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Resumen: El objetivo de este trabajo es analizar la importancia de insumos asociados al conocimiento ("cambio tecnológico") y precios relativos como determinantes de la demanda de factores en la agricultura argentina. Motiva este trabajo el incremento significativo (x 15) en la demanda de fertilizantes ocurrido en el período 1990-2019. Conocer los factores responsables de la demanda de fertilizantes resulta importante ya que estos insumos explican una parte significativa del producto agrícola en países con sectores agropecuarios altamente productivos, como es el caso de los EEUU y otros. En adición a lo anterior, la creciente preocupación por la sostenibilidad en el tiempo de los sistemas agrícolas enfatiza la necesidad de comprender la economía del uso de fertilizantes pues estos insumos, si bien contribuyen a la producción sostenible, (aumento de producción de grano y también de materia vegetal a ser incorporada al suelo) también generan inquietudes como resultado del consumo de energía necesaria para su producción y la posible contaminación de napas subterráneas que su uso puede generar. Los resultados muestran que en período 1990-2019 el incremento en la demanda de fertilizantes resultó no solo de bajas en el precio relativo fertilizante/grano, sino también del aumento de la productividad marginal del fertilizante. Esto sugiere la creciente importancia de "insumos asociados al conocimiento" en el proceso productivo.

Abstract: The objective of this paper is to analyze the relative importance of knowledge inputs (or "technical change") and input prices in explaining factor demand in Argentine agriculture. Motivation for the paper is the fifteen-fold increase in fertilizer demand observed in Argentina in the 1990-2019 period. Understanding the factors affecting fertilizer use is important, as this input accounts for a significant portion of output in countries with a highly productive agricultural sector, such as the U.S. and others. In addition, increased concern for the sustainability of agricultural systems requires understanding of the economics of fertilizer use, as fertilizers can both contribute to sustainable production (via increased production not only of marketable products, but also dry matter to be incorporated to the soil), but at the same time raise issues, in particular, related to groundwater contamination and energy (in the form of fertilizer) used in the agricultural sector. Results show that in the 1990 – 2019 period increase in fertilizer demand was a result not only of a fall in the fertilizer/crop price ratio, but also on increased marginal productivity of the fertilizer input. It is suggested that this is a result of the increased importance of "knowledge inputs" in the production process.

JEL: D24, Q10, Q12

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I. Introduction

A steady inflow of "knowledge inputs" characterizes the agricultural sector of most countries. This has resulted in significant increases both in output as well as productivity and a long-term decrease in commodity prices. Productivity increases resulting from knowledge inputs originate in many sources: in some cases, new inputs such as seeds, agricultural chemicals and farm machinery. They also include "non-tangible" inputs such as more appropriate planting dates, crop rotations, improved soil diagnosis for fertilizer application and many others. Disentangling the contribution of each of these sources is an important and complex issue.

The importance of knowledge inputs in agriculture – including improvements in the productive capacities of the human agent – was pointed out early on in a seminal paper by T.W. Schultz (Schultz, 1956). Here, the author argues that understanding agricultural supply requires attention to be focused more on the improvements in inputs used, and on the way in which they are used, than in physical quantities of these inputs.

For producers, rapid adaptation to opportunities opened up by technical change results in an income differential with respect to those adapting at a slower rate. Cochrane (1958) identifies a "technological treadmill" for producers: new technologies open up profit possibilities, but also result in an increased competition for land and a downward pressure of output prices. "Adapt or

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die" seems to be the motto in modern agriculture. New technologies not only result in increased output, but also in changes in substitution rates between outputs and inputs, and between inputs themselves. This results in incentives to change both absolute input levels, as well as input combinations.

The objective of this paper is to analyze the relative importance of knowledge inputs (or "technical change") and input prices in explaining factor demand in Argentine agriculture. Motivation for the paper is the fifteen-fold increase in fertilizer demand observed in Argentina in the 1990-2019 period. Understanding the factors affecting fertilizer use is important, as this input accounts for a significant portion of output in countries with a highly productive agricultural sector, such as the U.S. and others (see, e.g. Stewart, 2005). In addition, increased concern for the sustainability of agricultural systems requires understanding of the economics of fertilizer use, as fertilizers can both contribute to sustainable production (via increased production not only of marketable products, but also dry matter to be incorporated to the soil), but at the same time raise issues, in particular, related to groundwater contamination and energy (in the form of fertilizer) used in the agricultural sector. In relation to this last point, it is to be expected that Argentina and other important exporters of agricultural commodities will in the near future be subject to scrutiny as relates to inputs used in the agricultural sector, and the overall sustainability (including impacts on climate change) of production practices (see, e.g. Beckman and others, 2020). Fertilizers are an important aspect of this discussion.

II. Input demand and adaptation to change

Profit-maximizing input demand calls for equating input marginal productivity with the relevant input/output price ratios. This assumes that producers have perfect information both on the marginal productivity schedule, as well as on relevant input/output ratios.

Several factors complicate the logic presented above. For some inputs in agriculture (e.g. fertilizer) risk aversion, in particular, may lead producers to choose input levels such that marginal productivity is higher than the w/p ratio: a subjective risk-premium "δ" ($1 < \delta$) may be operative such that input level is chosen to equate $MPi = (wi/p)\ \delta$. This risk premium results in either lower fertilizer levels than those suggested by market prices of inputs and outputs, or directly to non-use of some potentially profitable input. Increased farmer knowledge of the relevant production technology may result in a gradual fall in this risk premium, resulting in an increase in the quantity demanded of the input. Movement is therefore along a given demand schedule.[2]

Risk-premium δ can be expected to be positively related to price variability faced by producers: as will be discussed below, Argentine farmers have not only faced unfavorable input/output price ratios, but have also experienced significant between-year variability in these prices. "Noise" in price signals can be expected to dampen the impact that these signals have on necessary farmer adaptation, either because of risk-premiums associated with input use, or, simply, due to the information-processing limitations of decision-makers.

Identifying the impact of risk on producer demand is a complex endeavor: even a sophisticated (and costly) approach based on deriving utility functions is of questionable value due to the inherently normative – and not necessarily descriptive - nature of this approach. Indeed, as pointed out be cognitive psychologists (see, e.g. Kahneman and Tversky, 1979), normative models do not necessarily represent actual decision-making processes.

But even ignoring the problem of risk and risk attitudes, additional issues remain. Two will be mentioned here: the impact of new knowledge on production possibilities (or technical change), and farmer adaptation to this change. This last point refers to the extent to which producers perceive new opportunities (resulting from new technologies, or changing prices) and adjust behavior accordingly.

II.1 Technical change and input productivity

Technical change is defined as an increase in output resulting from a given input bundle, or alternatively, a reduction in input needed for a given output. Factor prices influence the direction of technical change: in agriculture "land-saving" and "labor-saving" technical change has been identified, respectively, with land-scarce and labor-scarce agricultural economies (Hayami and Ruttan, 1985). If technical change can be assumed "neutral", in the sense of leaving substitution rates among inputs unchanged, a Cobb-Douglas production technology can be used to represent

[2] Alternatively, δ may be interpreted as a "risk discount" factor affecting the position of the (perceived) demand schedule. In this case, $0 \leq \delta \leq 1$. The perceived schedule results, for a given input/output price ratio, in lower quantity of input demanded. For any level of input, "perceived" marginal product is less than the "objective" marginal product resulting from input use.

production possibilities. Here technical change is modelled in a shift through time in the parameter A(.).

$$[1] \qquad Y = A(t)\, X_1^{\alpha} X_2^{\beta}$$

Under this model, not only output will increase for every input vector, but input marginal productivity as well. Marginal productivity, in effect, is directly proportional – for a given input level – to A(t) and thus to output resulting from a given input bundle:

$$[2] \qquad MP_i = \alpha\, A(t)\, Y/X_i$$

Input demand schedule is thus affected (rightward shift) by knowledge inputs incorporated into the production process. Thus, the impact of these inputs occurs via two channels: increased output for every input bundle, and increased demand for inputs at any input/output price ratios.

II.2 Producer learning and technology adoption

T.W. Schultz (1975) distinguishes between “static” and ‘dynamic” conditions of the economic environment. In the former, adaptation is unnecessary: “trial and error” methods have been used over the years and have resulted in “optimum” levels of input use and output patterns. The “poor but efficient” hypothesis results: in less developed economies, slow or no introduction of new technologies results in no opportunities, or need, for resource re allocation (Schultz, 1964). In contrast with the above, returns to the “ability to deal with disequilibrium” are high in economies where a steady inflow of new technologies opens up opportunities for change. As relates to Schultz’s hypothesis, Welch (1970) distinguishes two dimensions related to farmer ability: the “worker” and “allocative”. The former related to “technical efficiency” (increased output per unit of input), that latter to allocative decisions: i.e. cost minimizing input combinations. Welch also shows that the allocative effect explains why optimum firm size is not unique but is positively related to farmer education. Huffman (1977) estimates the relationship between farmer education and agricultural extension services on adjustment in fertilizer use to changing relative prices and crop fertilizer response. Huffman reports a significant relationship between these two variables on the observed adjustment process (for a survey on the impacts of human capital on adoption of technologies see Huffman, 2000).

The relative role of prices and non-price factors in explaining producer decisions has been subject to debate. A frequently-cited case is the exchange between Zvi Griliches (an economist) and Everett Rogers (sociologist). Focus here was on the determinants of the adoption of corn hybrid seeds in the U.S.A. Griliches emphasized profit opportunities as the main factor explaining adoption, while Rogers highlighted aspects such as knowledge diffusion, community networks and related aspects (Griliches, 1962, Rogers y Havens, 1962). Although apparent conflict exists between these two visions, points in common emerge. In particular, and as pointed out by Griliches, many of the factors considered important by sociologists (e.g. learning processes, information channels, community leadership) are themselves a response to changing economic opportunities.

Recent developments in behavioral economics provide additional insights that are useful for understanding farmer decision-making, technology adoption and, more generally adaptation to change. For example, a recent crop failure due to drought may lead farmers to resist adoption of yield increasing technologies, even when probability the recent drought may not be representative a what can be expected in future years (the “availability” bias). In turn, the “anchoring” bias results in estimates of (for example) crop yields to not take into account relevant variability, but in a subset of yield values.

Production processes generate information, and this information is used to update beliefs. For example, a farmer adopts a new technology on a trial basis or changes the level used of a given input. Prior to observing results, the farmer forms expectations on output resulting from this technology. A-posteriori, new results emerge. The relevant question is: How should expectations be revised in the light of new information? Bayes Theorem provides a logical framework for revising expectations, and can be thus interpreted as a procedure for “learning from experience” (Anderson, Dillon and Hardaker, 1977, p. 55). However, empirical results of experiments suggest that the Bayes rule may or may be not used to update prior expectations: depending on the circumstances, both over- and under-adjustment to new information may occur. Again, human capital can be expected to reduce errors in revisions of prior information, and thus lead to higher efficiency in technology adoption decisions.

Summarizing the above: the quantity demanded of an input results from an optimization process where producers attempt to equate *perceived* input marginal productivity with the relevant price ratio. But, perceived productivity may be quite different from the *objective* productivity that can be expected on a given plot of land. Change over time in production possibilities, producer knowledge about these, price changes and variability in production conditions result in the "profit maximizing" input level being an elusive target. Further, risk attitudes introduce additional complications: as (unobserved) utility, and not profits, may be the relevant objective function to be taken into account. Issues such as these most probably play an important role in cases such as analyzed here where in a three-decade period where use of an input (fertilizer) evolved from practically less than half a million to five million tons a year.

III. The fertilizer input in Argentine agriculture

III.1 Overview

Crop production in Argentina dates from the second half of the XIX century. In the early 1900's some 4 million hectares were planted, increasing to 20 million by the 1930's. As a result of both of policies which resulted in distortion of incentives, as well as neglect of agricultural research and the development of new technologies, planted area remained unchanged for half a century. Only in early 1980s area started to steadily grow, reaching in 2020 38 million hectares in extensive grain production (Reca, 2016).

The rate of introduction of new technologies picked up in the early 1960's, after the creation of INTA, the national institute for agricultural research. Modern ("mexican") wheat varieties, hybrid sunflower, new corn hybrids and improved crop management practices were adopted. In this period, however, the very low level of fertilizer used is an anomaly of Argentine agriculture with respect to other important grain producers. Indeed, in the mid 1970s, most of the national demand for fertilizers (some 70.000 tons annually) was accounted for by fruit and horticultural crops (which represented less than 10 percent of the value of output), and practically none by the important grain producing sector. Fertilizer use increased steadily during the 1990's, averaging some 500.000 tons in the 1990/94 period, and 4.7 million tons three decades later (Figure 1). Despite the substantial increase that has occurred in the last three decades, per-hectare fertilizer levels in Argentina are still ¼ to ½ of that in other important temperate-climate producers such as the U.S, Canada, France and Germany (Table 1).

Up to the 1960's low fertilizer use can possibly be explained by depressed crop prices (result of export taxes and exchange rate controls), high fertilizer prices (result of import restrictions) and also limited availability of technologies complementary with the fertilizer input (in particular – but not only - high fertilizer response seeds). The steady flow of new technologies occurring in the 1970's set the stage for increased adoption of fertilizers. However unfavorable relative price ratios hampered this process. Cirio, Danelotti and White (1981) report that in the 1970's, in Argentina 6-10 kg of wheat was necessary to purchase 1 kg of fertilizer (elementary nitrogen), while in Australia, the U.S and France the relative price was one-third to less than one-half of the above. Price differentials are thus a strong candidate explaining low fertilizer use.

The long long-term trend of real fertilizer price faced by Argentine producers (Figure 2) shows a decline through time. However, this trend obscures variability in different periods. During the 1970's prices though lower than those of the previous decade, were still by international standards high: as shown in Figure 2, during the 1980s and 1990s, approximately 2 tons of wheat were necessary to purchase a ton on nitrogen in the U.S.; in Argentina, relevant price ratios varied from 4 to more than 6: a two or three-fold increase. Elimination of barriers to trade, and exchange rate controls resulted during the 1990's in relative prices converging – albeit slowly - to international levels. However, after 2001 re-imposition of export taxes for agricultural commodities drove the relative price upward, although not to the level of the 1980's and (particularly) the 1970's. A brief period of market liberalization resulted (2016/19) in a new period of relative price decline; however prices were still substantially (+ 60 %) above those faced by U.S. producers.

Argentine producers not only faced substantially higher input/output price ratios than those of U.S. producers, but also higher variability (as measured by CV's) as well: as shown in Figure 3, fertilizer/wheat price CVs were, during the 1980's and 1990s, more than double of those in the U.S. As mentioned previously, price variability not only increases risk premium (or "required rate of return"), but also introduces noise into the decision making process: is it worthwhile to allocate attention to this input?

III.2 Production response – late 1970's early 1980's

A comprehensive summary of response to fertilizers in Argentine agriculture will not be attempted here – only selected highlights will be presented in order to obtain rough parameters that allow inferences to be made on the role of prices and overall technical change on observed increases in the adoption of the fertilizer technology.

Economic analysis of fertilizer demand in the wheat crop as of the early to mid-1980s is found in Gallacher (1982). This study focused on the main corn/soybean area of the country. Increased yields for "average" fertilizer levels (40 kg/ha elementary nitrogen) were 11 percent of base yields on high fertility soils, and 16 percent of base yields for soils of low fertility. Higher (80 kg/ha) levels resulted in increases ranging from 17 to 28 percent of base yields. Note, percentage-wise yield increases are a positive function of fertilizer dose, as absolute yield increases, while base yield remains constant [3]. The higher fertilizer response observed in "new" as compared to "older" wheat varieties is reported in Gallacher (1986). For the case of phosphorous fertilizer, the Marginal Product (MP) schedule for "older" varieties MP = 8.6 - .06 P shifts upward to MP = 12.9 – 0.06 P for the newer ones. This results in a significant increase in the "optimum" fertilizer rate. For a relative price of 6 (phosphorous/wheat price) the profit maximizing fertilizer level is 12 kg/ha with the older, as compared to 83 kg/ha for the newer ones. This result highlights the importance of factor other than price in determining the extent of usage of the fertilizer input.

Additional results of fertilizer response in wheat production in the late 1970's to early 1980's are reported in Gallacher (1986). [4] Yield increases resulting from the application of 40 kg/ha on nitrogen are .68 and .82 tons/hectare for, respectively, Marcos Juarez and Pergamino, two important agricultural areas of the country. Yield increases from the fertilizer dose used here for calculations (40 kg/ha) represented, respectively 31 end 38 percent of baseline (i.e no fertilizer) yield. Given prevailing the fertilizer/wheat prices, profit maximizing fertilizer (nitrogen) levels were respectively 40 and 60 kg/ha. Given a fertilizer/wheat price ratio of 8 prevailing at the time, these results, if valid for a wider area, suggest an existence of disequilibrium in the use of this input: marginal product exceeded marginal factor cost by a significant amount.

[3] However, decreasing marginal product of the fertilizer input appears throughout.

[4] Response trials in 9 locations, 248 trials and some 4.400 observations.

The impact of nutrient depletion resulting from continuous cropping is a significant issue to be addressed, in particular in view of the declining importance of rotations involving multi-year pastures. Figure 4 shows the impact of continuous cropping on corn response to nitrogen fertilizer. Results were obtained from a production function fitted to 231 observations in the locality of Pergamino (standard errors in parenthesis):[5]

$$[3]\ Y = 7617 + \underset{(5.3)}{16.0\,N} - \underset{(0.04)}{0.116\,N^2} - \underset{(12.0)}{113.9\,t} + \underset{(0.15)}{0.57\,N\,t} \qquad R^2 = 0.45$$

Where N denotes nitrogen fertilizer (kg/ha of elementary N), and t denotes years under continuous agriculture. The comparison of a situation with 5 to one with 25 years under agriculture, which would approximately contrast a farm under crop/pasture rotation with one under continuous (as of the late 1970s) crop production, results in a significant shift in input marginal productivity: yield increase for 40 kg/ha of input would be 0.6 t/ha in the former, but 1.2 t/ha in the latter. Yield increases, as a compared to base yield would be 7.8 and 10.4 percent respectively. For a fertilizer/wheat price ratio of 8, maximum profit nitrogen level would increase from 20 to 60 kg/ha for farms under “crop-pasture” and “continuous cropping” rotations respectively.

Evidence presented above broadly suggests response to the fertilizer input in the early to mid 1980’s. These response results are a function of crop production knowledge incorporated into decision-making processes at that time. As mentioned previously, increase in crop area, and production of major grain crops occurred starting in the late 1980s – early 1990s, thus the 1980s represent a period previous to the one where significant changes would occur.

III.3 Production response: late 1990’s to the present

García and Darwich (2009) summarize milestones related to fertilizer supply and demand in Argentina since the mid 1960’s. Systematic research on fertilizer response started in the late 1960’s as a result of a joint project between INTA, CYMMIT and the Ford Foundation. A decade later, response models were available for selected areas of the country (García and Darwich, 2009). To be noted is that despite these early research efforts, takeoff in fertilizer use had to wait at least until

[5] Gallacher, 1987.

the early 1990s, that is, two decades later than when fertilizer research was initiated. High fertilizer prices during the 1970s and 1980s are the most likely explanation for this fact.

Interest in this input increased in the early 1980's, leading to additional applied agronomic research by both INTA as well as private groups. A swap program of fertilizers for grain was implemented by the Ministry of Agriculture in 1983, and the first large-coverage soil fertility maps were completed by INTA. The first manual of soil fertility and fertilizer use was published in 1989 (García and Darwich, p.428). Crop area increased modestly, if at all, during the 1980's, but significantly during the 1990's and, particularly in the 2000-2010 period. Area of major crops thus jumped from some 17 million hectares in the 1980s, to 36 million in 2019. In many areas, the doubling of crop area resulted in abandonment of the traditional crop-pasture rotation, as well as tillage of natural grasses and forest/scrubland. Agronomists are insistent on their concern related to increased "pressure" put by continuous cropping on soils (see, e.g. Sainz Rosas and others, 2019) and on the "deficit" resulting from fertilizer levels not covering nutrient extraction by crops (see Grassini and Monzón, 2021).

Although an important volume of research related to fertilizer use has been completed since the 1990s (see, e.g. Álvarez and others [2015], Correndo, Boxler and García [2015], García and Salvagiotti [2009]) summarizing results for economic analysis is not easy. Figure 11 in García and Darwich (p. 434) provide a starting point. Table 2, adapted from this figure, reports yield estimates for the fertilized and non-fertilized wheat crop (experimental results). Two issues stand out. First, in the period analyzed yields for the non-fertilized treatment increased 75 percent, most possibly as a result of improved seeds.[6] Second, response to the fertilizer input increased both in absolute as well as relative terms: the average product of the fertilizer input was 500 kg/ha in 1970 (25 percent of baseline yield), but 2000 kg/ha in 2000 (57 percent of baseline). Although these – admittedly "rough and ready" - result pertain only to the wheat crop, they are illustrative of changes occurring in the Argentine agricultural sector.

García and Darwich (Table 10, p. 438) summarize the "agronomic efficiency" of fertilizer use in the wheat, corn and soybeans crops of Argentina. This term is used to denote additional output resulting from added input (fertilizer). In the language of microeconomics, the Average Product (AP) resulting from the input. Fertilizer AP varies considerably among crops, nutrient and

[6] Changes in overall crop management are probably minor, as these are results from experimental plots and not farmer fields.

experimental trials. However, a first approximation of 15 -20 kg/kg for wheat, 15-30 kg/kg for corn, and 12-20 kg/kg for soybeans can be taken as a starting point. [7]

Opportunities opened up lower fertilizer prices, as well as by technical developments related to fertilizer use result in an increase in the demand for information leading to improved decision-making. Figure 5 shows an index of the number of soil samples tested in a private laboratory in the 1991-2020 period. Soil tests increased nearly 400 percent between the beginning and the end of the period. The soil-testing lab from which this data originates started operations in 1962, thus growth in the 1991-2020 period most probably reflects growth in demand for services, and not mere "growth in customer base" due to recent starting of operations.

IV. Accounting for the increase in fertilizer use

To be explained here is the increase in fertilizer use in Argentina in the 1990 – 2019 period. Two sub-periods are distinguished in these 3-decade period: 1990 – 1999 and 2000-2019. The first ("Period 1") is a "learning/adoption" stage, where (relatively recent) experimental and farm-level results are gradually made available to producers. Note that while fertilizer research was underway since the early to mid 1970's, it is only in the mid to late 1980's that fertilizer prices show a steady decline, and in the 1990's that crop expansion starts in earnest. This period also coincides with the rapid adoption of no-till technology, which resulted both in changes in crop management practices as well as in improved efficiency (in particular, water use and planting dates). Period 1 therefore marks the start of widespread adoption of fertilization in extensive crop production.

"Period 2" (2000-2019) corresponds to the "knowledge" stage, characterized by a significant stock of agronomic research as well as on-farm experience related to fertilizer use. Increased knowledge on the use of this input suggests a decrease in the risk premium associated with allocating funds for fertilization. Further, gradual crop intensification suggests tightening of constraints related to soil fertility.

Focus is placed on fertilizer use per unit of area. For a fixed input of land and (non-fertilizer) input services complementary to land, output is assumed to result from:

[7] Both N and P fertilizers for wheat and corn, only P for soybeans. No information is provided on input levels to which these AP's refer.

$$[4] \quad Y(F) = A(t) F^{\alpha}$$

Where Y is output per unit of land and F fertilizer input per unit of land. A(t) results from overall improvements in technology or technical change, a function of time. The profit-maximizing level of input F results from equating input marginal productivity to the relative input/output price:

$$[5] \quad B(F) = p\, A(t)\, F^{\alpha} - w\, F$$

$$[6] \quad dB(F)/dF = \alpha p\, A(t)\ F^{\alpha-1} - w = 0$$

$$[7] \quad F^*(p, w) = [\alpha\, (p/w)\, A(t)]^{1/(1-\alpha)}$$

Denoting by t = 0 or t = 1 for initial and final stages of the two periods analyzed here (1990/99, 2000/19), the predicted increase in the use of F is:

$$[8] \quad F_t^*(p_1, w_1)/F_0^*(p_0, w_0) = \{[(p/w)_1\, A(1)] / \{[(p/w)_0\, A(0)]\}^{1/(1-\alpha)\}}$$

The above can be decomposed in "'price effect" and a "technology effect":

$$[9] \quad \text{Price effect} = \{[(p/w)_1]/[(p/w)_0]\}^{1/(1-\alpha)\}}$$

$$[10] \quad \text{Technology effect} = \{A(1)/A(0)\}^{1/(1-\alpha)\}}$$

The above assumes that fertilizer marginal productivity is a function of overall technology (A(.)) and non-fertilizer inputs applied per unit of land. These are assumed constant over the period. However, it is possible that α changes over time. This can occur via two channels. First, improved soil diagnosis and fertilizer application methods. Second, and probably more important, gradual decline in soil fertility due to continuous cropping. As mentioned previously, evidence of both these factors is available.

Impacts of the above may be modelled by assuming $\alpha(t) = \alpha 0(1 + \delta)$ where $\delta = 0$ for the Period 1 ("learning/adoption" stage), and $\delta > 0$ for Period 2 ("knowledge" stage). A value of 0.3 will be assumed here for δ.

Table 3 reports assumed valued for price ratios, accumulated technical change for the "learning adoption" and "knowledge" periods and output elasticity of the fertilizer input. As shown, α is assumed equal to 0.25 in the learning/adoption and 0.32 in the knowledge periods, respectively. The Appendix provides background for the chosen values. Estimates of the impact of prices and technical change are also shown in Table 3. Real fertilizer prices fell from approximately 5.2 in the late 1980's, to 4.0 during the 1990's. In this period, the price effect accounts for 42 percent of increased fertilizer use. Technical change, resulting in increased fertilizer productivity, accounts for another 58 percent. Rounding numbers, total predicted increase is thus 124 percent.

In the "knowledge" period, technical change accounts for a predicted increase in 89 percent in fertilizer use. Relative prices (w/p), however, remained unchanged thus the impact of prices in nil. The combined effect of technical change, and input prices is a predicted increase of 89 percent in fertilizer usage.

How do these predictions compare with actual changes during the period? In Period 1, the prediction of a 2.24 increase in (per-hectare) fertilizer demand is lower than the observed increase (x 3.1). In period 2, predicted change (x 1.89) is slightly higher than the observed change (x 1.8). Overall observed increase in the 1990-2019 period (x 5.6) is higher that the one estimated here (x 4.0). Comparison of "observed" with "estimated" figures should be made cautiously, as they are highly sensitive not only to assumptions on technical change and fertilizer output elasticity, but also on assumptions on prices used by farmers in the decision-making process: in particular under the highly volatile economy of Argentina, ex-ante price expectations can be quite different from what ex-post statistical data shows.

V. Final Comments

Argentine agriculture has experienced significant growth in the last half-century. This has occurred despite policies that resulted in a distortion of the incentives faced by producers. This paper attempts to understand determinants of the fifteen-fold increase in fertilizer use that has occurred since 1990. Evidence presented her suggests that previous to the late 1980's, unfavorable price ratios were a significant constraint to fertilizer adoption. But prices were not the only factor: incipient development of fertilizer use technology (in particular, soil testing), as well as variable and frequently low fertilizer response were contributing factors.

During the 1990's, more favorable relative price ratios, significant improvements in overall crop productivity, and increased cropping intensity (with resulting increase in fertilizer response) triggered growth in fertilizer application per unit of land. As shown in Figure 2, relatively low fertilizer/crop prices during the 1990s were followed by two decades of substantially higher (+ 50 percent or more) price ratios. Fertilizer use, however, continued to grow. An intriguing question is the role that favorable prices on a given period have in input use of subsequent periods: favorable prices encourage increased input use, and indirectly, accumulation of knowledge related to this technology. A possible hypothesis is then that economic the economic liberalization that occurred in Argentina in the 1990s, contributed to growth not only in this period but in subsequent periods as well.

The evidence presented in this paper suggests that both reductions in relative prices (in particular, in the 1990/99 period, as compared to the previous decade) as well as overall technical improvements were responsible for increased fertilizer use. Crop productivity (and thus response to fertilizer) as a determinant of demand for the fertilizer input is particularly important after 2000, when despite variable or even increasing real fertilizer prices, demand for this input continued to increase. Disentangling the effects of prices and input productivity in producer decision-making is a complex but important research topic. Progress in this area will most possibly require close collaboration between professionals with backgrounds in agronomy with those in economics.

VI. References

Alvarez, R., H.S. Steinbach, C.R.Alvarez and J.L.De Pape (2015), Fertilizer use in Pampean Agroecosystems: Impact on Productivity and Nutrient Balance. Chemical Engineering Series – Fertilizer Technology Vol.2: Biofertilizers. Eds S.Sinha, K.K.Pants, S.Bonpai and J.N.Govil. Studium Press, LLC USA.

Anderson, J.R., J.L. Dillon and J.B. Hardaker (1977), Agricultural Decision Analysis. The Iowa State University Press.

Beckman, J., M.Ivanic, J.Jelliffe, F.G.Baquedano and S.Scott (2020), Economic and Food Security Impacts of Agricultural Input Reduction Under the European Union Green Deal's Farm to Fork and Biodiversity Strategies. USDA – ERS - Economic Brief No. (EB-30) 59 pp

Cirio, F.M., I. Danelotti and D. White (1981), Productividad, eficiencia y el problema energético en la agricultura. Convenio AACREA-Banco de la Nación Argentina – Fundación Banco de la provincia de Buenos Aires. Año 4, Número 20.

Cochrane, Willard W. (1958): Farm Prices, Myth and Reality. Minneapolis: University of Minnesota Press, 1958, vii + 186

Correndo, A.A., M.Boxler and F. García (2015) Análisis económico del manejo de la fertilización con un enfoque en el largo plazo. Cienc Suelo (Argentina) 33(2): 197-212, 2015

Gallacher, M. (1982), Análisis económico de la fertilización de trigo. Resultados de la zona maicera. Convenio AACREA-Banco de la Nación Argentina – Fundación Banco de la provincia de Buenos Aires. Año 4, Número 24.

Gallacher, M. (1985), Nuevas tecnologías en la producción de trigo-fertilizantes en la pradera pampeana. Centro de Investigaciones sobre Política Agropecuaria. Documento de Trabajo de investigación Nro 4.

Gallacher, M. (1986), Implicancias económicas del cambio tecnológico. Nuevas variedades en la región triguera IV. Estudios Económicos IV(NS) Nro 7/8 pag.1-11.

Gallacher, M. (1987), Perspectivas de la producción de granos en la pradera pampeana. Estudio sobre políticas de producción, transporte, almacenamiento y embarque de granos. Instituto Interamericano de Cooperación para la Agricultura (IICA) Junio 1987.

García, F. and N.Darwich (2009), La fertilización: tecnología para sostener la productividad de nuestros suelos. In: D.Ricci (2009), La revolución tecnológica del agro. Hacia el desarrollo integral de nuestra sociedad. CASAFE.

García, F. and F. Salvagiotti (2009), Eficiencia en el uso de nutrientes en sistemas agrícolas del Cono sur de Latinoamerica. In: J. Espinosa and F. Garcia (ed.). Memorias del Simposio "Uso eficiente de nutrientes". XVIII Congreso Latinoamericano de la Ciencia del Suelo. San Jose, Costa Rica. pag. 37-48.

Garcia, F., J. Minteguiaga , R. Pozzi, (2010), La red de nutrición de la región Crea Sur de Santa Fe : Resultados
y conclusiones de los primeros diez años 200-2009. 1a ed. - Buenos Aires : Asoc. Argentina de Consorcios. Regionales de Experimentación Agrícola - AACREA, 2010.
64 p. ; 26x20 cm.

Grassini, P. and J.P Monzón (2021), De brechas de rendimientos a brechas de nutrientes. Diagnóstico para la Argentina. Conference in the National Academy of Agronomy and Veterinary (Academina Nacional de Agronomía y Veterinaria). Buenos Aires, June 15, 2021.

Griliches, Z. (1962), 'Profitability Versus Interaction: Another False Dichotomy," Rural Sociology, vol. 27, pp. 325-330.

Hayami, Y and V.W. Ruttan (1985), Agricultural Development: An International Perspective. Baltimore: Johns Hopkins Univ.

Huffman, W.E.(1977), Allocative efficiency: the role of human capital. Quarterly Journal of Economics (91): 59-77.

Huffman, W. E., "Human Capital, Education, and Agriculture" (2000). Economic Staff Paper Series. 341. http://lib.dr.iastate.edu/econ_las_staffpapers/341

Kahneman, D. and A.Tversky (1979), Prospect theory: an analysis of decision under risk. Vol. 47, No. 2 (Mar., 1979), pp. 263-291

Lema, D.R. (2016) Crecimiento y productividad total de factores en la agricultura argentina y del Cono Sur 1961-2913. Serie de informes técnicos del Banco Mundial en Argentina, Paraguay y Uruguay Nº 1, 2015

Márgenes Agropecuarios (2002/2020). www.margenes.com

Reca, L. G. (2016), El sector agropecuario argentino: despegue, caída y resurgimiento (1875 y 2005). Estud. Econ. vol.23 no.47 Bahía Blanca Julio 2006

Rogers, E.M. and A. E. Havens (1962), "Rejoinder to Griliches' 'Another False Dichotomy," Rural Sociology, vol. 27: pp. 332-334.

Sainz Rozas, H. M. Eyherabide, G. Larrea, N. Martínez Cuesta, H. Angelini, N. Reussi Calvo y N. Wyngaard (2019), Relevamiento y determinación de propiedades químicas en suelos de aptitud agrícola de la región pampeana. Simposio Fertilizar Asociación Civil. Buenos Aires.

Schultz, T.W.(1956) Reflections on agricultural production, output and supply. Journal of Farm Economics (38 No 3):748-762.

Schultz, T.W.(1964), Transforming traditional agriculture. Yale University Press.

Schultz, T.W.(1975), The value of the ability to deal with disequilibria. Journal of Economic Literature (13):827-846.

Stewart, W.M., D.W. Dibb. A.E. Johnston and T.J.Smyth (2005), The contribution of commercial fertilizer nutrients to food production. Agronomy Journal (97): 1-6.

Welch, F. (1970). Education in production. Journal of Political Economy, 78(1).

Tables and Figures

Figure 1: Argentina - Fertilizer Consumption (millon tons)

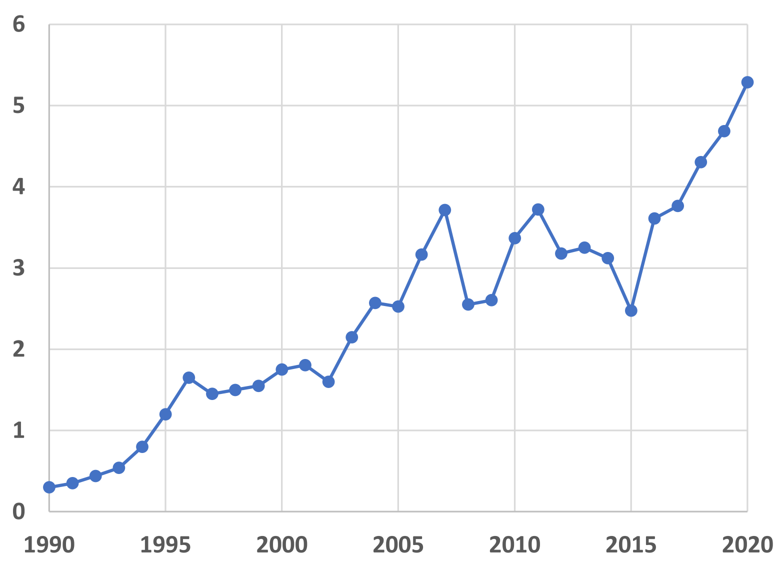


Table 1: Fertilizer Use per Hectare

	Argentina	Canada	France	Germany	USA
			kg/ha (N + P + K)		
2000/04	35	62	204	218	113
2005/09	36	111	78	87	102
2010/14	36	154	74	92	112
2015/18	39	166	76	84	113

Source: FAOSTAT

Figure 2: Fertilizer Relative Price Index
(Price ton N /Price ton Wheat)

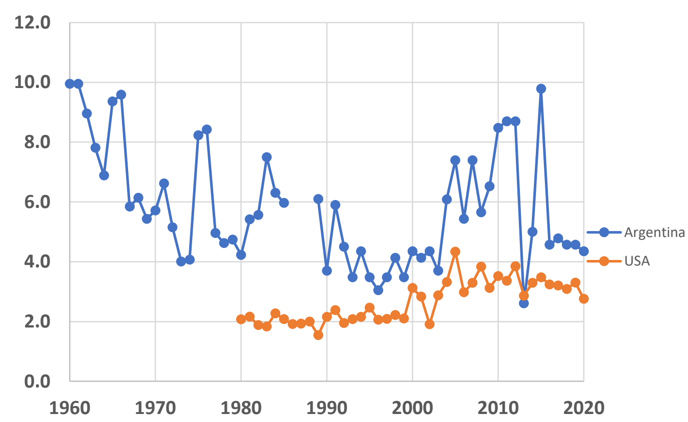
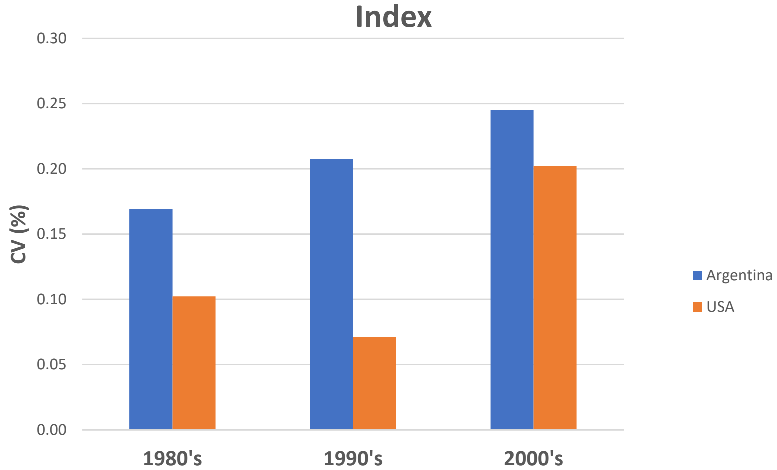


Figure 3: CVs (%) of Fertilizer/Wheat Price Index



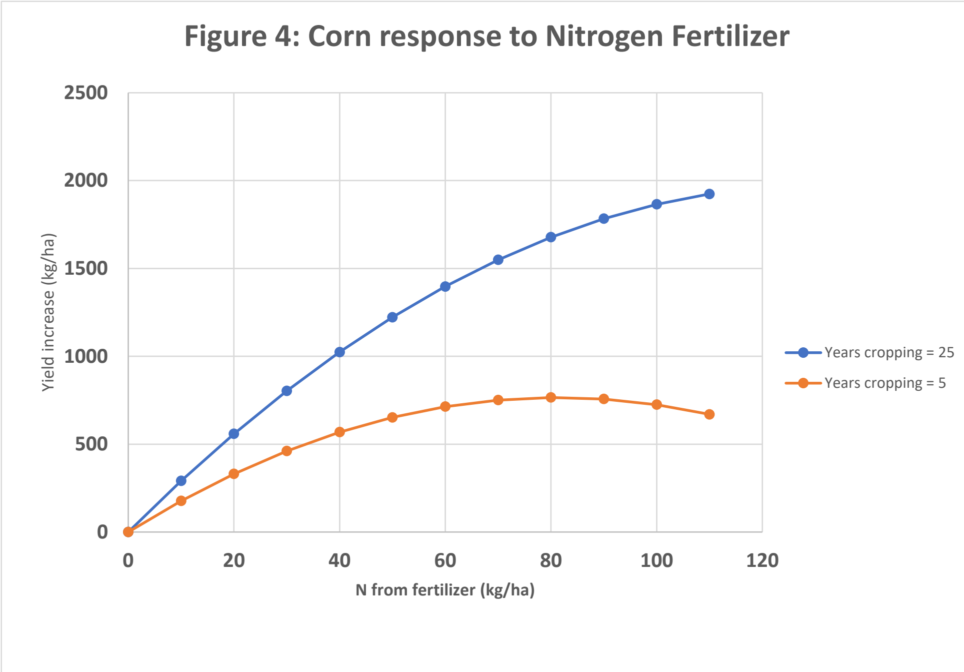


Table 2: Wheat Crop - Yield Increases from Fertilization

Year	Baseline	Fertilized	Yield Increase	Increase/ Baseline
	kg/ha	kg/ha	kg/ha	%
1970	2000	2500	500	25
1980	2500	3500	1000	40
1990	3200	4200	1000	31
2000	3500	5500	2000	57

Source: Figure 11 of Garcia and Darwich (2009)

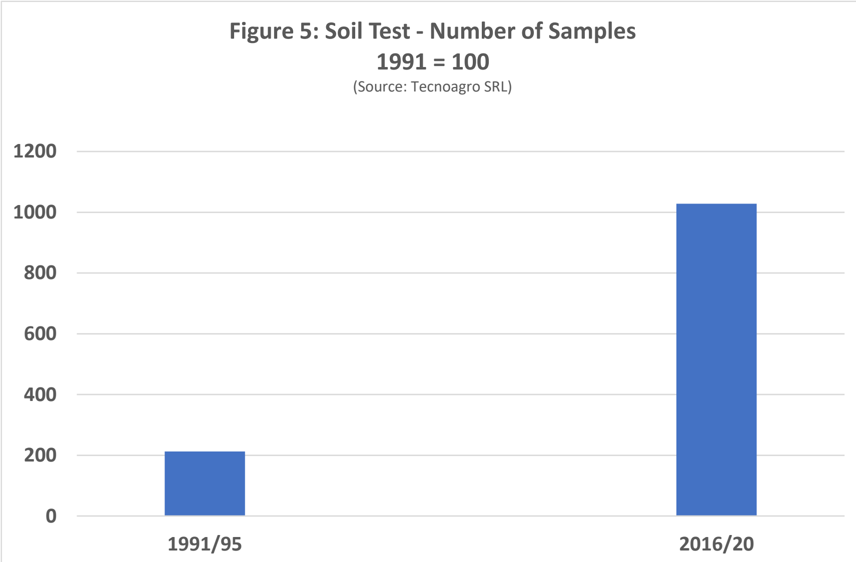


Table 3: Results

	Period 1: "Learning/Adoption"	Period 2: "Knowledge"
Assumed values:		
A(1)/A(0)	1.41	1.54
(p/w)1	4.00	4.60
(p/w)0	5.20	4.60
α	0.25	0.32
Results:		
Technical Change Effect	1.58	1.89
Price Effect	1.42	1.00
Total Effect	2.24	1.89

Appendix 1

Assumed values for technical change (A(t)), relative prices (w/p) and fertilizer output elasticity (α)

<u>Technical change (A(t))</u>

Lema (2016) reports estimates of TFP change in Argentine agriculture during the last decades. Table 3 summarized results as follows:

Period	TFP growth per year (%)
1961-1989	2.76
1990-2001	3.89
2002-2007	2.59
2008-2013	1.96

For Period 1 (1990-99) the value of 3.89 per year reported by Lema is used. For Period 2 (2000-2019) the average estimated by Lema for the 2002-2007 and 2008-2013 (2.3 % per year) are taken as representative. Total TFP change is thus 41 percent for Period 1 ($1.0389^9 – 1$) and 54 percent ($1.023^{19} – 1$) for Period 2.

<u>Relative prices (w/p)</u>

An index of fertilizer/crop prices is used. Elementary nitrogen and wheat prices are used to construct the index. Fertilizers are used in several grain crops other than wheat, and also phosphorous is also used in addition to nitrogen. However, the simple index used here possibly adequately captures changes in real fertilizer prices faced by producers. Further, price changes, and not absolute prices are the relevant variable used in calculations. Relative prices were obtained from Gallacher (1987) and Márgenes Agropecuarios (several years). Prices faced by producers at the beginning and ending stages of Periods 1 and 2 were estimated from data used in Figure 2

Period 1: Price ratio of 5.2 was assumed at the beginning of the period (prevailing price late 1980s, early 1990s). Price ratio of 4.0 at the end of the period.
Period 2: Price ratio of 4.6 at the beginning (2000-2004), and at the end (2016-2019) of the period.

Fertilizer Output Elasticity (α)

Only rough estimates of elasticity of output with respect to fertilizer application are available. Some figures are reported in Section III of this report. The objective here is not to attempt to obtain "the" relevant value for α for the Argentine agricultural sector, but only to discuss possible implications of input marginal productivity and prices in explaining shifts in fertilizer use.

The following are some examples that have been commented in Section 3 (yield increases resulting from fertilizer use):

Gallacher (1982):	11 – 16 % (lower dose)
Gallacher (1982)	17 – 28 % (higher dose)
Gallacher (1985):	31 – 38 %
Gallacher (1987):	8 – 10 %
García and Darwich (2009):	33 % (1970s and 1980s)
García and Darwich (2009):	44 % (1990s, 2000)
Garcia, Minteguiaga and Pozzi, (2010):	21 %

Overall assessment by García and Darwich (2009) indicate "agronomic efficiency" (i.e Average Product) of fertilizer use of 15-20 for wheat, 15-30 for corn and 12-20 for soybeans. Assuming an input use of 60 kg/ha for wheat and corn, and 40 kg/ha for soybeans, this would result in yield increases of 900-1200, 900-1800 and 480-800 kg/ha for the three crops considered here. These increments represent, respectively 27-36; 15-30 and 18 – 30 percent of country-wide yields. Note that all "elasticity" values reported here result from experimental plots and not farmer fields. Farmer response can be expected to be somewhat lower due to managerial and constraints operating on the system.

As a result of the evidence presented above, and admittedly in an ad-hoc manner, a value of $\alpha = 0.25$ will be assumed for Period 1, and $\alpha = 0.25(1 + \delta) = 0.25(1 + 0.3) = 0.32$ for Period 2.

Fertilizer usage per hectare

Fertilizer use data is reported by *Fertilizar Asociación Civil*.[8] Area of major crops by the Ministry of Agriculture (SAGPyA).

For Period 1, increase in fertilizer is expresses as the ratio between the 1998-2000 and 1990-1992 average annual use. For Period 2, the ratio between 2018-2020 and 2000-2002 averages.

[8] https://fertilizar.org.ar/estadisticas/#