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# Public R&D Investment and Cost Behaviour in Italian Agriculture: 1960-1995.

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# Public R&D investment and cost behaviour in Italian agriculture: 1960-1995.

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## Abstract

*The public R&D capital stock is introduced as a quasi-fixed input in a variable cost function. The relative shadow price allows the correct measurement of the equilibrium levels of quasi-fixed inputs thus explicitly assessing the hypothesis of public R&D under (over) investment. By introducing an appropriate R&D price in the long-run equilibrium, the model can also provide empirical evidence on the rationale driving public R&D investment and on the hypothesis that free-riding on public R&D can explain over-investment. Moreover, the model allows a formal testing of the induced innovation hypothesis and a more accurate calculation of both internal rate of return to R&D and residual exogenous productivity growth. The empirical implications of the model are appraised in the case of Italian agriculture for the period 1960-1995.*

## 1. Introduction

The role of public R&D investment as source of technical progress in agriculture has produced a growing debate (Echeverria, 1990; Schimmelpfening *et al.*, 2000). The empirical literature provides evidence that not only is the social rate of return of public R&D very high compared with that of investment in physical capital but, more importantly, since the second half of the eighties, a reduction of publicly funded research in agriculture has been taking place giving scope, in a number of developed and developing countries, for private R&D (Huffman - Just, 1999; OECD, 1995; Rausser, 1999).

The apparent contradiction between actual policies and empirical evidence is intriguing. The major theoretical issue is what drives the level of public research investment. The rationale behind the public research investment is a subtle matter because it concerns a public good also producing private benefits since it can enhance input productivity in agriculture. It is also well known that constant returns to scale at the private farm level, and consequently the assumption of perfect competition, can be consistent with increasing returns to scale at the aggregate-sectoral level, whenever research investments behaves as a public good at the level of the agricultural sector (Jones, 1995; Griliches, 1995). These aspects also rise the major question how to define the optimal level of investment since this level can differ according to the private (farmers) or social point of view<sup>1</sup>.

In principle, we could think of a social planner using the private (conventional inputs) as

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<sup>1</sup> For a review on public funding of agricultural research see Barnes (2001).

the farmers would do and providing the public input (R&D stocks) according to its social costs, once it is appropriately calculated. Under this assumption, the optimal public R&D investment should depend on some behavioural rule and on external variables, mainly prices including also the (social) price of the research itself. Under this general framework, not only its own price affects R&D investment. Also conventional private inputs influence somehow the public R&D provision, while research investment can also affect, via R&D-induced biases, the conventional inputs use. This is the general idea of the induced innovation hypothesis (Ruttan, 1997; Chavas *et al.*, 1997, Esposti, 2000b). Finally, the relation between conventional (private) inputs cost and public R&D in this common behavioural framework, can allow to decompose the conventional total factor productivity growth attributing it to the R&D stock, the returns to scale and to the still unexplained residual.

In this study, we model the technology of Italian agriculture with a variable cost function, which includes the public R&D stock among the quasi-fixed inputs. The paper shows how we have constructed the relevant research price and provides empirical evidence on three main aspects. Firstly, it assesses whether optimal investment really occurs from the social point of view and gives an estimate of the actual returns to R&D investment. Secondly, it analyses the interaction between knowledge stock and conventional inputs in Italian agricultural inputs, by testing the induced innovation hypothesis, as well. Finally, it disentangles the primal productivity growth in its cost-side components, including the contribution of changes in public R&D stock and of increasing returns to scale due to the public good.

## 2. Micro foundations and methodological issues

### 2.1. A simple theory of public R&D investments

A relevant impulse to the analysis of the role of the R&D investments on growth, of its returns and of the consequent aggregate economies of scale has been given by the so-called endogenous growth theory (Jones, 1995). On the empirical side, however, the separation of the various sources of growth, including R&D, has been accomplished only in recent years, thanks to developments in duality theory and of flexible functional forms (Morrison-Schwartz, 1996a, 1996b; Morrison-Siegel, 1997; Nadiri-Mamuneas, 1994; Mamuneas-Nadiri, 1996; Nadiri-Prucha, 1993).

Under the hypothesis of cost minimisation, the variable cost function provides the dual representation of the agricultural short-run technology (Chambers, 1988):

$$(1) C_v = G(\mathbf{W}, \mathbf{X}, \mathbf{S})$$

where  $C_v$  is the minimised variable cost,  $\mathbf{W}$  is the vector of price of the variable inputs  $\mathbf{V}$ ,  $\mathbf{X}$  is the vector of the quantity of the quasi-fixed inputs with user cost  $\mathbf{P}$  (not affecting the variable cost) and  $\mathbf{S}$  is a vector of the fully exogenous variables. In this latter, usually the sectoral output  $Y$  is included together with a trend  $t$ , a proxy of the exogenous technological level, i.e. not explained by the public R&D investments<sup>2</sup>. Equation (1) expresses the minimum expense  $\mathbf{W}' \mathbf{V}$  for the variable inputs.

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<sup>2</sup> Here, we follow the traditional assumption that the *ex post* output equals the *ex ante* unobserved output. Actually, this hypothesis has important consequences in terms of estimate consistency. Recently, Moschini (1999) has discussed the implications of the output endogeneity within the duality framework.

The question is to understand how R&D enters this model<sup>3</sup>. In a number of studies, research appears among the elements of  $S$ . Hence, likewise  $t$ , R&D would be fully exogenous and no adjustment to some long-run (cost-minimising) level takes place. This assumption can be too strong for private R&D investment; however, the hypothesis is more plausible and sometimes accepted if public research is considered (Kuroda, 1997; Mullen *et al.*, 1996).

Alternatively, the knowledge stock can be viewed as an element of  $\mathbf{X} \equiv (\mathbf{X}_P, X_R)$ , where  $X_R$  is public research and  $\mathbf{X}_P$  the vector of the remaining quasi-fixed inputs (Mamuneas-Nadiri, 1996). Under this hypothesis, the R&D stock becomes endogenous as a price driven adjustment can take place in the long run. This specification allows to measure the difference between observed and equilibrium public R&D stocks thus allowing to test the hypothesis of under (over) investment in agricultural research (Harris-Lloyd, 1991).

Here, the key-element is the shadow price  $Z_R = -\partial G / \partial X_R$ , indicating the marginal contribution of R&D to the reduction of variable costs. The adjustment will last until  $Z_R = P_R$  and this is the basic behavioural rule driving the long-run R&D investments. However, who is going to carry out this adjustment? From a private point of view, farmers minimise (1) and do not bear any cost for using the public research capital (for them  $P_R = 0$ ) (Morrison-Schwartz, 1996b), hence in the long run they would demand R&D according to the behavioural rule  $Z_R = P_R = 0$ .

Decisions about public R&D investments, however, are taken by public institutions (Morrison-Siegel, 1997). Hence, from the social point of view,  $P_R > 0$  (social cost) and the R&D adjustment will be lead by the behavioural rule  $Z_R = P_R > 0$ . Therefore, we could analyse the public agricultural R&D investment by interpreting model (1) from the point of view of a social planner. He/She would minimise cost by considering both the public costs of the research and the private costs of the conventional inputs, and would invest in R&D to satisfy the long-run optimality condition  $G + \mathbf{Z}_P' \mathbf{X}_P + Z_R X_R = G + \mathbf{P}_P' \mathbf{X}_P + P_R X_R$ . In this framework it is possible to assess both whether the actual public R&D expenditure follows this social planner rule and how much the current R&D stock differs from the optimum.

## 2.2. Public R&D and induced innovation

The induced innovation hypothesis requires two distinct activities, at least: production and invention (Ruttan, 1997). For the induced innovation to hold, the conventional input a price increase should induce a reduction in the input use, through a selective research activity. Movement of (along) the Innovation Possibility Curve requires that resources be devoted to R&D before a new production process can be introduced. Therefore, if  $d(\ln V_j) / d(\ln W_j) < 0$  as effect of the research activity (since  $d(\ln V_j) / d(\ln W_j) = \partial \ln V_j / \partial \ln X_R \times \partial \ln X_R / \partial \ln W_j$ ) the induced innovation hypothesis holds (Chavas *et al.*, 1997, Esposti, 2000b). This hypothesis is empirically testable through price elasticity estimates.

Firstly, while the short run price elasticities for variable inputs are calculated as usual as  $\varepsilon_{ij} = \partial \ln V_i / \partial \ln W_j$  with  $\sum_j \varepsilon_{ij} = 0$ ,  $\forall i$ <sup>4</sup>,  $\varepsilon_{ik} = \partial \ln V_i / \partial \ln X_k$  measures the change of the variable

<sup>3</sup> It is usually excluded that the research input can behave as a variable input, since a several-years lag between the investment and the effects on production is always observed.

<sup>4</sup> From the sign (and the size) of these elasticities it is possible to assess if (and how much) the inputs are substitutes ( $>0$ ) or complements ( $<0$ ).

inputs use as the fixed input stocks change. Secondly, we can introduce the shadow prices elasticities, which provide information about the effects of other variables (prices and stocks) on the stock desired level. Shadow prices elasticities with respect to the variable inputs market prices,  $\varphi_{kj} = \partial \ln Z_k / \partial \ln W_j$ , with  $\sum_j \varphi_{kj} = 1, \forall k$ , can be interpreted as indirect measure of capacity utilisation. For instance, if  $\varphi_{kj} > 0$ , an increase in  $W_j$  implies also an increase of  $Z_k$  which in turn means higher utilisation of  $X_k$  ( $X_k^* / X_k$  increases). This effect would influence, in the long run, the optimal stock level  $X_k^* = X_k^*(\mathbf{W}, \mathbf{P}, Y, t)$ , since it is obtained by equalising the shadow and the market prices ( $P_k = -\partial G / \partial X_k = Z_k$ ). Also the long run variable inputs elasticities is affected by the stocks adjustment, since it is  $V_i^* = V_i^*(\mathbf{W}, \mathbf{X}^*(\mathbf{W}, \mathbf{P}, Y, t), Y, t)$  (Pierani and Rizzi, 1994).

Combining all these elasticities for R&D provides useful information about the induced innovation hypothesis.  $\varphi_{Rj} = \partial \ln Z_R / \partial \ln W_j$  indicates how much the variable input price change provides incentives to invest more in public research; this incentive should then generate an increase in the research stock in the long run ( $\partial \ln X_R / \partial \ln W_j$ )<sup>5</sup>.  $\varepsilon_{jR} = \partial \ln V_j / \partial \ln X_R$  indicates how the increase in the research effort actually and selectively affects the variable input use. The induced innovation hypothesis thus involves both the private (conventional input use) and the public (R&D investment) choices and the adjustment from the short to the long run. If  $\varphi_{Rj} = \partial \ln Z_R / \partial \ln W_j$  (and  $\partial \ln X_R / \partial \ln W_j$  in the long run)  $> 0$  and  $\varepsilon_{jR} = \partial \ln V_j / \partial \ln X_R < 0$ , then the results are consistent with the induced innovation hypothesis in the j-th variable input case.

Finally, since the shadow prices depends also on the other stocks endowment, we can also calculate the following coefficients of flexibility:  $\varphi_{kl} = \partial \ln Z_k / \partial \ln X_l$ . When two stocks are substitutes (complements) in the long run it follows that  $\varphi_{kl} < 0$  ( $\varphi_{kl} > 0$ ). Again, this measure can help in assessing the induced innovation hypothesis in the case of conventional quasi-fixed inputs.  $\varphi_{kR} = \partial \ln Z_k / \partial \ln X_R < 0$  means that an increase of R&D stock makes an investment in the for the k-th conventional stock less profitable. If also  $\partial \ln X_R / \partial \ln P_k > 0$  in the long run, then the induced innovation hypothesis holds for the k-th stock<sup>6</sup>.

### 2.3. Productivity growth decomposition

In our model, the growth of the total factor productivity (TFP) can be decomposed into the exogenous technical change and the other determinants such as capacity utilisation (Morrison-Diewert, 1990), scale effects and R&D contribution (Morrison-Siegel, 1998).

Assuming perfect competition, Ohta (1974) showed that the dual technical change rate ( $-\varepsilon_{Ct}$ ) equals the primal rate ( $\varepsilon_{Yt}$ ) adequately corrected by a scale factor ( $\varepsilon_{CY}$ ):

$$(2) \quad -\varepsilon_{Ct} = -\frac{\dot{C}}{C} + \varepsilon_{CY} \frac{\dot{Y}}{Y} + \sum_i S_i \frac{\dot{W}_i}{W_i} = \varepsilon_{CY} \frac{\dot{Y}}{Y} - \sum_i S_i \frac{\dot{V}_i}{V_i} = \varepsilon_{CY} \varepsilon_{Yt}$$

where the dot indicates the time derivative,  $S_i$  is the i-th variable input total cost share and

<sup>5</sup> However, this is true only if  $\partial \ln Z_R / \partial \ln X_R < 0$  and  $(\partial \ln X_R / \partial \ln P_R) < 0$ .

<sup>6</sup> Again this happens when  $\partial \ln Z_R / \partial \ln X_R < 0$  and  $(\partial \ln X_R / \partial \ln P_R) < 0$  where  $\partial \ln Z_R / \partial \ln X_R$  is the direct flexibility of R&D stock measuring the marginal effect of a change in the stock on its own profitability. For instance,  $\varphi_{kRR} > 1$  (in absolute value) indicates a rigid demand for that input, since an increase in the stock  $X_R$  reduces more than proportionally the convenience in increasing the desired stock level.

$\varepsilon_{CY} = \partial \ln C / \partial \ln Y$ ,  $\varepsilon_{Ct} = \partial \ln C / \partial t$ ,  $\varepsilon_{Yt} = \partial \ln Y / \partial t$ .<sup>7</sup> When some inputs are quasi-fixed and their stocks do not correspond to the long-run cost minimising levels (occurring when  $P_k = Z_k = -\partial G / \partial X_k$ ), equation (2) does not hold anymore. Firstly, for fixed inputs, the value of the marginal productivity corresponds to its own shadow price and can differ from the market price  $P_k$  according to the disequilibrium of the factor endowment. Secondly, the short-run cost flexibility  $\varepsilon_{CY}$  does not correspond to the inverse of the long run returns to scale, and can differ from 1 depending on the short run disequilibrium, therefore on the capacity utilisation. Morrison (1992) proposes a measure of this disequilibrium given by the ratio between the shadow and the actual total cost<sup>8</sup>:  $CU_C = C^* / C$ , also showing that it is a combination of the scale and subequilibrium effects:  $CU_C = [1 - \sum_k (\varepsilon_{kY} / \varepsilon_{CY}^L) \varepsilon_{Ck}]$ , where  $\varepsilon_{Ck} = \partial \ln C / \partial \ln X_k = (P_k - Z_k) X_k / C$  is the cost flexibility with respect to the k-th stock;  $\varepsilon_{kY} = \partial \ln X_k / \partial \ln Y$  is the long run elasticity of the stock demand with respect to output and equals 1 under long run constant returns to scale;  $\varepsilon_{CY}^L$  is the long run cost flexibility, i.e. the inverse of the long run returns to scale. If the temporary and the long-run equilibrium correspond, then  $P_k = Z_k$ , therefore  $\varepsilon_{Ck} = 0 \forall k$  and the capacity is fully utilised ( $CU_C = 1$ ). Alternatively,  $\varepsilon_{Ck}$  can be positive or negative depending on whether there is excess or shortage of the stock  $X_k$ ; the prevalence of under ( $CU_C < 1$ ) or overutilisation ( $CU_C > 1$ ) depends on the algebraic contribution of any stock.

Equation (2) can be adjusted to have a correct measure of the short-run residual  $-\varepsilon_{Ct}^*$ , thus separating the R&D contribution from the exogenous technical change (Morrison-Schwartz, 1996b):

$$(3) \quad -\varepsilon_{Ct}^* = \varepsilon_{CY} \frac{\dot{Y}}{Y} - \sum_i S_i \frac{\dot{V}_i}{V_i} - \sum_k S_k^* \frac{\dot{X}_k}{X_k}$$

where  $S_k^* = Z_k X_k / C$ , is the k-th stock shadow share on the total cost.

If for simplicity we assume constant returns to scale, the contribution of R&D to productivity growth emerges clearly; combining (3) with the expression of  $\varepsilon_{CY}$ ,<sup>9</sup> the traditional (primal) total factor productivity growth measure can be disentangled as follows (Morrison, 1992):

$$(4) \quad \begin{aligned} \varepsilon_{Yt} &= -\varepsilon_{Ct}^* + \left[ (1 - \varepsilon_{CY}^L) \frac{\dot{Y}}{Y} \right] + \sum_k \varepsilon_{Ck} \left[ \varepsilon_{kY} \frac{\dot{Y}}{Y} - \frac{\dot{X}_k}{X_k} \right] = \\ &= -\varepsilon_{Ct}^* + \left[ (1 - \varepsilon_{CY}^L) \frac{\dot{Y}}{Y} \right] + \sum_{k \neq R} \varepsilon_{Ck} \left[ \varepsilon_{kY} \frac{\dot{Y}}{Y} - \frac{\dot{X}_k}{X_k} \right] + \varepsilon_{CR} \left[ \varepsilon_{RY} \frac{\dot{Y}}{Y} - \frac{\dot{X}_R}{X_R} \right] \end{aligned}$$

<sup>7</sup> Only under constant returns to scale, the primal and dual measures are equal in absolute value (if  $\varepsilon_{CY} = 1$ ,  $-\varepsilon_{Ct}^* = \varepsilon_{Yt}$ ).

<sup>8</sup> Where shadow cost is  $C^* = G + Z_p \cdot X_p + Z_R X_R$ .

<sup>9</sup> Interpreting  $\varepsilon_{CY}$  and  $\varepsilon_{CY}^L$  as short-run and long-run cost flexibility respectively, a relation among them can be formulated as  $\varepsilon_{CY} = \varepsilon_{CY}^L \left[ 1 - \sum_k (\varepsilon_{kY} / \varepsilon_{CY}^L) \varepsilon_{Ck} \right] = \varepsilon_{CY}^L \cdot CU_C$  (Morrison, 1992).

Equation (4) shows that the primal productivity growth ( $\varepsilon_{Yt}$ ) is the algebraic sum of four distinct effects: the “real” exogenous technical change ( $-\varepsilon_{Ct}^*$ ), the “pure” long run scale effect, the disequilibrium effect due to conventional stock fixity and the disequilibrium effect due to R&D stock fixity<sup>10</sup>. Therefore, under long run equilibrium,  $\varepsilon_{CK}=0 \forall k$ , the primal measure corresponds to the dual measure.

### 3. Model specification

The agricultural technology is described by an aggregate production function, with three variable factors (inputs for animal production  $V_A$ , inputs for crops  $V_C$  and hired labour  $V_L$ ), three quasi-fixed inputs (family labour  $X_F$ , physical capital  $X_K$  and public research  $X_R$ ) and the disembodied exogenous technical change  $t$ . The aggregate variable cost function, dual to the production function, it is approximated with the Generalised Leontief (GL) function (Morrison, 1988):

(5)

$$C_v = G(W, X, Y, t) =$$

$$Y \left[ \sum_i \sum_j \alpha_{ij} W_i^{0.5} W_j^{0.5} + \sum_i \delta_{it}^{0.5} W_i + \sum_i \delta_{iY} Y^{0.5} W_i + (\gamma_{iY} t^{0.5} Y^{0.5} + \gamma_{Yt} t^{0.5} Y^{0.5} + \gamma_{it} t + \gamma_{YY} Y) \sum_i W_i \right] +$$

$$Y^{0.5} \left[ \sum_i \sum_k \delta_{ik} W_i X_k^{0.5} + \sum_i W_i \sum_k \gamma_{ik} X_k^{0.5} t^{0.5} + \sum_i W_i \sum_k \gamma_{Yk} X_k^{0.5} Y^{0.5} \right] + \sum_i W_i \sum_k \sum_l \gamma_{kl} X_k^{0.5} X_l^{0.5}$$

According to the Shephard Lemma, the variable inputs demand functions can be obtained by differentiating the variable cost function with respect to  $W_i$ :  $V_i = \partial G(.) / \partial W_i$  ( $i = A, C, L$ ).

The parameters of the variable cost function are estimated by a system of four equations: the three variable input demands (in input-output form, to avoid possible heteroscedasticity):

$$(6) \quad V_i / Y = (1/Y) \partial G(.) / \partial W_i + u_i \quad (i = A, C, L)$$

and the marginal cost equation:

$$(7) \quad P_Y = \partial G / \partial Y + u_Y$$

where  $u_i$ ,  $u_k$  and  $u_Y$  are I.I.D. disturbance terms.

The maximum likelihood estimates and the approximate standard errors (White, 1980) are computed with the LSQ algorithm in TSP ver. 4.5. Based on the estimated parameters and the analytical derivatives of the cost function, all the relevant measures concerning the research stock can be derived. Furthermore, through the R&D shadow price we can calculate the Internal Rate of Returns (IRR) to R&D investments in the short run and compare it with the long run returns (Thirtle-Bottomley, 1989; Schimmelpfenning *et al.*, 2000). The marginal value of an unit increase in the R&D stock in the short run is provided by its shadow price; therefore the IRR is computed as follows:

$$(8) \quad \sum_{n=0}^{L_R} \frac{w_n Z_{R,t-L_R}}{(1 + IRR)^n} = 1$$

<sup>10</sup> See Morrison and Schwartz (1996b) for details.



where  $L_R$  is the maximum length admitted for the investment effects and  $w_n$  is the age/efficiency function of the research investment over the  $L_R$  period (Esposti-Pierani, 2000b). In the long run the marginal value is the long run marginal productivity, therefore the IRR can be computed as follows:

$$(9) \sum_{n=0}^{L_R} \frac{w_n Y_{t-n}}{\varepsilon_{RY,t-n} X_{R,t-L}^* (1 + IRR)^n} = 1$$

#### 4. Data

The R&D stock price plays a major role in the depicted model and it has to be adequately defined (Morrison – Schwartz, 1996b). Firstly, the nominal R&D investments have to be correctly deflated to allow intertemporal comparison on a real base. This is the problem of the Investment Price Index (IPI), which has always to be calculated either when the R&D enters the model as stock or as flow, as exogenous shifter or as quasi-fixed factor. Secondly, if the R&D stock enters as a quasi-fixed input and if the social planner point of view has to be considered, the calculation of an appropriate R&D stock user cost (to be used as  $P_R$ ) is needed and it requires the construction of a Stock Price Index (SPI).

The problem of the R&D IPI has been already raised in the literature. Many studies still use the GDP deflator or the Consumer Price Index when no alternative index is available (Morrison-Siegel, 1997; Thirtle-Bottomley, 1989)<sup>11</sup>. However, it is largely acknowledged that the composition of research expenditure relevantly differs from the composition of national product. The use of the GDP deflator can thus significantly bias the real R&D effort (Mansfield *et al.*, 1983). A proper IPI has to be based on the actual composition of the R&D expenditure that can, in turn, change over sectors and over different kinds of research effort (basic, applied, development). Mansfield (1984; 1987) calculates an R&D IPI based upon a survey on 100 manufacturing firms. However, this index could not necessarily be also valid for the agricultural sector and for public R&D. Dealing with the public R&D capital, Nadiri and Mamuneas (1994) use the price deflator of the government purchases of goods and services. For the agricultural public R&D, Pardey *et al.* (1989) and Bengston (1989) define an appropriate IPI based on the expenditures composition of the State Agricultural Experimental Stations.

In our work we follow this general idea to estimate the specific IPI for the Italian public agricultural R&D expenditure composition<sup>12</sup>.

The SPI is affected by the IPI but does not coincide with it. In fact, the implicit R&D stock price at time  $t$  is the cost beard to hold one unit of stock in that year. This user cost is determined by three components (Caiumi *et al.*, 1995): the opportunity cost of the invested money, capital gains or losses caused by inflation, and capital depreciation. Jorgenson (1989) proposes a specification of the user cost that can be written as follows:

$$(10) \quad SPI_t = IPI_{t-1} [r_t - \pi_t + (1 + \pi_t) \rho_t]$$

where  $r$  is the interest rate,  $\pi$  is the expected capital gain (or loss) rate due to inflation, and  $\rho$  is the R&D stock *depreciation rate*. In equation (10),  $P_{t-1}(r_t - \pi_t)$  expresses in real terms the

<sup>11</sup> Using the GDP deflator as research IPI is frequent also in the official R&D statistics, as in the Italian case (ISTAT, various years).

<sup>12</sup> For the sake of space we skip the detailed procedure, which is available upon request.

opportunity cost of a unit of invested capital, while  $P_{t-1}(1+\pi_t)\rho_t$  is the depreciation corrected for inflation. Confirming previous results (Griliches, 1984; Mansfield 1984 and 1987), the GDP deflator overestimates the real research investment increase: the average annual growth during the period 1960-1995 is 6,4% when the GDP deflator is used, while it is 5,1% with the IPI.

All the data, except the R&D investments, are taken from the AGRIFIT database for the Italian agriculture (Caiumi *et al.*, 1995 ). The public agriculture R&D investments include all the public expenditure (government, public University, regions, other public research institutions) and are described in Esposti-Pierani (2000a). The R&D stock series (figure 1) have been calculated from the investment series using the parameters calculated in Esposti-Pierani (2000b) where also the R&D stock depreciation rate is reported; this is needed for the calculation of the SPI. Inflation and interest rates are taken from AGRIFIT. Finally, for the calculation of the IPI, the salary index for the R&D labour has been taken from Franco (1993), while the investment price index comes from AGRIFIT. The fixed weights among research sources and inputs have been taken from ISTAT (various years). These data, and the following econometric analysis, cover the period 1960-1995.

## 5. Estimation results

In general terms, the estimation provides satisfactory results. Most parameters are statistically significant<sup>13</sup>. As expected, the cost function is monotonous in  $W$  and  $Y$  (non-decreasing) and in the three stocks (not increasing) in the entire sample. Moreover, the estimated function is concave in  $W$  and convex in both conventional stocks ( $X_K$  and  $X_F$ ) in any sample point. However, is convex in  $X_K$  only in some sample points; we will comment on this later on. The model goodness of fit ( $R^2$ ) varies from a minimum of 0.87, for the demand of the inputs for animal production, to 0.99 for the marginal cost equation.

Table 1 assembles all the short-run partial equilibrium indicators discussed in section 2. Since the dual measure  $CU_C$  depends on the stocks disequilibrium, the partial utilisation for the three stocks are also reported as the ratio between the estimated shadow price and the rental (market) price. Figure 2 reports the estimated  $CU_C$  over the all sample; it clearly shows that the Italian agriculture passes from overall over utilisation to under utilisation around 1980. Therefore, estimates are reported also for the sub periods 1960-1980 and 1981-1995. A different behaviour emerges for family labour and physical capital. Capital shows large over-utilisation in the first period and, then, an evident under utilisation; these two patterns compensate in the whole period when the capacity utilisation is slightly over the equilibrium. As expected, family labour is always excessive since capacity utilisation is always under 1, particularly in the second period. Therefore, both the constant decline of family labour and the constant growth of investment in physical capital in Italian agriculture can be interpreted as the adjustment to the long-run equilibrium levels although the adjustment is somewhat partial in the case of labour while, on the contrary, we observe over-adjustment in the case of capital.

The pattern of the R&D stock follows to some extent what observed for the physical capital stock; we observe overutilization in the first period and large underutilisation in the second one. The interpretation of this result from a social point of view (in fact, the long run

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<sup>13</sup> Parameter estimates are not reported here; however they are available upon request.

equilibrium is reached when  $Z_R=P_R>0$ ) is that the public R&D investment is short until the eighties and then largely excessive in last fifteen years. Also in the case we can interpret this behaviour as over-adjustment which is, however, much more evident in the case of the public good since the utilisation over the whole period is evidently less than one (about 0.6). The different pattern of the conventional and non conventional stocks with respect to the long-run equilibrium level, eventually explain the overall  $CU_C$  which is quite close to one over the whole sample: over the whole period, a 7% excess of production capacity is observed.

Since, the variable cost is decreasing in R&D, it follows that returns to research are positive. Therefore, the R&D IRR can be correctly computed from equations (8) and (9) and the estimated shadow prices and elasticities. The calculation is based on a 20-years maximum length of the research effects (Schimmelpfenning *et al.*, 2000); therefore, data of period 1976-95 is considered. Table 2 clearly indicates that the returns computed under the short run (temporary) equilibrium is much lower than the long run case. This latter is however an unreliable measure since it refers to the long-run equilibrium which is not actually observed and clearly shows how IRR calculations can be strongly affected by model specification. The short-run measure is indeed the correct one and is much lower than the average estimates reported in the literature (Alston *et al.*, 2000), which, in turn, are commonly acknowledged as excessive. A 4,2% is a more plausible return, if compared to other long-run investment; moreover, although the R&D investment could be considered as a risky one, the expected risk premium is probably lower in the case of public expenditure compared to private investments.

### 5.1 Elasticities and induced innovation

Table 3 reports the estimates of the short run input demand elasticities in the sample mean. They seem correctly estimated for variable inputs since the direct price elasticities show the correct signs, all effects are lower than 1, suggesting a rigid production structure, and all the estimates are statistically significant. In the short run, the intermediate inputs  $V_A$  and  $V_C$  are substitutes for labour, and slightly complements between them. More relevant response can be observed to changes in conventional stocks. In particular,  $V_A$  is complement to capital and substitute for family labour;  $V_C$  and  $V_L$  are both substitute for capital and complement to the family labour.

The main interest here, however, is for the relation between the non-conventional R&D stock and the conventional inputs use and price. On the one hand, increase in variable inputs price induces growth in the R&D shadow price in the case of  $V_A$  and  $V_C$  and decline in the case  $V_L$ . On the other hand, increase in the R&D stock reduces use of both  $V_A$  and  $V_C$  while increases the use of hired labour. In the case of the conventional stocks, in the short run both physical capital and family labour behaves as complements to R&D stock, while are substitutes between them. According to the discussion in section 2.2, these results suggest that the induced innovation hypothesis could be consistent for  $V_A$  and  $V_C$  and not for both hired and family labour and for physical capital. Except for physical capital, these results confirm previous studies on induced innovation in the Italian agriculture (Esposti, 2000b).

Table 3 shows that for the sample average, but also for most sample points, it results  $\partial \ln Z_R / \partial \ln X_R > 0$  which also implies that the variable cost function is not convex in  $X_R$  as it is for the conventional stocks. On the one hand this results, suggest that marginal returns to

R&D stock are not decreasing as for all the conventional inputs. On the other hand, it also follows that it would be convenient to invest in R&D indefinitely and no the long run equilibrium level could not be reached unless  $\partial \ln X_R / \partial \ln P_R > 0$  in the long run. Nevertheless, this is what happens in most sample point and in sample average (table 4). Differently from the conventional inputs, it results  $\partial \ln X_R / \partial \ln P_R > 0$  suggesting that the investment behaviour of the hypothetical social planner is guided by some different non-economic criteria, but still allowing the long-run cost minimising investment rule  $Z_R = P_R > 0$  to hold.

This particular character of the R&D stock and the behaviour of the public investor also affect the consistency of the induced innovation hypothesis. As stated in section 2.2, however, for induced innovation really occur in the long run it has to be  $\partial \ln Z_R / \partial \ln X_R < 0$  and  $(\partial \ln X_R / \partial \ln P_R) < 0$ . Otherwise,  $\partial \ln Z_R / \partial \ln W_i > 0$  in the short run would not generate an incentive to increase the R&D stock in the long run. Table 4 shows that this actually happens:  $V_A$  and  $V_C$  are complements to R&D while  $V_L$  is substitute, in contradiction with the short-run evidence. Therefore, although the induced innovation is consistent in the short-run, it does not really occur since it is contradicted by the actual R&D investment behaviour.

As expected, with the only exception of the elasticity between  $V_L$  and  $V_C$ , in the long run the variable inputs demand is more responsive (table 4), as stated by the Le Chatelier principle<sup>14</sup>. With the already mentioned exception of R&D, all directed elasticities are correctly negative.  $V_A$  and  $V_L$  remain substitutes in the long run, while  $V_C$  and  $V_L$  become complements,  $V_A$  and  $V_C$  substitutes. In the long run, the variable inputs are also substitutes for the physical capital, with the only exception of  $V_A$  which is Allen complement. The opposite happens with the family labour:  $V_C$  and  $V_L$  are complements, while  $V_A$  is substitute. Also the two conventional stocks, capital and family labour, behaves as substitutes.

## 5.2. Productivity growth decomposition

Table 5 reports the decomposition of the primal productivity growth measure as described in section 2.3. First of all it shows that in the whole period, and in the two sub-periods, there is still an unexplained productivity growth<sup>15</sup>,  $-\varepsilon_{Ct}^*$ , of about 1,4% *per year*. The results also confirm that, by introducing the public R&D input in the sectoral technology, the aggregate returns to scale can be increasing; in fact, the cost flexibility  $\varepsilon_{CY}^L$  is constantly around .70-.80 indicating returns to scale of about 1.35. Increasing returns to scale would correct downward the primal productivity growth measure  $\varepsilon_{Yt}$ .

However, the decomposition of the primal productivity is also affected by the stocks utilisation itself. As emerges from table 5, while R&D disequilibrium has a negligible effect on the productivity measure, much more relevant are the conventional stocks. In particular, considering the whole period, the physical capital eventually corrects the primal measure upward while the family labour corrects downward. Putting together all the components,

<sup>14</sup> It must be noted, however, that while most of the short-run elasticities are statistically significant, this does not hold in the long run. In particular, cross-elasticities are hardly significant in the case of  $V_C$ ,  $X_K$  and, mainly, R&D.

<sup>15</sup> It is the exogenous technical change measured as rate of reduction of the short run cost, i.e.  $\partial \ln G / \partial t$ .

the primal productivity growth measure turns out to be lower by 0.4% *per year*.

This residual productivity growth, i.e. the exogenous technical change rate, also affects the variable inputs use (table 6). The estimated exogenous technical change saves the inputs for animal production (-.046) while uses inputs and for crops (.029) and hired labour (-.011). These biases are at odds with the inputs growth rate and, in fact, are not strong enough to prevent the decline of hired labour use in absolute terms, evidently driven by the relative prices dynamics. It must also be noted that for  $V_A$  and  $V_L$  the effect of the exogenous technical change is in concordance with the effect of R&D (table 3): both effects induce saving of  $V_A$  and use of  $V_L$  while they end to compensate in the case of  $V_C$ .

## 6. Concluding remarks

This paper aims to analyse the role of the public R&D investments in the Italian agriculture with major reference to its long run equilibrium level, the interaction with the conventional private farm inputs and the contribution to productivity growth and returns to scale. The study uses an econometric model taking into account the public good nature of this input as well its endogenous long run optimal level. This model allows to explicitly test the hypothesis of over or under-investment in public agricultural R&D by calculating an appropriate public research price index. The study would benefit from longer time series of public R&D investments and prices. Moreover, the appropriate calculation of the R&D stock price would require more detailed information about the sources and composition of the research spending. Further research effort in data analysis and construction is therefore needed.

The empirical evidence suggests that, whenever the partial equilibrium in R&D stock endowment is admitted, the estimated returns are lower than 5%, thus much more plausible if compared to alternative investments with similar associated risk. According to the estimation results, the Italian agriculture shows under-investment in public R&D in the sixties and seventies, while this investment becomes largely excessive in the eighties and nineties. Therefore, the recent reduction of the public research expenditure (in real terms) could be explained as a rationale response of the hypothetical underlying social planner to the over-investment of the previous years and that made the provision of public R&D sub-optimal. It also emerges that induced innovation hypothesis, while in principle consistent with the short run evidence, is not actually supported by a consequent long-run R&D investment behaviour.

The depicted framework confirms that public R&D stock contributes in generating increasing returns to scale at the sectoral level. Moreover, it is also possible to disentangle primal productivity growth. Even when the impact of the R&D investment, the scale and the capacity utilisation effects are appropriately admitted and separated, there is still a significant space left to the exogenous time trend on both the cost reduction and inputs use. This result also indicates that other sources of agricultural innovations should be considered more in detail. In particular, intersectoral and international spillovers, both private and public, could explain technical change besides (or together with) the national public agricultural R&D (Mamuneas-Nadiri, 1996). Some steps in this direction have been taken in analysing the Italian agriculture case (Esposti, 2000a). However, so far, data available for spillovers calculation, do not allow long enough time series to be included in the model here adopted.

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Table 1: Capacity Utilisation of R&D and conventional stocks  
(sample averages – approximated standard errors in parenthesis)

Period	$CU_{C=\varepsilon_{CY}}$	$Z_R / P_R$	$Z_K / P_K$	$Z_F / P_F$
1960-80	1.038 (.014)	1.492 (.092)	1.506 (.067)	.927 (.039)
1981-95	.902 (.007)	0.414 (.086)	.764 (.017)	.771 (.015)
1960-95	.926 (.013)	.592 (.089)	1.152 (.052)	.645 (.037)

Table 2: Internal rate of returns (IRR) to R&D under alternative hypotheses

Hypotheses	TRI
Short run equilibrium	4,2%
Long run equilibrium	161%
Public and private agricultural R&D (avg. of 1772 estimates), Alston <i>et al.</i> (2000)	74%

Table 3 : Short run demand elasticity and shadow prices flexibility  
(sample averages – approximated standard errors in parenthesis)

1960-95	$W_A$	$W_C$	$W_L$	$X_R$	$X_K$	$X_F$
$V_A$	-.379 (.009)	-.060 (.001)	.439 (.010)	-.011 (.004)	.226 (.116)	-1.631 (.147)
$V_C$	-.062 (.001)	-.323 (.003)	.385 (.004)	-.024 (.004)	-.139 (.073)	.338 (.066)
$V_L$	.270 (.038)	.229 (.032)	-.499 (.071)	.014 (.004)	-.807 (.105)	.148 (.095)
$Z_R$	.922 (.474)	1.901 (.458)	-1.802 (.804)	1.569 (.538)	2.254 (.659)	1.339 (.599)
$Z_K$	-.184 (.088)	.110 (.058)	1.074 (.081)	.228 (.005)	-1.150 (.158)	-.130 (.186)
$Z_F$	1.534 (.179)	-.307 (.061)	-.227 (.171)	.016 (.007)	-.149 (.211)	-.414 (.312)

Table 4: Long run demand elasticity  
(sample averages – approximated standard errors in parenthesis)

1960-95	$W_A$	$W_C$	$W_L$	$P_R$	$P_K$	$P_F$	$Y$
$V_A$	-6.121 (2.573)	1.292 (.740)	1.411 (.486)	-.024 (.027)	-.472 (.432)	3.194 (1.662)	.654 (.725)
$V_C$	1.638 (.778)	-.684 (.246)	-.197 (.216)	-.010 (.005)	.363 (.183)	-1.110 (.488)	.528 (.244)
$V_L$	1.138 (.421)	-.0778 (.137)	-1.129 (.258)	-.003 (.003)	.571 (.193)	-.499 (.237)	1.296 (.158)
$X_R$	-3.687 (3.752)	-1.080 (1.117)	.299 (.601)	.080 (.127)	1.357 (.571)	.904 (.415)	.409 (.890)
$X_K$	-.632 (.490)	.228 (.150)	.739 (.179)	.010 (.003)	-.659 (.122)	.314 (.322)	.451 (.175)
$X_F$	3.482 (1.776)	-.799 (.516)	-.566 (.282)	.012 (.016)	.224 (.255)	-2.354 (1.161)	.904 (.415)

Table 5: Primal productivity growth and its components

Period	$-\varepsilon_{Ct}^*$ $\varepsilon_{CY}^L$		Family Labour			Physical capital			R&D			$\varepsilon_{Yt}$
			$\varepsilon_{CF}$	$\varepsilon_{CF}$	$\varepsilon_{FY}$	$\varepsilon_{CK}$	$\varepsilon_{CK}$	$\varepsilon_{KY}$	$\varepsilon_{CR}$	$\varepsilon_{CR}$	$\varepsilon_{RY}$	
1960-80	.019	.794	.023		.021	-.059		-.027	-.001		.000	.014
1981-95	.013	.714	.045		.037	.050		.018	.002		.001	.012
1960-95	.014	.797	.098		.081	-0.25		-.119	.002		.001	.010

Table 6 - Exogenous technical change rate and technological biases  
(sample averages – approximated standard errors in parenthesis)

1960-95	Share	Bias	Growth rate
Animal production inputs	.278 (.022)	-.046 (.005)	.044
Crops inputs	.269 (.015)	.029 (.003)	.024
Hired Labour	.453 (.037)	.011 (.003)	-.019
Weighted sum	1	0	.010

Figure 1 – Public agricultural R&D stock in Italy (billions of 1985 Italian Lire) and its user cost

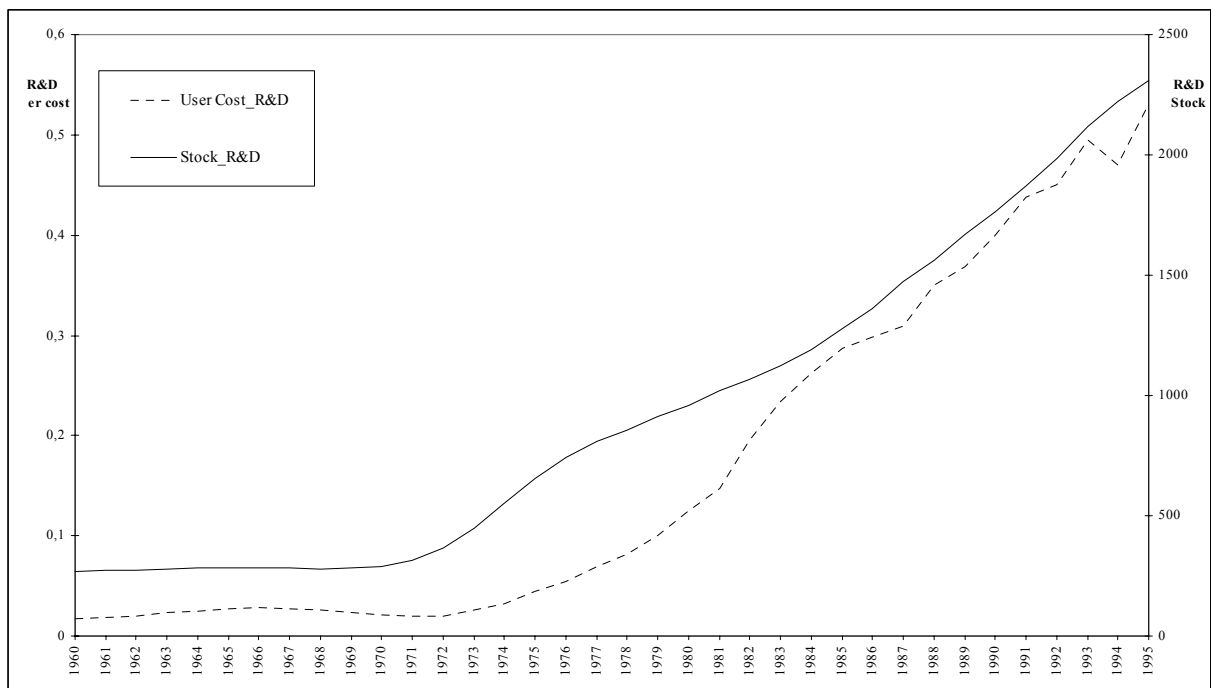


Figure 2 - Estimated  $CU_C$  over the all sample period



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