer price ratio

4. Time series and cointegration tests

Induced innovation implies a long-run relationship between technical change and a measure of factor scarcities. Cointegration is essentially based on the idea that there may be a long-run co-movement between trended economic time series so that there is a common equilibrium relation which the time series have a tendency to revert to (Engle and Granger, 1987). Therefore this technique appears particularly suitable to modelling inducement hypothesis.

Testing for cointegration involves two steps. First, determine the degree of integration in each of the series to verify if variables are integrated of the same order. Second, estimate the cointegration regression of which error terms must be of a lower degree.

To test the degree of integration of the variables we used two test: Phillips-Perron test (PP) (Phillips, 1987) and Kwiatkowski test (KPSS) (Kwiatkowski et al., 1992). The first tests the null hypothesis that the series have a unit root, whereas the second one compares the null hypothesis of stationarity against the alternative of a unit root. Schlitzer (1995) indeed demonstrate that a combined use of unit root and stationary test would significantly reduce the number of erroneous conclusion.

Table 1 shows the results of the two tests; both the level and first difference of each series were tested. The results of the PP test show that all variables are non-stationary in levels but stationary in first differences at 0,05 significance level. KPSS procedure confirms that the series are unit root in level and stationary in first differences.

Table 1. PP and KPSS tests results

Variables	PP test	KPSS test
Log. of Q_M/Q_L	-2.003	0.252*
Δ log. of Q_M/Q_L	-3.623**	0.145
Log. or $P_{M/}P_L$	-2.631	0.391*
Δ log. of P_M/P_L	-6.276**	0.081
Log. of Q_F/Q_{LAND}	-1.7421	0.361*
Δ log. of Q_F/Q_{LAND}	-5.095**	0.033
Log. or $P_{F/}P_{LAND}$	-2.869	0.551*
Δ log. of P_F/P_{LAND}	-4.883**	0.038
Log. or $P_{LAND/}P_L$	-1.650	0.29*
Δ log. of P_{LAND}/P_L	-4.162**	0.055
Log. of R&D	-0.426	0.363*
Δ log. of R&D	-6.1904**	0.0941
Log. of PT_{AGR}	-2.263	0.228*
Δ log. of PT_{AGR}	-5.331**	0.090
Log. of PT_{YTC}	-1.561	1.4656*
Δ log. of PT_{YTC}	-4.004**	0.204
Log. of PT_{CH}	-2.797	0.169*
Δ log. of PT_{CH}	-5.149**	0.090

*** indicates the reject of the null hypothesis at 0.05 significance level*
** indicates the reject of the null hypothesis at 0.05 significance level*

Having assumed that each series are first order integrated I(1), cointegration procedure can commence. Provided that the asset are not integrated on pair-wise basis but in some multivariate way, we must suppose that the assets are cointegrated jointly. In order to test for higher orders of cointegration we adopt the approach of Johansen (1988) and Johansen and Juselius (1990) where if we have N endogenous variables I(1), there can exist from 0 to N-1 linearly independent cointegrating vector that represent long-run equilibrium relationships. The number of these equations is called the "cointegrating rank" and the Johansen tests can determine the number of cointegrating equations. In a multivariate test we are interested whether there exists at least one cointegrating vector. In fact if the rank is equal to 0, then no series of the variables can be expressed as a linear combination of the remaining series. Of contrary, if we obtain only one cointegrating vector, we can assert that one long-run relationship between variables exists and with rank greater than 1 we obtained more simultaneous relationships that can be hard to justify in economics terms.

The results of the machinery/labour cointegration are reported in tab. 2. The variables that result cointegrated each others are: Q_M/Q_L, P_M/P_L, PT_{YTC}. The tests show that public R&D, P_{LAND}/P_L and agricultural patents are not significant to explain long-run relationship machinery/labour. This result can appear quite surprising, but we must consider that research on mechanical innovations, being easily patentable, is carried out primarily by private rather than public sector. The Schwartz criterion was used to determine the maximum lag length, which was found to be 4 years. The Trace and Maximum Eigenvalue Test indicate the presence of only one cointegrating vector thus a clear lung-run relationship exists.

Table 3 summarises cointegration results of fertilizer/land equation. Strong cointegration is found between Q_F/Q_{LAND}, P_F/P_{LAND}, P_{LAND}/P_L, R&D and PT_{CH}. Using Schwartz criterion it was found the maximum lag length to be 2 and in this case the two tests yield different results: 3 cointegrating vectors found with Trace Test and 1 cointegrating vector with Maximum Eigenvalue Test, so we can confirm the presence of cointegration.

It is interesting note that chemical plus agricultural patent (PT_{CH}) and not only agricultural patent are significant in this long-run relationship.

Table 2. Cointegration results for machinery/labour relation: test for the number of cointegrating vectors

- Series: Q_M/Q_L, P_M/P_L, PT_{YTC}

Hypothesized No. of Cointegr. vectors	Trace Test	Critical Value at 0.05 signif.	Prob.**
None *	58.169	42.915	0.001
At most 1	25.700	25.872	0.052
At most 2	9.094	12.518	0.175
Hypothesized No. of Cointegr. vectors	Max-Eigenvalue Test	Critical Value at 0.05 signif.	Prob.**
None *	32.470	25.823	0.006
At most 1	16.606	19.387	0.121
At most 2	9.094	12.518	0.175

** denotes rejection of the hypothesis at the 0.05 level*
*** MacKinnon-Haug-Michelis (1999) p-values*

Table 3. Cointegration results for fertilizer/land relation: test for the number of cointegrating vectors

- Series: Q_F/Q_{LAND}, P_F/P_{LAND}, P_{LAND}/P_L, R&D, PT_{CH}

Hypothesized No. of Cointegr. vectors	Trace Test	Critical Value at 0.05 signif.	Prob.**
None *	117.206	60.061	0.000
At most 1	44.265	40.175	0.018
At most 2	24.315	24.276	0.049
At most 3	8.860	12.321	0.177
At most 4	2.874	4.130	0.106
Hypothesized No. of Cointegr. vectors	**Max-Eigenvalue Test**	**Critical Value at 0.05 signif.**	**Prob.****
None *	72.941	30.440	0.000
At most 1	19.950	24.159	0.168
At most 2	15.455	17.797	0.109
At most 3	5.986	11.225	0.351
At most 4	2.874	4.130	0.106

** denotes rejection of the hypothesis at the 0.05 level*
*** MacKinnon-Haug-Michelis (1999) p-values*

5. Empirical evidences and results

In order to achieve equilibrium, there exists a dynamic system that consists of short-run changes leading to long-run equilibrium. This dynamic system is known as the error correction model (ECM). Granger Representation theorem (Engle and Granger, 1987) says that cointegration implies Error Correction Model (ECM) and *viceversa* and so ECM is a model designed for use with nonstationary series that are known to be cointegrated. This specification restricts the long-run behaviour of dependent variable to converge to their cointegrating relationships while allowing a wide range of short-run dynamics.

Following the theoretical model (1) and (2) and the results of cointegration procedure, ECM specifications for machinery/labour is:

$$\Delta \ln(Q_M/Q_L)_t = c_1 + \sum_{i=1}^{4}\alpha_{1i}\Delta \ln(Q_M/Q_L)_{t-i} + \sum_{i=1}^{4}\alpha_{2i}\Delta \ln(P_M/P_L)_{t-i} + \sum_{i=1}^{4}\alpha_{3i}\Delta \ln(PT_{YTC})_{t-i} +$$

$$+\lambda_1 \cdot \left[\ln(Q_M/Q_L)_{t-1} - \beta_1 \ln(P_M/P_L)_{t-1} - \beta_2 \ln(PT_{YTC})_{t-1} - c_2 - t\right] \quad (3)$$

where:

- $\Delta \ln(Q_M/Q_L)$ is first difference of log of machinery quantity (Q_M) and labour quantity (Q_L) ratio;

- $\Delta \ln(P_M / P_L)$ is first difference of log of machinery price (P_M) and labour price (P_L) ratio;
- $\Delta \ln(PT_{YTC})$ is first difference of log of patent estimated by Yale Technology Concordance;
- c_1 and c_2 are constants;
- α_1, α_2, α_3, β_1, β_2 are coefficients of variables;
- t is the trend;
- λ_1 is the error correction term of the first equation.

The equation for fertilizer/land relationships is defined as:

$$\Delta \ln(Q_F / Q_{LAND})_t = \sum_{i=1}^{2} \gamma_{1i} \Delta \ln(Q_F / Q_{LAND})_{t-i} + \sum_{i=1}^{2} \gamma_{2i} \Delta \ln(P_F / P_{LAND})_{t-i} +$$

$$+ \sum_{i=1}^{2} \gamma_{3i} \Delta \ln(P_{LAND} / P_L)_{t-i} + \sum_{i=1}^{2} \gamma_{4i} \Delta \ln(PT_{CH})_{t-i} + \sum_{i=1}^{2} \gamma_{5i} \Delta \ln(R \& D)_{t-i} +$$

$$+ \lambda_2 \cdot \left[\ln(Q_F / Q_{LAND})_{t-1} - \delta_1 \ln(P_F / P_{LAND})_{t-1} - \delta_2 \ln(P_{LAND} / P_L)_{t-1} - \right.$$

$$\left. - \delta_3 \ln(PT_{CH})_{t-1} - \delta_4 \ln(R \& D)_{t-1} \right] \quad (4)$$

where:

- $\Delta \ln(Q_F / Q_{LAND})$ is first difference of log of fertilizer quantity (Q_F) and land quantity (Q_{LAND}) ratio;
- $\Delta \ln(P_F / P_{LAND})$ is first difference of log of fertilizer price (P_F) and land price (P_{LAND}) ratio;
- $\Delta \ln(P_{LAND} / P_L)$ is first difference of log of land price (P_{LAND}) and labour price (P_L) ratio;
- $\Delta \ln(PT_{CH})$ is first difference of log of agricultural plus chemical patents;
- $\Delta \ln(R \& D)$ is first difference of public R&D;
- γ_1, γ_2, γ_3, γ_4, γ_5, δ_1, δ_2, δ_3, δ_4, are coefficients of variables;
- λ_2 is the error correction term of second equation.

The first part of the equations represents short-run and is in first differences while the part in square brackets denotes long-run and is in the levels. The λ_1 and λ_2 represent the long-run relations between cointegrating vector of M/L and F/LAND respectively and determine the speed of convergence to the long-run equilibrium. As Thirtle et al. (2002) argue, in this case the meaning of the variables in equation (3) and (4) is clearly known because the underlying model is the first-order condition of the two stage CES production function.

The equation (3) and (4) are estimated with OLS and results are reported in table 4.

The table shows only the results more significant in term of goodness of fit and of induced innovation. The machinery/labour model performed quite good with an adjusted R^2 equal to 0.312, not so low for an ECM. In short run some variables are significantly different from zero and the estimated coefficients can be interpreted as direct short run elasticity of substitution, provided that original variables are in logarithms. Chemical plus agricultural patents doesn't appear in the table because is not significant in short run.

In the long run model performs better: signs of estimated coefficients are in agreement with theory (Frisvold, 1991), and λ_1 is negative and highly significant, that means that system run toward equilibrium, like is request from an ECM. Furthermore, his value equal to -0.416 implies rapid adjustment.

Table 4. Results of the ECM for machinery/labour equation and fertilizer/land equation

M/L				**F/LAND**			
Variables	Coeff.	Value of coeff.	t-value	Variables	Coeff.	Value of coeff.	t-value
Short-run:				***Short-run:***			
$\Delta\ln(Q_M/Q_L)_{-1}$	α_{11}	0.482	*(2.203)*	$\Delta\ln(Q_F/Q_{LAND})_{-1}$	γ_{11}	0.446	*(2.182)*
$\Delta\ln(P_M/P_L)_{-1}$	α_{21}	0.823	*(2.325)*	$\Delta\ln(PT_{CH})_{-1}$	γ_{41}	-0.199	*(-2.452)*
$\Delta\ln(P_M/P_L)_{-3}$	α_{23}	0.581	*(2.092)*	$\Delta\ln(PT_{CH})_{-2}$	γ_{42}	-0.385	*(-3.275)*
				$\Delta\ln(R\&D)_{-2}$	γ_{52}	0.338	*(2.400)*
Long-run:				***Long-run:***			
$\ln(Q_M/Q_L)_{-1}$	λ_1	-0.416	*(-2.664)*	$\ln(Q_F/Q_{LAND})_{-1}$	λ_2	-0.443	*(-3.019)*
$\ln(P_M/P_L)_{-1}$	$\lambda_1 \cdot \beta_1$	-1.066	*(-4.660)*	$\ln(P_F/P_{LAND})_{-1}$	$\lambda_2 \cdot \delta_1$	-0.247	*(-2.074)*
$\ln(PT_{YTC})_{-1}$	$\lambda_1 \cdot \beta_2$	0.556	*(2.479)*	$\ln(P_{LAND}/P_L)_{-1}$	$\lambda_2 \cdot \delta_2$	-0.487	*(-3.463)*
				$\ln(PT_{CH})_{-1}$	$\lambda_2 \cdot \delta_3$	0.356	*(5.395)*
R^2		0.643		R^2		0.595	
Adj. R^2		0.312		Adj. R^2		0.370	

Note: critical t-values for 95% and 97.5% confidence are 2.04 and 2.35 respectively.

The fertilizer/land equation too runs quite well in term of goodness of fit with the most important coefficients related to induced innovation statistically significant and coherent with theory. Also in this case the value of error correction term λ_2 expresses that there is fast movements toward long run equilibrium.

Various elasticities for the two relationships were calculated on the basis of the results of the econometric estimates of the model. In the short term, the elasticity of replacement relating to a given technology can be read as movements in the isoquant curve whereas in the long-run, following Ahmad's concept of an innovation possibility curve (IPC) that represents the envelope of all possible unit isoquants (technologies), it can be read as movements in the IPC, given the state of scientific knowledge. In this sense, a system reaches long-term equilibrium only after adopting the technological innovations induced by the changes in their prices.

In relation to the short term, as mentioned above, the estimated coefficients can be interpreted directly as elasticity but, for the long term, it is necessary to divide the coefficients by the estimated values of λ_1 e λ_2. The results of these calculations are shown in the following table (tab. 5).

As induced innovation essentially takes place over the long term, short-term elasticities mainly take on the significance of a "substitution effect". In this sense, in the case of the machinery/labour relationship, the value of +0.823 binding the price and quantity ratios shows that the short-term replacement effect went in the direction of machinery-saving technology and, as we shall see, runs contrary to what happened in the long term. The effect of patents on the Q_M/Q_L ratio is obviously not significant because it is hardly likely that the new inventions would have had immediate beneficial effects on the mechanical sector. However, some interesting points can be made in relation to the long-term elasticities. The negative elasticity with regard to prices indicates that a reduction in the ratio between the prices of agricultural machinery and labour generates a labour-saving technological change that is in line with the hypotheses of induced innovation. Furthermore, the very high value of this elasticity suggests that the impulse is particularly strong. The introduction of chemical patents also led to a substantially greater use of machinery, as can be deduced from the relative elasticity value of +1.34. In addition, as already pointed out, the effect of public R&D did not have any significant effects, probably because the very nature of such financing means that it is mainly destined for interventions that cannot be directly perceived in terms of the replacement of labour by machinery.

It also seems to be worth noting the interpretation of elasticities in the relationship between fertilisers and land. In the short-term, the elasticity between the factors of the Q_F/Q_{LAND} ratio and their prices does not appear to be significant, thus leading to the conclusion that the replacement of land by fertilisers is not very substantial when short periods are considered. What is even more surprising is that the patents deposited in the agricultural and chemical sectors seem to have effects that are more negative than expected. On the other hand, the significance of the influence of public R&D is demonstrated by its elasticity of 0.34. However, the long-term results are fully in line with the hypotheses of induced innovation. Price elasticity is negative (-0.56), which means that the technological changes adopted in Italy during the period in question were of the land-saving type, even though the replacement effect was not as strong as that associated with mechanisation and labour. Further, the negative elasticity between the ratio of the factors fertilisers/land and the ratio between land and labour prices, indicates that labour and land are substitutes. Finally, it can be seen that the effect of agricultural and chemical patents positively influenced the use of fertilisers.

Table 5. Long-run elasticities for machinery/labour and fertilizer/labour equations

	Machinery/Labour	**Fertilizer/Land**
P_M/P_L	-2.56	-
P_F/P_{LAND}	-	-0.56
P_{LAND}/P_L	-	-1.10
PT_{YTC}	+1.34	-
PT_{CH}	-	+0.80

6. Induced innovation in Italian agriculture: results and policy implications

The results of the model discussed in the paragraphs above contain some aspects that allow not only the identification and quantification of some quantitative relationships between the use of the factors, their innovative content and the elements that have had a multiplying effect on the related phenomena, but also the development of some valid considerations for evaluating policy implications.

The relationship between mechanisation and labour confirms the major substitution of labour by capital partly in order to release the former, which is greatly sought by other sectors in order to satisfy their growth needs (as can be seen by looking at the relationships between their respective prices), and partly as a result of the increasing technological content of the capital/machines. In this sense, the introduction of technology is combined with a tendential reduction in machinery prices in a further play of substitution between *hardware* and *software*. The impact of public R&D does not seem to be significant, but it must be borne in mind that Italy has some major manufacturers such as the FIAT group (the current world leader in the field of agricultural machinery) and the SAME group (another international leader), together with a substantial proportion of SMEs (small and medium-sized enterprises) with a high degree of innovative capacity, whereas public interventions have mainly involved incentives in the form of subsidised fuel prices that have made it less expensive to use machinery, and have only recently involved incentives for demolition aimed at stimulating an artificial recovery in the demand for mechanical means. Finally, the analysis of patents point out that the innovation is prevalently exogenous: i.e. it originates in other sectors and is subsequently transferred to agriculture.

The relationship between fertilisers and land mirrors that relating to machinery, although this is not so obvious because the demand for fertilisers started to slow in the 1990s, and then contracted because of the increasing adoption of regulatory provisions aimed at reducing the use of chemicals and the growing pressure of public opinion in favour of ecologically compatible practices. The innovation in the sector is confirmed not only by the patent data results, but also on the empirical basis of the examination of the new sales formulations that have reduced the amounts used per hectare of cultivated land.

Despite the complexity of the system to which they apply, the results of the model highlight some important aspects. In the long-term, they clearly describe a series of phenomena that have occurred in Italian agriculture, and confirm the analyses of agricultural policies that have been developed over time. However, it must be remembered that the growth of the agriculture sector during this period benefited from particularly favourable conditions granted by the CAP support mechanisms, which were constructed in such a way as to keep prices high and thus guarantee agricultural profits. The main indicator for Italian and European farmer has therefore essentially consisted of the development of unit technical yields per hectare or per head of livestock. The relative importance of this support has been such as to absorb during some decades high factor prices. Factor productivity has been little considered in terms of choice because of the strong public support of prices, and therefore incomes.

The change in agrarian policies since 1992, which was accentuated by Agenda 2000 and the Mid-term review, requires the adoption of a new logic in choosing production adjustments. At the same purchase cost, the innovative content of the factors will become decisive because it will be necessary to restore competitiveness by reducing unit costs. This means that it will be necessary to orient the greater innovation in production factors (particularly capital) in order to reduce costs, for example by means of biotechnological innovations that can limit the recourse to chemical products and the machines for distributing them while simultaneously guaranteeing products that are less affected by cultivation adversities.

The introduction of innovation must allow the recovery of profitability and competitiveness in order to compensate for the decreased support of the CAP and permit producers to perceive that their incomes are in equilibrium with those arising from other activities.

R&D investments can be essentially oriented in this direction, at least as far as the public component is concerned, which is the component on which the choices of agricultural economic policies can be used to direct research.

References

Ahmad, S. (1966). On the Theory of Induced Innovation, Economic Journal 76: 344-357.

Antle, J. (1984). The Structure of U.S. Agricultural Technology, 1910-78. American Journal of Agricultural Economics 66: 414-421.

Baldi, L. (ed.) (2005). Analisi dei brevetti nell'agricoltura italiana durante il periodo 1970-2003. Roma, Italia: Aracne.

Binswanger, H. P. (1974). The Measurement of Technical Change Biases with Many Factors Production. American Journal of Agricultural Economics 66: 414-421.

de Janvry, A., Sadoulet, E., Fafchamps, M. (1989). Agrarian Structure, Technological Innovation, and the State. The Economic Theory of Agrarian Institutions. P. Bardhan, ed. Oxford: Clarendon Press.

Engle, R. F. and Granger, C. WJ. (1987), Co-Integration and Error Correction: Representation, Estimation, and Testing, Econometrica 55 (2): 251-276.

Esposti, R. (2000a). 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. (2000b). Spillover tecnologici e progresso tecnico agricolo. Rivista di Politica Economica 90 (4): 27-78.

Esposti, R. and Pierani, P. (2003), Public R&D investment and cost structure in Italian agriculture, 1960- 1995. European Review of Agricultural Economics 30(4): 509-537.
Esposti, R. and Pierani, P., (2002). Public R&D investment and cost behaviour in Italian agriculture: 1960-1995. Proceedings of the X EAAE Congress, – Saragozza, Exploring diversity in the European Agri-food System.
Evenson, R. E., Johnson, D. K. N. (1997). Innovation and Invention in Canada. Economic Systems Research 9(2): 177-192.
Frisvold, G.B. (1991). Endogenous Technological Change in U.S. Agriculture. A direct Test of the Induced Innovation Hypothesis. Technical bulletin No. 1790. Washington DC: U.S. Department of Agriculture, ERS.
Griliches, Z. (1990). Patent Statisitcs as Economic Indicators: A Survey. Journal of Economic Literature 28(4): 1661-1707.
Hayami, Y. and Ruttan, V. (ed.) (1985). Agricultural Development: An International Perspective, rev. ed. Baltimore, USA: Johns Hopkins University Press.
Johansen, S. (1988). Statistical Analysis of Cointegrating Vectors. Journal of Economic Dynamics and Control 12: 231-254.
Johansen, S. and Juselius, K. (1990). Maximum Likelihood Estimation and Inference on Cointegration-With Application to the Demand for Money. Oxford Bulletin of Economics and Statistics 52:169-210.
Khatri, Y., Thirtle, C., van Zyl, J. (1998). Testing the Induced Innovation Hypothesis: An Application to UK Agriculture, 1953-90. Economic Innovation and New Technology 6: 1-28.
Kwiatkowski, D., Phillips, P.C.B., Schmidt, P. and Shin, Y. (1992). Testing the Null Hypothesis of Stationarity Against the Alternative of a Unit Root: How Sure Are We That Economic Time Series Have a Unit Root? Journal of Econometrics 54**:** 159–178.
Machado, F. S. (1995). Testing the Induced Innovation Hypothesis Using Cointegration Analysis. Journal of Agricultural Economics, 46(3): 349-360.
MacKinnon, J. G., Haug, A., Michelis, L. (1999). Numerical Distribution Functions of Likelihood Ratio Tests for Cointegration. Journal of Applied Econometrics 14(5): 563-577.
Phillips, P. C. B. (1987). Time Series Regression with a Unit Root. Econometrica 55 (2): 277-301.
Schankerman, M. and Pakes, A. S. (1986). Estimates of the value of patent rights in European countries during the post-1950 period. Economic Journal 96: 1052-1076.
Schlitzer, G. (1995). Testing the Stationarity of Economic Time Series: Further Monte Carlo Evidence. Ricerche Economiche 49 (2): 125-144.
Thirtle, C. G., Schimmelpfennig D. E., Townsend, R. F. (2002). Induced Innovation in United States Agriculture, 1880-1990: Time Series Tests and an Error Correction Model. American Journal of Agricultural Economics 84(3): 598-614.
Thirtle, C. G., Townsend, R., van Zyl, J. (1998). Testing the Induced Innovation Hypothesis: An Error Correction Model of South African Agriculture. Agricultural Economics. 19: 145-157.