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Price, Private Demand and Optimal Provision of Public R&D in Italian Agriculture

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PRICE, PRIVATE DEMAND AND OPTIMAL PROVISION OF PUBLIC R&D IN ITALIAN AGRICULTURE

di Roberto Esposti and Pierpaolo Pierani[♣]

Abstract

The current paper presents a model in which public R&D stock is included as a quasi-fixed input in a variable cost function. Its price affects the long run desired level, while its shadow price indicates whether under (over) investment occurs in the short run. Two alternative R&D prices and—thus—two different long-run desired levels, are defined. One concerns the private (farmer) perspective, in which farmers express demand under the assumption of costless R&D. The other considers the societal point of view, in which the objective is the optimal public R&D supply conditioned on its cost. Application of the above model to the Italian agricultural context (1960-1995) suggests a significant difference between these private and social desired R&D levels. The latter are, on average, closer to the observed values, though over-investment has emerged since the mid-eighties.

Keywords: Public Agricultural R&D, Variable Cost Function, R&D Price

EconLit Classification: Q160, O300

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Contents

1. Introduction: the problem of optimal public R&D investment

There is, by now, a well-established empirical and theoretical debate about the optimal Research and Development (R&D) investment to be undertaken by a firm, sector or country. The issue originally arose in the applied productivity literature, in which adding the R&D stock to conventional growth accounting frameworks results in high rate of returns to R&D (Griliches, 1992). In particular, the estimated returns at the industry level are higher than the ones obtained at the firm level (Hall, 1996). This result is usually interpreted as the evidence that private R&D investments generate positive externalities (technological spillovers) within (or possibly outside) the sector, thus inducing higher social than private rates of return (Nadiri, 1993). It also follows that, from the point of view of hypothetical social planning, there may be too little private R&D investment.

Recently, the so-called “under-investment hypothesis” and the empirical evidence supporting it have been strongly questioned (Jones, 1995). Romer (1990), Grossman and Helpman (1991) and Aghion and Howitt (1992) admit incentives either to under- and over-investment in private research. If—on one hand—positive externalities (spillovers) may generate under-investment, the duplication of effort (or some form of congestion externalities) and creative destruction (especially in non-competitive sectors)—on the other—can induce firms to invest too much in R&D; that is, at least from the social point of view.

New growth theorists also suggest that empirical productivity growth models can be significantly biased and misleadingly support the under-investment hypothesis. Jones and Williams (1998; 2000) try to reconcile these theoretical and empirical contributions. By calibrating their theoretical model and taking the real rate of return of the economy (7%) as the benchmark cut-off rate, they calculate how much the decentralised economy under-invests in private R&D: the optimal social R&D investment rate/level would be at least four times greater than actual private spending (Jones and Williams, 1998).

However, these growth theory arguments often disregard another relevant aspect of the optimal R&D investment issue. In reality, R&D is at least partially "public" precisely because it is also provided through public finance measures or government spending. This is not a case of private R&D generating positive externalities, and thus partially behaving as a public good (Romer, 1990).

In new growth theory literature, this case can in some ways be related to the models of Barro (1990) and Barro and Sala-y-Martin (1992), where the growth engine is solely public/government expenditure, not the private R&D sector. Empirically, the question is how to model and measure the optimal provision of this public good, in order to assess if under or over-investment really occurs. This problem can actually be extended to a wide set of public assets, for instance infrastructure, and military defense investments, etc. (Morrison and Schwartz, 1996). In particular, what is "optimal" investment for these public assets may actually differ according to whether we look at the problem from the point of view of those private agents demanding the public good and using it for free, or from the point of view of the whole society that actually supplies it at a known cost.

An archetype in the above is agricultural R&D, both due to the prevalence of public R&D in this sector and the high rates of return enjoyed by public R&D, which are in general quite higher than those generated by private R&D (Alston *et al.*, 2000). This finding is normally regarded as evidence of under-investment (Roseboom, 2002).

In reality, private R&D in agriculture is not always negligible. In the US agricultural sector, private R&D investments are predominant and also play a key role in sector-level productivity growth (Yee, 1992; Chavas *et al.*, 1997). However, agriculture prevalently uses private R&D generated in other sectors (machinery, chemicals, drugs, etc.). If this private R&D *use* is regarded as intersectoral spillover (Johnson and Evenson, 1999; Esposti, 2002), then private *self-funded* R&D in the agricultural sector is really of minor relevance. Moreover, the calculation of these R&D spillovers to the agricultural sector, as well as assessing their linkage with public R&D investments, is particularly difficult and can be normally achieved only for quite short time periods (Esposti, 2002).[1]

For the above-mentioned reasons we assume herein that the intensity and direction of agricultural R&D is mostly carried out by the public sector. As in many other empirical studies, private research is omitted from the analysis, though we acknowledge this omission may lead to an upward shift in the estimated returns to public R&D investments (Alston *et al.*, 2000).

The issue of under-investment in public agricultural R&D has been broadly investigated and discussed (Harris and Lloyd, 1991; Roseboom, 2002) and this hypothesis is supported by a number of empirical works (see surveys in Alston *et al.*, 2000, and Evenson, 2001). In most cases, the empirical analysis estimates the social rate of returns to public R&D as being the major indicator of whether public investment is too low (Roseboom, 2002), or whether public R&D funding allocation, among alternative applications, is optimal (Roseboom *et al.*, 2003).

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[1] Actually, in the Italian case, the official statistics report private agricultural R&D data only for the *own* (i.e., self-financed) private agricultural R&D, which is — in fact — less than 5 per cent of public R&D budget (Esposti and Pierani, 2004). On the contrary, R&D spillovers might indeed be relevant but hardly quantifiable, especially over a long time period (Esposti, 2002). Analogous serious difficulties occur in attempting to separate R&D investments in terms of process and product innovations. Agricultural R&D statistical sources do not inform about this aspect and no coherent long time-series exist on new products (for instance, new crop varieties) in Italian agriculture. Thus, we disregard here the possible relevant implications of this aspect and we assume that all public R&D is

However, the social rate of return to public R&D, by itself, does neither demonstrate nor measure the degree of under (over) investment (Lopez, 2005). In fact, though empirical evidence is largely interpreted in favour of the under-investment hypothesis, it is in contrast with the slowdown and even the reversal of growth of public agricultural R&D observed in most countries in the last 10-20 years (Roseboom, 2002; Lopez, 2005). The optimal level should actually be derived according to some optimizing behaviour and not by conjectures about how high the social rate of return should be. Therefore, in this paper we propose an empirical analysis approaching the problem of the optimal public agricultural R&D within a short run cost-minimizing framework, following Morrison and Schwartz (1996).

The adopted model allows us to estimate how much public R&D stock would be optimal either in terms of private (farmers') demand and a public (social) supply perspective; these viewpoints are distinguished on the basis of a different specification of the R&D price (user cost). This approach may provide additional insights into the optimal public R&D debate, as well as on the relevance of the respective price (user cost), according to the alternative interpretations and perspectives regarding what optimality means. Comparing these points of view may offer a further contribution to the relative empirical literature, at least in the agricultural context. This is so because it allows us to assess which of the two cases—under (over-investment)—really occurs, and if actually-observed provision of public R&D is closer to farmers' demand levels or the level of social optimal provision.[2]

The rest of the paper is organised as follows. Section 2 describes the theoretical micro-foundation of the approach; the econometric model is presented in section 3, together with the

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cost-reducing, that is provides production process improvements. Nonetheless, we acknowledge that further research effort in this direction seems particularly needed.

[2] In the present paper, we disregard the fact that there may be several different economic, social and political reasons behind public funding of agricultural research rather than the pursuit of the

details on the calculation of the R&D social user cost. Section 4 applies the model to the specific case of Italian agriculture in the 1960-1995 period; this seems a particularly appropriate case study, given that public R&D in Italy largely surpasses private research (Esposti, 2000). Section 5 concludes.

2. Modelling public agricultural R&D investment: microfoundations

Given the developments in duality theory and flexible functional forms, production models can provide useful information on the role of agricultural research. The relevance of this information critically depends on the specification of agricultural technology and the way public R&D enters the model. Here, we follow previous studies (Mamuneas and Nadiri, 1996; Morrison and Schwartz, 1996a, 1996b; Morrison and Siegel, 1997, 1998; Nadiri and Kim, 1996; Nadiri and Mamuneas, 1994; Nadiri and Prucha, 1996), and assume that farmers minimize the cost of producing a given level of output, conditional on input prices, stocks of quasi-fixed inputs and technological levels. Under some regularity conditions, duality principles ensure consistency between variable cost and production function, so that either one will describe the farming activity equally well (Chambers, 1988). The restricted cost function is represented by:

$$(1) \qquad G = G^{*}(W, X, S)$$

where G is the minimum total variable cost W'V, with $W \equiv (W_1, .., W_N)'$ being the price vector of variable inputs $V \equiv (V_1, .., V_N)'$; $X \equiv (X_1, .., X_M)'$ is the vector of quasi-fixed inputs with user cost $P \equiv (P_1, .., P_M)'$; S is a vector of exogenous and/or predetermined variables, including

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social/private optimum. For a detailed review on this see Barnes (2001).

output Y and time trend t used as proxy of technological level[3].

In a number of studies, R&D appears among the elements of S; i.e., likewise t, it would be fully exogenous (Morrison and Siegel, 1997, 1998). In this case, no long run optimal level may be derived, therefore the under(over)-investment hypothesis can not be explicitly investigated and tested. Alternatively, the R&D stock can be viewed as an element of $X \equiv (X_P, X_R)$, where X_R is public research and X_P the vector of conventional quasi-fixed inputs. This specification makes it possible to measure the discrepancy between the observed (short run) (X_R) and the long run equilibrium ($X_k^* = X_k^*(W,P,Y,t)$) levels of public R&D, thus allowing to explicitly test the hypothesis of under(over)-investment in public agricultural research. 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. As far as R&D behaves as the conventional inputs, the adjustment taking place from the observed short run level to the long run equilibrium is price-driven and should pursue the equilibrium condition, i.e. $Z_R = P_R$.

This modelling approach is particularly helpful here, because this equilibrium stock may be computed under alternative hypotheses regarding its own price P_R. In particular, if $P_R = 0$, the R&D equilibrium level can be considered as the farmers' demand for free public R&D. On the other hand, $P_R > 0$ represents the cost incurred by the whole society for granting public R&D (so we can call P_R "social price" or "social user cost"), whereby the long run R&D optimal level can be interpreted as the optimal social supply of public R&D.

These two contrasting alternatives may be justified as follows. Farmers minimize (1) and, normally, do not bear any cost for "using" the public research capital (i.e. for them $P_R = 0$) (Morrison and Schwartz, 1996), hence, in the long run, they would like to "use" R&D until

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[3] We assume that the cost function is linearly homogeneous, non-decreasing and concave in W, non-

$Z_R = P_R = 0$.[4] Of course the short run cost function models the private sector's (farmers') optimizing decision making, hence farmers can not decide about the public R&D provision. Nonetheless, by assuming $P_R = 0$, the model is able to reveal the public R&D stock that would allow private optimization to be reached in the long run. For this reason, the long run public R&D stock under $P_R = 0$ can be interpreted as *the farmers' latent demand for public agricultural R&D*.

Decisions about public R&D investments are taken by public institutions. For the public decision maker, providing public R&D is costly, thus $P_R > 0$, and the R&D equilibrium level will be reached when $Z_R = P_R > 0$. Actually, this public decision maker cannot choose the use made of private inputs; nevertheless, she/he still rationally aims at combining the cost-minimizing choices made by farmers regarding the private inputs with cost minimizing choices concerning public input. Therefore, in the adopted cost-minimizing framework, and under a hypothesis of public R&D social costs ($Z_R = P_R > 0$), the R&D equilibrium stock represents the optimal choice for an hypothetical social planner aiming to simultaneously. take cost minimizing decisions on both the private and public inputs.

Thus, we interpret this other equilibrium R&D stock as the *social optimal provision of public agricultural R&D*. Therefore, the adopted model allows for two alternative definitions of optimal public R&D input. Though borderline cases, both values can eventually be compared to the actual (observed) public R&D stock level (X_R) to assess whether it is closer

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decreasing in Y, non-increasing and convex in X, non-negative, continuous and twice continuously differentiable in all its arguments.

[4] By assuming that R&D is cost-free for private agents (farmers), we implicitly disregard any adjustment/adoption costs related to the introduction of new technologies generated by the public research effort. This issue may be relevant and can make public R&D rather costly from the private perspective as well. These costs can, at least partially, be taken into account using a dynamic specification as in Nadiri and Kim (1996). This may be one possible future extension of the present empirical application.

to the long-run farmers' demand ($Z_R=P_R=0$) or to the social optimal supply ($Z_R=P_R>0$).

The long run envelope condition is $G+Z_P'X_P+Z_RX_R = G+P_P'X_P+P_RX_R$. The left hand side of this equality is the shadow total cost (C*) which is the same for the two cases, while the right hand side is the actual total cost (C): the latter clearly differs according to the P_R specification.

In the short run, the actual and shadow total costs may differ and the ratio $CU_C=C^*/C>1$ (<1) can be computed indicating the degree of over(under)-utilization of the production capacity. It is apparent that CU_C will be different depending upon the hypothesis adopted about P_R. Finally, within this approach it is also possible to analyse the relationship between R&D and conventional inputs in further detail, as well as compare the input response to R&D and exogenous technical change t in both the short and the long run. These effects can be measured using the conventional elasticity coefficients (Morrison, 1988).

In the growth accounting literature at the firm or aggregate level (Griliches, 1980), it is usually assumed that constant returns to scale occur in conventional (or primary) inputs, while increasing returns prevail overall, that is, when R&D is also included among factors of production. This assumption becomes even more attractive according to the new growth theory argumentations. In the Romer (1986) model, constant returns to scale in the conventional inputs are assumed at the private (firm) level, whereas increasing returns may occur in the whole economy; the latter benefits from knowledge spillovers generated by labour and capital used in private R&D activities.

Nonetheless, this specification of the scale economies is sometime rejected by empirical analyses at the sector level. A recent study by Aiello and Pupo (2004) suggests that, in Italian manufacturing sectors, decreasing returns to scale for conventional inputs actually prevail, while returns are very close to 1 (sometimes even lower) when R&D is also considered. This result can be compared to other studies on different countries and sectors (Griliches and Mairesse, 1983; Harhoff, 1998; Wakelin, 2001).

The question remains largely unanswered in the case of agriculture. One can argue that increasing returns to scale occur at the farm level, as demonstrated by recent empirical studies (Morrison Paul *et al*., 2004) and stressed by the general belief that small farm size represents a major impediment to achieving higher productivity performance. However, this does not necessarily hold at the aggregate sector level, where the assumption of constant returns to scale in primary inputs, indeed, seems more realistic and is often adopted in empirical applications (Mundlak, 2001); thus, when R&D is included, increasing returns to scale is the obvious consequence.

There seem to be no conclusive evidence in favour of the above specification. With specific reference to the Italian agricultural context, and including R&D as a factor of production, Esposti and Pierani (2003b) obtained returns to scale very close to 1 (precisely, 1.02 with error standard of 0.01) over the period 1963-1991, and model estimates that do not substantially differ from those obtained with a similar model, Esposti and Pierani (2003d), but assuming constant returns to scale overall.

Moreover, if we admit public R&D largely prevails in agriculture, the usual growth theory justification for increasing returns may also be questioned. Barro (1990) and Barro and Sala-y-Martin (1992) deal with scale economies actually generated by public expenditure, and they emphasize how overall increasing returns may have problematic implications when a public good is involved. Feehan *et al*. (2004) argue that these returns-to-scale implications depend on how the public good behaves, as differences exist according to whether it is a pure public good or congestion occurs. If congestion exists, aggregate increasing returns to scale may not emerge, simply because congestion causes the returns to scale in primary inputs to eventually decrease. This issue is often disregarded in empirical studies even when congestion-prone public inputs, such as infrastructures, are considered (Morrison and Swartz, 1996).

In the present paper we explicitly admit congestion in public agricultural R&D. In general terms, congestion externalities may occur in R&D activities due to uncoordinated duplication of research efforts, which are frequently observed in competitive private R&D investments, but can not be excluded even in publicly funded R&D (Jones and Williams, 1998).

More specifically, public agricultural R&D exhibits several congestible characteristics (Esposti and Pierani, 2003a), and thus should not be considered a pure public good. In fact, the rise in agricultural output not only requires the multiplication of conventional inputs, but also usually occurs by means of an increasing number of product types, crop varieties, animal breeds, and production modes. Two major consequences result. Firstly, this fact increases the amount of research directions and conservation investments that are required to keep the existing knowledge set effective. Secondly, the R&D stock is not only made up by a set of "pure" ideas, but also by a given amount of labour and human and physical capital that—once dedicated to specific research activities—somehow are perceived as rivaling other research projects. Of course, this rivalry increases with the spectrum of the alternatives. Both effects are indisputably forms of congestion.

Thus, according to previous studies on Italian agriculture and the congestible nature of the public agriculture R&D, we assume overall constant returns to scale, which implicitly impose congestion in the adopted model.[5] Imposing congestion also allows for a more comprehensive understanding of the R&D user cost, P_R. Under congestion, the public good actually behaves as a common property (rival but not excludable) good. In this case, Feehan *et al*. (2004) show how an efficient allocation of the public good can not be achieved by allowing free access; therefore, the financing mechanisms adopted to cover the public good provision costs should not rely on general revenues or lump-sum taxes. On the contrary, the appropriate financing device should imply some form of fee or price to be paid by those having the access to the congestion-prone public good.[6]

In this respect, under congestion, $P_R>0$ can be then interpreted as the optimal price/fee farmers have to pay for accessing public agricultural R&D. Though this fee payment regime may remain merely hypothetical, the comparison between the two long run optimal levels can be then alternatively interpreted as the comparison between the farmers' demand under free access to a common congestible resource (*the free access case*), and the demand under access conditioned on a fee payment (*the fee payment case*).

3. The econometric model

3.1. The variable cost function

The Italian agricultural technology is described with a restricted cost function G^* with constant returns to scale, three variable inputs (inputs for animals V_A, inputs for crops V_C, and labour V_L), two quasi-fixed factors (physical capital X_K and public research X_R) and

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[5] Feehan and Batina (2003; page 5) state that: "If it is established that the returns to scale are constant in all inputs then the public input must fall into the congestible category. If the returns to scale in the primary inputs are constant then the public input must be a pure public input".

[6] It must be remembered that, once the financing mechanism of the public good is explicitly included in the analysis, its social optimal provision should more correctly be evaluated within general equilibrium models, as this mechanism (for instance, various forms of taxation) might affect and bias private activities in a different way. This further aspect is beyond the scope of the present study;

disembodied exogenous technical change t. The model deals with physical and R&D capital exactly in the same way, though the former is provided by the farmers and the latter by the public decision maker. Empirically, G^* is depicted by means of the Generalised Leontief (GL) form (Morrison, 1988), because it is flexible, in the sense of providing a second-order approximation to an unknown function at any given point.

The estimated model is:

$$\begin{aligned} G = {} & Y\left\lfloor \sum_i \sum_j \alpha_{ij} W_i^{0,5} W_j^{0,5} + \sum_i \delta_{it} t^{0,5} W_i + \gamma_{tt} t \sum_i W_i \right\rfloor + \\ & Y^{0,5}\left[\sum_i \sum_k \delta_{ik} W_i X_k^{0,5} + \sum_i W_i \sum_k \gamma_{kt} X_k^{0,5} t^{0,5} \right] + \sum_i W_i \sum_k \sum_l \gamma_{kl} X_k^{0,5} X_l^{0,5} \end{aligned} \tag{2}$$

with i,j = A,C,L and k,l = K,R.

For the econometric implementation, a set of cost-minimizing variable input demands V_i can be derived from (2) applying the Shephard’s lemma. Here, optimal input-output coefficients are considered to reduce possible heteroskedasticity:

$$V_i / Y = (1/Y)\partial G(.)/\partial W_i + u_i \quad (i = A,C,L) \tag{3}$$

System (3) contains all the relevant model parameters. However, greater efficiency in estimation can be achieved by forcing more structure onto the data, e.g., including additional information such as shadow value equations.

Under long-run constant returns to scale, it is possible to determine the *ex post* returns to quasi-fixed inputs as the gross operating surplus, $Rv=P_Y Y-G$, where P_Y is output price and Rv is revenue. However, if two or more quasi-fixed inputs exist, there is no way to independently identify the returns to each of them. Hence we estimate the following fixed shadow cost equation (Morrison, 1988):

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details can be found in Martinez-Lopez (2004).

(4) $-Rv = \sum_k \partial G(.)/\partial X_k + u_{Rv}$ (k = K,R)

Model parameter estimates are obtained estimating the (3)-(4) system of equations with iterative Zellner techniques[7] under the usual assumption that u_i and u_{Rv} are i.i.d. error terms.

Based on the estimated parameters and the analytical expressions of derivatives, all the relevant measures concerning Italian agricultural technology and capacity utilization can be then computed. The optimal level of the quasi-fixed inputs can be derived by imposing the envelope conditions $Z_K=P_K$ and $Z_R=P_R$, respectively. As we consider two quasi-fixed factors, long run stocks are computed simultaneously by solving the system of two equations.

3.2. The R&D price index

In the depicted model, R&D price (i.e., user cost P_R) plays a major role, as it affects the desired long run R&D level. However, the construction of an appropriate user cost for public agricultural R&D is often omitted. In general terms, its calculation involves two steps. Firstly, an appropriate Investment Price Index (IPI) must be computed to correctly deflate nominal public R&D and allow for intertemporal comparison and aggregation on a real base. Secondly, the public R&D user cost (P_R) is then obtained through an appropriate Stock Price Index (SPI).

Many studies still use the GDP deflator or the Consumer Price Index, as IPI for R&D, given that no alternative index is available (Thirtle and Bottomley, 1989; Morrison and Siegel, 1997)[8]. However, it is largely acknowledged that the composition of the research expenditure, in terms of goods, services, labour and capital, relevantly differs from the composition of the overall national product. The use of the GDP deflator can thus misrepresent the real R&D

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[7] We used the LSQ command of TSP 4.5, whose HETERO option computes consistent standard errors even in the presence of unknown heteroskedasticity.

[8] The use of the GDP deflator as the research IPI is also frequent in the official R&D statistics, as in

effort (Mansfield *et al.*, 1983).[9] For agricultural public R&D, Bengston (1989) and Pardey *et al.* (1989) define an appropriate specific IPI based upon the expenditure composition of the State Agricultural Experimental Stations. Here, we follow their general idea.

Two different sources of public agricultural R&D are considered: public universities (U) and other public institutions (O)[10], each with three different R&D input categories: labour (research and non-research) W, capital (land, buildings and equipment) S, and operating expenses E. By indexing the different sources of public research (j = U, O) and the different research inputs (i = W, S, E), we can calculate their respective weights s_{j0} and w_{ji0} on total expenditure in the base year 0. It follows that the IPI index is:

$$(5) \qquad IPI_t = \sum_j s_{j0} \sum_i w_{ji0} P_{it}$$

where P_i defines the i-th input price index.[11]

This IPI is then used to calculate the R&D price (user cost), that is the SPI.[12]

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the Italian case.

[9] The specific research IPI calculated by Mansfield (1984; 1987) grows more than the GDP deflator, and this result is confirmed by other analogous studies (Griliches, 1984; Nadiri and Kim, 1996). Both the deflators by Mansfield and Jaffe-Griliches (on which the Nadiri and Kim study relies) are based on an *ad hoc* survey on manufacturing firms; dealing with public R&D capital, Nadiri and Mamuneas (1994) use the price deflator of government purchase of goods and services.

[10] As concerns agricultural research, the Italian University system is almost entirely public.

[11] The price indices are derived as follows: the salary deflator of the Ministry of Education is used for W (until 1990, the public University system was in charge of this Ministry); the investment price deflator of agricultural investment (Caiumi *et al.*, 1995) is adopted for S; the GNP deflator is used for E. The input price indices are assumed equal for both U and O. The IPI of the Italian public agricultural R&D is then computed with a Laspeyres formula, as both weights (for the R&D sources and inputs) are not available on an annual basis. So, the price indexes have to be calculated using fixed weights. These fixed weights among research sources and inputs have been taken from ISTAT data and refer to the 1984, 1985, 1986 average. The weights are calculated as follows: $s_{j0} = \frac{\sum_i P_{i0} X_{ji0}}{\sum_j \sum_i P_{i0} X_{ji0}}$ and $w_{ji0} = \frac{P_{i0} X_{ji0}}{\sum_i P_{i0} X_{ji0}}$ where *P* is the price and *X* the quantity, respectively.

[12] Comparing real public R&D investments in Italian agriculture deflated with this IPI and with the GDP deflator confirms previous results (Griliches, 1984): the GDP deflator overestimates the real research investment increase. During the period 1960-1995, the R&D stock grew by ten times if the GDP deflator is used, and “only” by 6 times using the IPI. Consequently, also the estimation results

The implicit R&D stock price is given by the current value of all the services it can provide in the future. This user cost is determined by three components (Caiumi *et al*., 1995; Nadiri and Kim, 1996): the opportunity cost of the invested money, capital gains or losses caused by inflation, and capital depreciation. Jorgenson (1989) proposes, for physical capital, a specification of the user cost that can be adapted here as follows:

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

where r is the interest rate, π is the expected capital gain (or loss) rate due to inflation, and ρ is the R&D stock *depreciation rate*. In equation (6), $IPI_{t-1}(r_t-\pi_t)$ expresses in real terms the opportunity cost of a unit of invested capital, while $IPI_{t-1}(1+\pi_t)\rho_t$ is the depreciation corrected for inflation.

As a final remark, it must be noted that, in the definition of this R&D price, attention should also be paid to how public and private R&D (i.e., mostly spillovers from other sectors) possibly interact in the agricultural context. This interaction may significantly affect some of the basic parameters behind user cost calculation (Esposti and Pierani, 2003). In particular, the depreciation rate in (6) might depend on whether public and private R&D behave as substitutes, and are therefore reciprocally redundant, or as complements, thus reinforcing each other. However, as mentioned, the form of this interaction can be complex and available data do not allow a long term analysis in this respect.[13] Thus, for the time being, we assume that public R&D price (user cost) is not affected by other relevant agricultural R&D sources.

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significantly differ when the GDP deflator is used instead of IPI. Results under this different R&D price specification are available upon request.

[13] See Esposti (2002) for a specific analysis of this issue in the case of Italian agriculture.

4. Data and estimation results

All relevant data, except the public R&D investment series, are taken from the AGRIFIT database for the Italian agriculture (Caiumi *et al.*, 1995). The agricultural research investments include all the public expenditure as described in section 3, and are also detailed in Esposti and Pierani (2000). The R&D stock series have been calculated from the investment data, using the parameters calculated in Esposti and Pierani (2002) that also report the R&D stock depreciation rate adopted for the calculation of the SPI.[14] These data, and the following econometric analysis, cover the period 1960-1995.

The estimated GL restricted cost function is monotonic in W and Y (non-decreasing) and the two stocks (non-increasing), concave in prices and convex in capital and R&D stock at all sample points. The R^2 goodness of fit varies between 0.35 for animal input demand and 0. 96 for labour demand.[15]

Table 1 reports the short run variable input and shadow price elasticities[16].

In general terms, variable inputs are more responsive to scale of production than prices, so that short run changes in factor proportions mainly depend on output level, as shown by elasticities with respect to output. Own- and cross-price elasticities are accurately estimated and much smaller than unity, which implies a rather rigid production structure. Cross effects show that hired labor substitutes for the other two inputs, which, in turn, behave as complements.

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[14] Inflation and interest rates are taken from the AGRIFIT data base.

[15] Parameter estimates are not reported here; however they are available upon request.

[16] Given that results do not show marked variations over time, for the sake of space we discuss only sample mean estimates. The value of P_R does not affect short run elasticities but only long run results. These long run elasticities for both $P_R=0$ and $P_R>0$ are not reported here but are available upon request. In estimation, analytical derivatives and approximated standard errors are obtained through the TSP commands DIFFER and ANALYZ, respectively.

The table also reports the variable inputs elasticities, with respect to the quasi-fixed inputs. It emerges that V_C substitutes for both stocks, while V_A is a complement to both physical capital and research. However, these elasticities are not statistically different from 0 in either cases. V_L is a substitute for physical capital, as expected, while it is a complement to public R&D stock. The latter effect, though statistically significant, is almost negligible.

For the symmetry relationships pertaining to the twice continuous differentiability of cost functions, we obtain that quasi-fixed input demand elasticities and shadow price elasticities do share similar information, though with the opposite sign[17].

Concerning R&D shadow price, an increase (decrease) in W_C or W_L (W_A), *ceteris paribus*, induces an increase in the long run equilibrium stock, thus increasing its utilization. Moreover, the R&D shadow price elasticity, with respect to the physical capital stock, signals substitutability between the two stocks, though it is not statistically significant. Together with the complementarity between R&D and labour, this result would suggest that the innovations generated by public R&D are not prevalently embodied in new vintage physical capital[18] but – rather – favour labour-using techniques, thus supporting results obtained by Esposti and Pierani (2003c).

The changes in input utilisation due to public R&D stock can be confronted with the effects of the conventional exogenous technical change. Table 2 reports the residual productivity growth measure and the related input biases. The exogenous technical change

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[17] Namely, $\partial V_i/\partial X_k=-\partial Z_k/\partial W_i$, which can be re-phrased in terms of elasticities as: $\varepsilon_{ik}=-(\omega^*_i/\omega^*_k)\ \varphi_{ki}$, where ω^*_i and ω^*_k are the input shares on shadow cost C^*, and φ_{ki} gives the impact of W_i on the quasi rent of stock k.

[18] This result should be more carefully investigated by looking at the new products generated by either public and private agricultural R&D. However, in note 1 we already emphasized serious data problems in this respect.

rate is quite high (yearly 3.9% on average)[19] and also significantly affects input use: the estimated exogenous technical change uses the inputs for animal production (with a statistically significant bias of .037) and for crops (.035) while it saves labour (-.011). This latter bias largely offsets the slight labour use inducement generated by public R&D.

Table 3 assembles the major primal capacity utilization measures. Since the dual measure CU_C clearly inverts its pattern around 1983 (figure 1), these measures are also calculated for the two sub-periods 1960-1983 and 1984-1995. Results suggest that capacity is over-utilized until the early eighties and subsequently then becomes excessive.

Here, in particular, we are interested in the partial utilization measures, that is, the ratio between the observed and the long-run equilibrium levels, providing evidence about under(over)-investment. Both assumptions about P_R are considered. In both cases, R&D stock is scarce until the late seventies; during this period, under-investment is clearly observed from whatever perspective, though as expected it is more evident from the farmers' demand perspective (with free access), that is P_R=0. In the later period, public R&D stock becomes excessive, particularly when a positive social cost (P_R=0), i.e. the social optimal provision (or demand under fee payment regime), is considered. Figure 2 clearly shows that, in the last decade, actual research expenditure follows the farmers' demand (under free access) more closely, while it is nearer to the social optimal provision in the previous period. This suggests that the recovery from the under-investment observed in the sixties and seventies was, in any event, overstressed. However, in particular, this adjustment did not take into account the proper social cost (or the hypothetical fee payment) of the public R&D stock provision.

However, it must be noted that, when the average R&D partial utilization is calculated

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[19] This is the exogenous technical change measured as the reduction rate of the short run cost, i.e.

over the whole period, the actual R&D stock is very close to the equilibrium under $P_R>0$. Meanwhile, as expected, large under-investment is observed when the farmers' perspective (under free access) is maintained.

These findings seem to support the view that optimal R&D provision significantly differs according to the two assumptions of farmers' demand (with free access) and the social optimal supply (or farmers' demand under a fee payment regime). It emerges that during the whole period of investigation, public decision-making has been consistent with the hypothetical social optimal provision. Alternatively, since we can interpret both optimal levels as farmers' demand under two different hypothetical access regimes (free access, i.e, $P_R=0$, and fee payment. i.e. $P_R>0$), results suggest that – overall – the actual R&D pattern is closer to the farmers' demand under fee payment, though excessive supply is observed in the last part of the period.

Finally, the estimated shadow prices and elasticities allow us to calculate the Marginal Internal Rate of Return (MIRR) to public research in the short and long run. Here, the MIRR does not provide any particular further insight about under (over) investment; it rather sums up the year-by-year returns over the service life of the R&D investment. We use this indicator only to compare it with previous studies, which used it as major evidence of the degree of under-investment. Alston *et al*. (2000) review a large number of studies on agricultural R&D, reporting an average estimate of the MIRR of 74%, with public R&D usually outperforming private research. The average MIRR of the latter is "just" about 24%. Thus, this survey strongly supports the hypothesis of under-investment in public agricultural R&D, if we refer to the benchmark cut-off rates of Roseboom *et al*. (2003), that suggest a MIRR ranging between 7% and 12% according to the context (developing vs. developed countries or poor

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$\partial \ln G/\partial t$ and is reported in table 2 as the weighted sum of the variable input growth rates.

vs. rich farmers). In any case, most estimates concerning public agricultural R&D largely surpass this threshold.

The return rate can be computed in the short run and in the long run. The former is the actual rate of return to public R&D and, obviously, only depends on the R&D shadow price.[20] The latter is the return that would be observed if R&D were in equilibrium, thus it is dependent on P_R.[21] We obtain a MIRR of 18% in the short-run and of 31% in the long-run (under $P_R>0$). Since over-investment prevails in the 1976-1995 period, the higher long-run MIRR is consistent with expectations.[22] Both values are much lower, and more realistic, than the average values reported by Alston *et al.* (2000), but higher than the benchmark rates suggested by Roseboom *et al.* (2003); thus suggesting that under-investment occurs but to a lesser, and more reasonable, extent than usually observed.

Finally, the above estimates indicate that MIRR calculation can actually be very sensitive to model specification (short vs. long-run equilibrium), as well as to the calculation of the R&D user cost.

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[20] In the short run, the MIRR is simply computed as $\sum_{n=0}^{L_R} \frac{w_n Z_{R,t-L_R}}{(1+MIRR)^n} = 1$ where L_R is the maximum length admitted for the investment to be effective and w_n is the age/efficiency function of the research investment over the L_R period (both are taken from Esposti and Pierani, 2003a).

[21] In the long run, the R&D marginal value corresponds to its long run marginal productivity; therefore the MIRR can be computed as $\sum_{n=0}^{L_R} \frac{w_n Y^*_{t-n} \; \varepsilon_{YR,t-n}}{X^*_{R,t-L} \; (1+MIRR)^n} = 1$ where $\varepsilon_{YRt-n} = \partial \ln Y^* / \partial \ln X_{R,t-n}$. However, given that, when $P_R=0$ the marginal productivity of R&D must be zero in the long run ($\partial Y^* / \partial X_{R,t-n} = 0$), in this case the long-run MIRR is indeed meaningless in economic terms. Thus, we only refer to the long run MIRR under the $P_R>0$ hypothesis.

[22] The calculation of IRR is based on a 20-year maximum length of the research effects; therefore, the 1976-95 period is considered.

5. Concluding remarks

This paper analyses the role of public R&D investments in agricultural production, making specific reference to the Italian case. The empirical study adopts an econometric model that allows the explicit testing of the hypothesis of under or over-investment in public agricultural R&D. This is achieved through the identification of the long run optimal level. It also takes into account the fact that the public good nature of this input may justify two alternative specifications of the long run equilibrium level, according to two alternative specifications of the R&D price (user cost). In this respect, the appropriate calculation of the R&D stock price is itself critical, and this paper also specifically focuses on this aspect.

Despite the encouraging results, it must be acknowledged that further research efforts in data collection and elaboration seem still required. More accurate information about private R&D spillover and distinction between process vs. product innovations, as well as further comparisons among different specifications of the R&D deflator and user cost, may provide deeper insight on the results here obtained.

The empirical application to Italian agriculture suggests that under-investment in public R&D is observed when the farmers' perspective (under a free access regime) is considered. On the contrary, when the hypothetical social planner point of view (or farmers' demand under fee payment regime) is considered, under-investment eventually vanishes, and the actual public R&D provision seems quite close to the optimal level; at least, this is true when considering the whole sample average.

On the one hand, these results reverse the traditional argument in favour of the under-investment hypothesis proposed in the new growth economics literature, where under-investment may occur from the social point of view while optimality holds at the private level. On the other hand, the empirical evidence emphasizes how, when public R&D is considered, the hypothesis of under-investment critically depends on the perspective adopted, that is — on the R&D user cost and how it is calculated. Eventually, this also underlines how strongly the estimation of the rate of return can depend on R&D price specification, and on its underlying assumptions. Thus, it furthermore points out the extent to which the use of the MIRR in applied research, to obtain indirect information about under-investment, may generate misleading results.

Table 1: Short run variable inputs demand and shadow prices elasticities (at the sample means - standard errors in parenthesis)

	W_A	W_C	W_L	X_R	X_K	Y
V_A	-.037*	-.019*	.056*	.013	.245*	.742*
	(.001)	(.001)	(.001)	(.008)	(.101)	(.106)
V_C	-.022*	-.053*	.075*	-.015	-.241*	1.257*
	(.001)	(.003)	(.003)	(.009)	(.073)	(.075)
V_L	.009*	.011*	-.020*	.004*	-.192*	1.196*
	(.001)	(.001)	(.002)	(.002)	(.024)	(.0251)
Z_R	-.606	.639	.966*	-.589*	-.424	1.013
	(.327)	(.373)	(.353)	(.201)	(.747)	(.849)
Z_K	-.214*	.186*	1.028*	-.008	-.906*	.914*
	(.081)	(.058)	(.085)	(.014)	(.417)	(.428)

* Statistically significant at 95%

Table 2 - Exogenous technical change rate and technological biases
(at the sample means - standard errors in parenthesis)

	Share	Bias	Growth rate
Animal production inputs	.125* (.004)	.037* (.002)	.006* (.001)
Crops inputs	.110* (.002)	.035* (.002)	.003 (.003)
Labour	.765* (.003)	-.011* (.001)	-.043* (.002)
Weighted sum	1	0	-.032* (.002)

* Statistically significant at 95%

Table 3: Primal capacity utilisation (CU_Y) and partial utilization measures of R&D (X_R) and physical capital (X_K) (sample averages)

Periods	**$P_R = 0$**			**$P_R > 0$**		
	$CU_Y = Y/Y^*$	X_R^* / X_R	X_K^* / X_K	$CU_Y = Y/Y^*$	X_R^* / X_R	X_K^* / X_K
1960-83	1.299	3.263	1.318	1.473	1.265	1.554
1984-95	.714	.763	.733	.601	.660	.623
1960-95	1.007	2.424	1.113	.974	1.060	1.233

Figure 1 – Estimated CU_C over the sample period

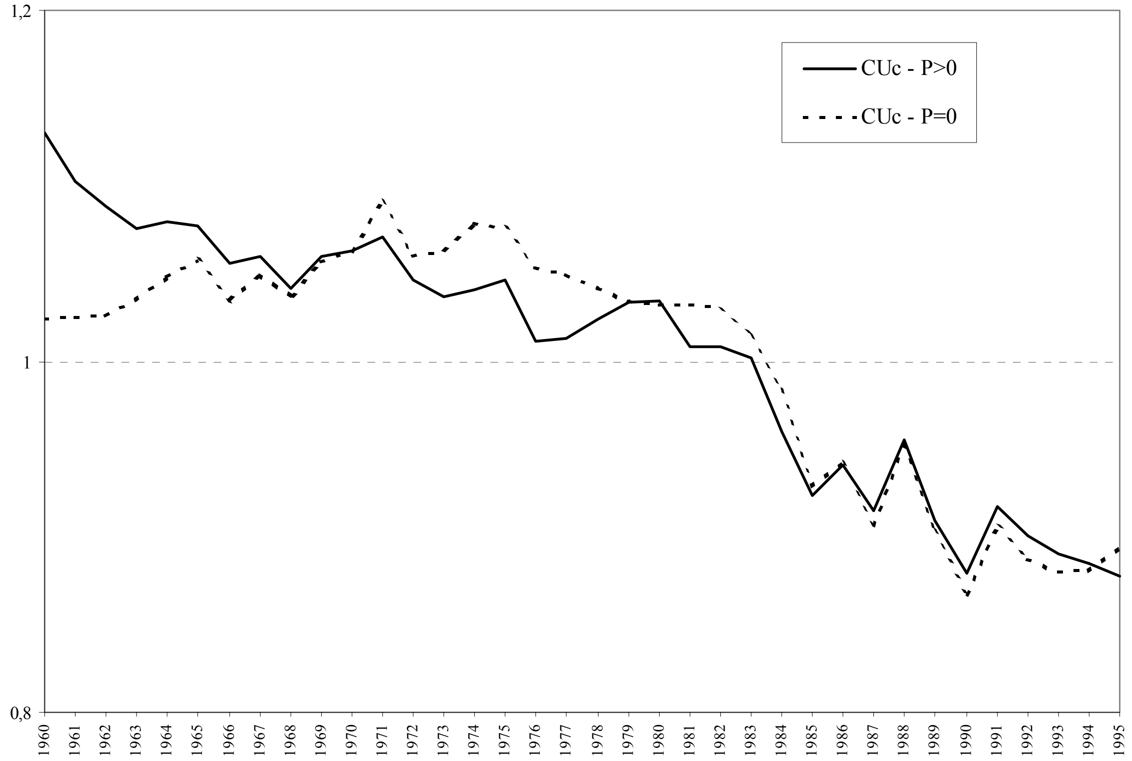
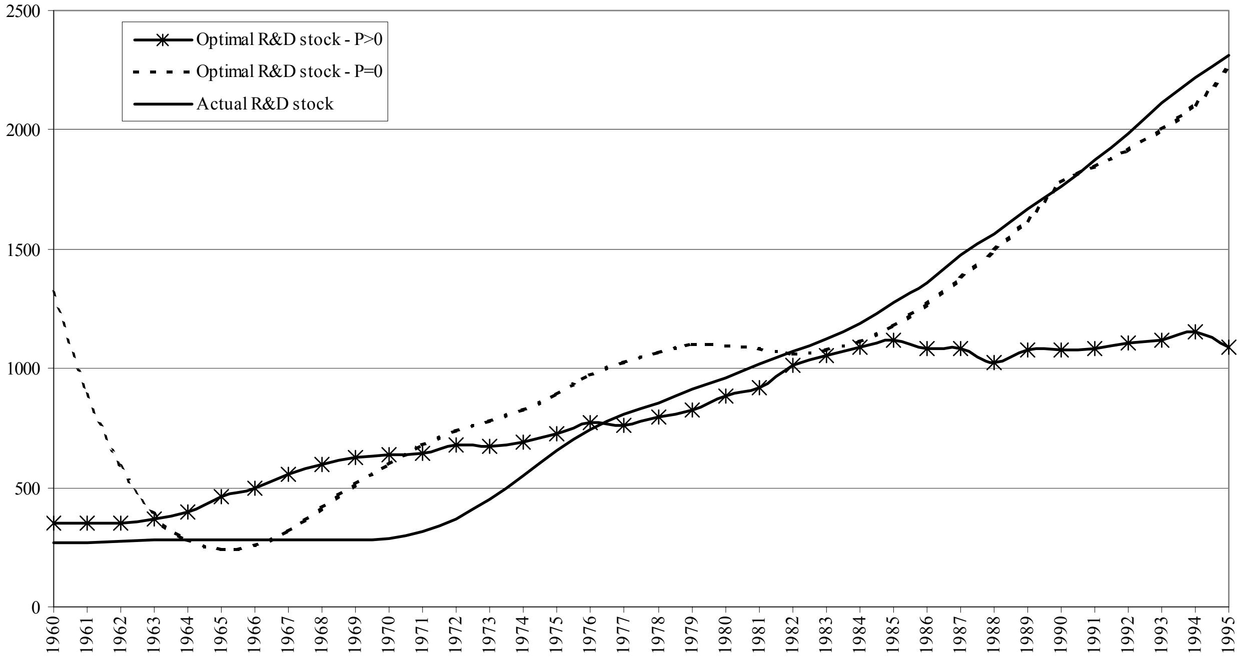


Figure 2 – Actual and optimal R&D stock over the sample period



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