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THE HUMAN FACTOR IN ARGENTINE AGRICULTURE

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The human factor in Argentine agriculture

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Resumen

El objetivo de este trabajo es identificar los determinantes de la reducción de uso del factor trabajo en el sector agropecuario argentino. El trabajo focaliza atención en el período 2002-2018, período comprendido entre los dos últimos Censos Nacionales Agropecuarios con resultados confiables (el CNA 2008 quedó incompleto). El trabajo pasa revista a las tendencias en cuanto a uso de trabajo y tamaño de empresa en Argentina, y presenta tres posibles hipótesis que explican los cambios observados: (a) sustitución de trabajo por capital, (b) cambio tecnológico ahorrador de mano de obra (labranza reducida y siembra directa) y (c) cambio en el tamaño de empresa y en el tipo de capital (maquinarias) utilizadas.

Palabras clave: trabajo en el sector agropecuario argentino, elasticidad de sustitución

Abstract

The objective of this paper is to identify determinants of the reductions in the use of labor observed in Argentine agriculture. The paper focuses on the 2002-2018 period, using data from the last two publications of the *Censo Nacional Agropecuario* (the census undertaken in 2008 is incomplete). The paper summarizes trends of labor use and firm size in Argentina, and presents three possible hypothesis accounting for observed changes: (a) capital-labor substitution, (b) labor-saving technical change (reduced and no-tillage) and (c) changes in farm size and the types of capital (machines) used.

Keywords: labor in the Argentine agricultural sector, elasticity of substitituion

JEL Codes: Q1, D2

THE HUMAN FACTOR IN ARGENTINE AGRICULTURE [1]

INTRODUCTION

Since the early 1960's Argentine agriculture experienced considerable growth. This contrasts with the relatively poor performance of the previous decades. Output growth resulted from a steady stream of new technologies which included new wheat varieties, sunflower hybrids, the introduction of the soybean crop in the 1960's and early 1970's, increased us of fertilizer (1980s) and rapid adoption of no-till production methods (1990's). This latter technology resulted in reduction in the costs of production as well as improved soil management. It also triggered a substantial shift of land from livestock to crop production, in particular in land previously considered "marginal" for crops.

The Argentine agricultural sector is highly heterogeneous, including both "extensive" crops such as cereals and oilseeds, and "intensive" fruit and vegetable production. More than three quarters of output is accounted for by cereal, oilseed, beef, dairy and poultry production. Heterogeneity in outputs and in production conditions results in a wide variety of input combinations being used: labor share in total costs range from less than 10 percent in cereal and oilseed crops, to more than 50 percent in fruits and vegetables.

The objective of this paper is to identify forces affecting labor use in the Argentine agricultural sector. While several studies have outlined the general input and output trends of the Argentine agricultural sector, the "human factor" has received less attention.

Economic development is accompanied by a reduction in the labor force employed in agriculture. This change is a result of substitution of other inputs for labor in the production process, as well as "technological change" that allows increased output to be produced with the same input levels. Reduction in labor use in agriculture occurs simultaneously with changes in the types of labor employed. Shifts in the demand for skills resulting from new technologies increase returns to managerial ability and thus the quantity supplied of both managerial as well as operator know-how. Evidence of the impact of human capital in agriculture is abundant (see e.g. Evenson, 1988; for Argentina Gallacher, 2010, Gallacher, 2012 and Gallacher and Lema, 2018).

In the case of Argentina, data limitations restrict "what can be learned" in relation to the labor input in agriculture.[2] With this caveat, the following are some of the relevant issues related to the "human factor" that merit attention:

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[1] Arguments presented here are my own and do not necessarily correspond to those of the University of CEMA. This Working Paper replaces a previous one. Corrections were made to calculations.

[2] The term "labor" is used here somewhat loosely, including both "workers" and managers/entrepreneurs. Unless otherwise stated, "labor" and "human factor" will be thus used interchangeably to refer to various inputs of human effort.

1. **1.** To what extent is the agricultural sector becoming less "labor dependent": i.e. are production processes tending towards lower ratios between labor and other inputs.
2. **2.** How responsive is the ratio between labor and other inputs to relative price changes: i.e. can we get a grip on the relevant elasticity of substitution? How is the elasticity of substitution affected by characteristics of the technology used in production?
3. **3.** How does the marginal productivity of the labor input compare to the relevant factor price: is disequilibrium the norm, suggesting continued labor out-migration?
4. **4.** What changes are occurring in the types of labor inputs used: is increasing human capital evident?
5. **5.** What complementary relations exist between the on-farm labor input, and the supply off-farm know-how (public extension services, private advisors).

Items (1) – (5) include an ambitious research agenda, and are included here only as a "road map" of issues that merit attention. This paper will focus on items (1) and (2).

I. LABOR USE TRENDS

Falling share of agriculture in the economy-wide employment is a well-established fact for most countries. World Bank data (World Development Indicators [WDI]) shows for the Latin America and Caribbean region a decline in the share of agricultural over total labor from 20.8 in 1995 to 13.7 percent in 2019. For the OECD countries relevant data are respectively 8.5 and 4.8 percent, while for the U.S., an advanced economy with an export-oriented agricultural sector, the reduction was from 1.7 percent in 1995 to less 1.4 percent in 2019. Figures for Canada and Australia show in general a similar pattern to that found in the U.S. Middle and low-income economies show considerably higher labor employment shares, but these are also characterized by a declining trend.

WDI agricultural labor data for Argentina are not trustworthy, as for recent years they report labor shares well below 0.1 percent, an unreasonable figure given observed trends in other countries.[3] The wide range of existing estimates is highlighted comparing WDI data mentioned above (less than 0.1 percent employment), with for example that reported by a private think-tank according to which jobs in the primary agricultural sector are some 9.5 percent of total jobs in the country. (Pisani Claro and Mazo, 2019).[4]

A first (and crude) approximation to labor use <u>trends</u> (as opposed to absolute values) in agriculture can be obtained looking into evolution of population residing in rural areas. If the ratio of agricultural employment to rural area population remains fairly constant over time, rural population trends can suggest – if not absolute labor employment – at least ag employment trends. As shown in Figure 1, in Argentina rural as a fraction of total population decreased continuously over time, from approximately 30 percent in the late 1950's, to 8.2 percent in 2019. In the period analyzed, fall in rural population seems to have slowed down significantly from a fall of 7-8 percentage points per decade in the 1950's, to less than 1.5 percentage points in the last decade of the series. For 2018, the rural/total population ratio was 8.2 percent.[5]

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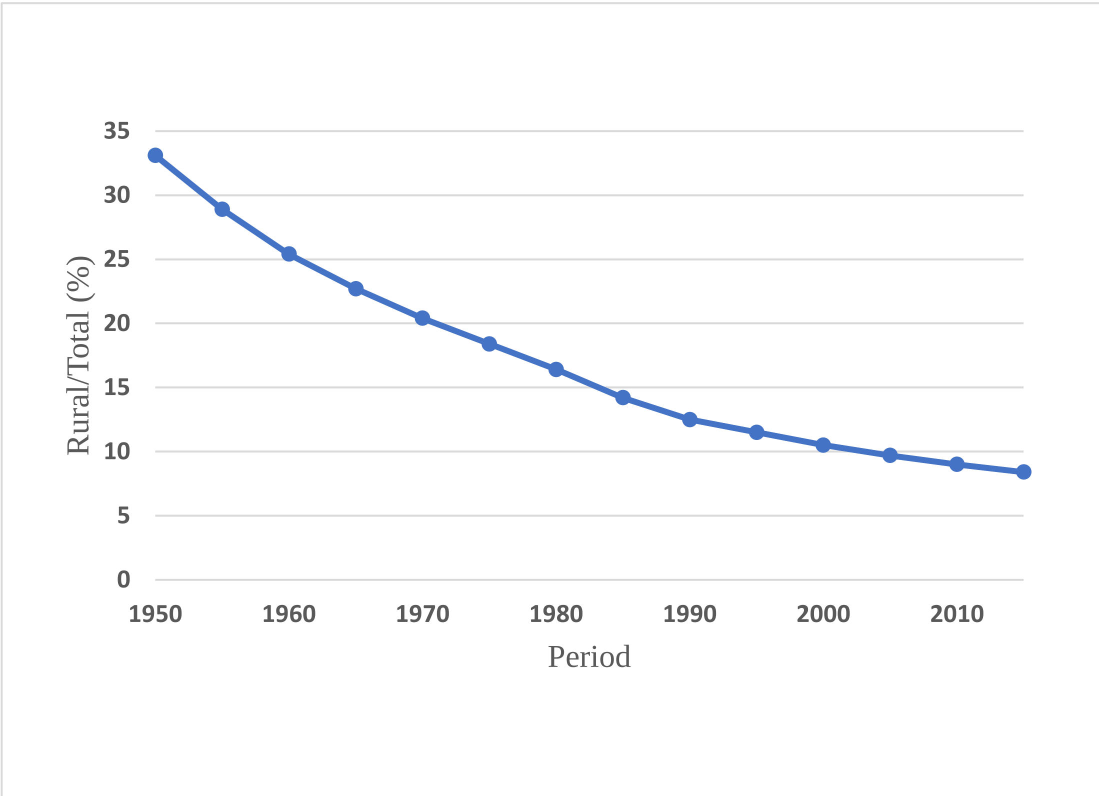
[3] Labor surveys are done in metropolitan areas, thus excluding rural residents.
[4] The FADA report estimates employment by using data on "sector-specific jobs" produced by a government agency.
[5] According to INDEC, "Urban" population refers to population residing in rural areas or towns of more than 2.000 inhabitants. "Rural" population is the difference between total and urban population.

Figure 1: Argentina -
Rural/Total Population



Source: FAOSTAT
Urban Population: residing in towns/cities > 2000 inhabitants
Rural Population: Total - Urban

The national employment figure for 2018 was 18.8 million. Assuming identical labor force participation in rural and urban areas, this would result in some 1.54 million workers residing in rural areas. Taking his figure as a starting point, estimation of workers engaged in primary production requires estimates on:

1. Workers in non-rural areas engaged in primary ag production
2. Decomposition of the 1.54 million workers residing in rural areas into:
    i. Primary ag production
    ii. Workers not engaged in primary ag production. This includes both ag- as well as non-ag related activities.

The above only suggests data needs involved in estimating labor input in the primary agricultural sector, but allows no progress to be made in obtaining relevant figures. However, it suggests possible shifts in occupational patterns through time. In particular:

1. Allocation of labor among: (i) ag-primary production, (ii) ag-related, but not primary production; and (iii) non-ag activities depends on several factors. If the elasticity of substitution between labor and capital substitution is higher in (i) than in (ii) or (iii), labor should migrate accordingly. But ease of substitution is not the only factor: increased local demand for non-agricultural as compared to agricultural (export + domestic) output plays an additional role.[6]

2. In relation to the last point, during the last decade municipal employment increased 40 percent (Susmel, 2020), resulting additional competition for labor with ag-related activities. This factor is particularly important in areas where labor-intensive activities take place, and can account for part of the reduction in labor allocated to agriculture.

Census data do not report labor hours used in agriculture but “permanent labor” (family + non-family). Estimation of labor use is further complicated by the fact than a considerable portion of crop area receives labor services in the form of custom work by contractors not classified as “farmers”. Thus, these services should be added to the existing on-farm labor services (see Appendix for calculations)

Table 1 shows an estimate of labor use changes between the 2002 and 2018 censuses. This estimate was derived by adding reported permanent farm labor to an estimate of person-years of labor provided by contractors. Labor is measured by headcount and not the more appropriate labor-hours metric. Available evidence thus points to a 42 % country-wide reduction in labor input, ranging from 30 % in the *pradera pampeana* to 55 % in the non-pampean area. These averages mask considerable disparities in fall in labor-use, from a minimum of 24 % in Buenos Aires to over 70 % in Tucumán.

[6] Of course, labor mobility is not restricted to “local” areas (rural and non-rural) but includes the possibility of substantial geographical re-location.

Table 1: Labor in Primary Agricultural Production

(Labor on farms + estimate of labor provided by contractors)

	2002	2018	% Change Labor
	('000)	('000)	
Total	801	470	-0.41
"Pradera Pampeana" Provinces:			
Buenos Aires	127	97	-0.24
Cordoba	69	52	-0.25
Entre Rios	45	27	-0.40
Santa Fe	66	43	-0.35
La Pampa	17	12	-0.29
Selected "Zona Extra-Pampeana" provinces:			
Chaco	38	17	-0.55
Salta	29	17	-0.41
Santiago del Estero	55	26	-0.53
Tucuman	26	7	-0.73
Total "Pradera Pampeana"	326	234	-0.28
Total Selected "Zona Extra-Pampeana" provinces:	149	69	-0.54
Rest	325	167	-0.49

Source: INDEC - Censo Nacional Agropecuario 2002 and 2018

II. EXPLAINING THE REDUCTION IN THE USE OF THE LABOR INPUT

Estimates presented above are crude: "permanent" labor as reported in the census hides the fact that the degree of utilization of this labor may have changed through time. As an example, if remaining laborers each supplied in 2018 more labor hours than that supplied per worker in 2002 the 41 % country wide reduction in reported labor (most of which is "permanent" labor) may over-estimate the actual reduction in *labor services*. [7] The point made here is that disequilibrium may result under-utilization of labor stocks. Adjustment then takes place reducing labor stocks, with a resulting increase in labor flows from existing stocks. "Measured" reduction in labor use may then over-estimate actual reduction. Despite these caveats, the evidence points out that a significant reduction in labor has taken place during the last decade and a half.

Three possible hypotheses may explain reductions in labor use observed during the last decade and a half in Argentine agriculture:

1. H1: Capital (in particular, farm machinery) has substituted for labor inputs.

2. H2: Technical change: widespread adoption of reduced tillage systems allowed for reductions in the labor input due to the considerably lower requirements per unit of cropland of reduced as compared to conventional tillage systems.

3. H3: Economies of size: reduction in labor requirement per unit of output as a consequence of increased farm size and a resulting increase in labor-use efficiency (increased specialization, reduced inefficiencies due to "lumpiness")

II.1 H1: Input Substitution

Labor-use changes are a function of changes in the relative price of labor and (in particular) labor-saving capital inputs. The extent to which capital can substitute for labor depends on the characteristics of the technology of production. Operations such as planting, spraying and harvesting of cereal and oilseed crops lend themselves to mechanization, while in others such as vegetable production labor inputs are not so easily replaced by machinery. A standard measure of the "ease" of substituting capital for labor inputs is the elasticity of substitution:

$$\sigma_{KL} = \%\Delta(K/L)/\%\Delta(w/r) =$$

$$100 * \{[(K/L)_1 - (K/L)_0]/[(w/r)_1 - (w/r)_0]\} * \{ [(w/r)_0 + (w/r)_1]/[(K/L)_0 + (K/L)_1] \}$$

where w and r denote, respectively, wage and the price of capital services. Subscripts denote two relative price situations.

Ideally, σ_{KL} should be estimated using econometric procedures. However, data availability precludes this approach to be used here. Attempt is then made to obtain a rough

[7] Allocation of time to off-farm work is an important issue to be addressed in future work. Preliminary analysis of this issue, however, suggest relatively modest changes in the proportion of producers reporting off-farm work. No information exists for off-farm work for family or hired labor.

approximation to σ_{KL} by comparing the *K/L* ratio in two time periods with the relative prices faced by producers in those periods. We use the 2002 and 2018 censuses to obtain *K/L* ratios for nine provinces of the main agricultural area of Argentina. The Appendix details calculations involved in deriving relevant indices.

The capital input used in each period can be obtained – at least as a first approximation - in a relatively straight forward manner. A more significant problem arises in the measurement of the labor: census data reports labor stocks and not labor flows allocated to production. Sub-utilization of labor stocks can therefore be expected to bias results: if sub-utilization has decreased over time "measured" changes in the use of labor will over-estimate "real" changes in labor flows.

Additional issues emerge as relates to the relevant *w/r* price ratio. Two issues are worth mentioning. First, data on agricultural wages are hard to come by. Published data is based on very rough estimates and not on formal surveys. Further, no dis-aggregation by geographical area is available, a significant source of bias given that agricultural labor markets are not perfectly integrated. Second, how do changing *w/r* relative prices enter into the producers decision-making process? This is particularly important in a country such as Argentina, where high and variable inflation results in significant ups and downs in real wages over time. Prices of capital inputs also experience changes due to changing import tariffs, credit availability and other factors. As a result, the producer can be expected to react in a parsimonious way to price signals received, in particular due to the significant time period necessary to recoup funds invested in items such as tractors, combines and other expensive pieces of machinery. Given the above, price ratios used here refer to averages of several years centered in the initial and in the final time period analyzed.

Table 2 shows *w/r* ratios resulting from three alternative methods of estimation (see Appendix for calculations). As shown, $\%\Delta(w/r)$ varies widely, ranging from a minimum of 20 percent to an 80 percent increase in the price of labor with respect to capital. This last figure appears unreasonably high, in particular given the poor performance of the Argentine economy in the period under consideration. The lower and upper bounds of $\%\Delta(w/r)$ used here for discussion purposes are respectively 20 and 60 percent although, again, 60 percent seems "far off" from what would be expected. As a compromise values in the order of 30 – 40 percent increase in the price of labor with respect to capital can be taken as a starting point.[8]

[8] Juan Luis Bour reports for the 1990-1993 period a reduction of 40 percent in the price of capital with respect to labor. This reduction was a result of elimination of import tariffs and reduction in country risk, both of which result in reduction in the price of capital inputs. Bour's results highlight the significant changes in relative prices that characterize the Argentine economy. The period analyzed here (2002-2018) is – from a macroeconomic perspective - diametrically opposite to the 1990-1998 "convertibilidad" period which includes, however even allowing for errors in our calculations, the ***w/r*** relative price seems to have increased in the 2002-2018 period.

Table 2: Changes in the *w/r* price ratio

Alternative w/r indexes	2002	2018	*%Δ(w/r)*
Index 1: w/Tractor Price	0.11	0.20	62
Index 2: w/Non Labor Machine Service Cost	40.40	94.76	80
Index 3: w/Non Labor Machine Service Cost	1.8	2.2	20

Index 1 and 2: data source "Margenes Agropecuarios" publication
Index 3: data source AACREA
Calculations in Appendix

Table 3 shows estimates of σ_{KL} for the country as a whole and for several provinces. The lower and upper bounds of *%Δ(w/r)* are used to derive the relevant figures. While interpreting these results, the very crude estimation procedure used should be kept in mind. Results can be summarized as follows. First, the country wide estimate of σ_{KL} ranges from 0.9 to 2.8. The lower value of 0.9 is "close" to the elasticity of substitution resulting from the Cobb-Douglas functional form widely used in agricultural economics research. Elasticity of substitution is higher in the non-pampean than in the pampean provinces (1.4 - 4.2 for the former, versus 0.7 - 2.0 for the latter). This result appears reasonable: labor "surplus" is probably higher in the non-pampean areas, resulting in increased opportunities for reduction of this input as additional capital becomes available. As partial evidence of the above, output per farm in 2002 of non-pampean areas was only ¼ of that observed in the pampean region, indicating both smaller farm size as well as lower productivity per unit of land. In 2018 the gap between these two regions had narrowed, still non-pampean output per farm was 1/3 of that observed in the pampean region. Lower output per farm suggests (although not conclusively) lower returns to labor and management.

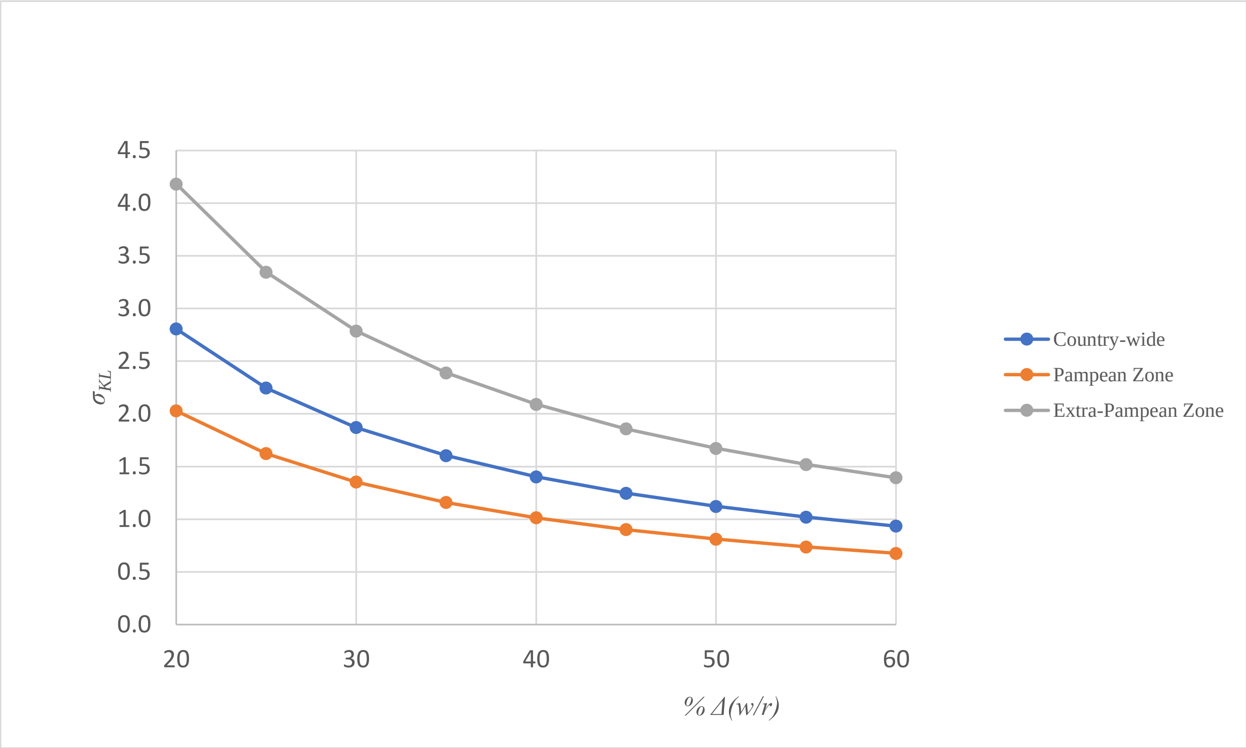
Table 3: Elasticity of Substitution

	K/L		*Δ K/L (%)*	σ_{KL}	
				Δ w/r (%)	
	2002	2018	2002-2018		
	(K/L index)		%	20	60
Total	41333	73579	56	2.8	0.9
"Pradera Pampeana" Provinces:					
Buenos Aires	69828	94815	30	1.5	0.5
Cordoba	81411	127054	44	2.2	0.7
Entre Rios	53274	98125	59	3.0	1.0
La Pampa	16769	30523	58	2.9	1.0
Santa Fe	323281	458488	35	1.7	0.6
Selected "Zona Extra-Pampeana" provinces:					
Chaco	35524	86059	83	4.2	1.4
Salta	17964	33648	61	3.0	1.0
Santiago del Estero	9830	34889	112	5.6	1.9
Tucuman	35412	104885	99	5.0	1.7
Total "Pradera Pampeana"	72486	109383	41	2.0	0.7
Total Selected "Zona Extra-Pampeana" provinces:	22515	54870	84	4.2	1.4

Source: INDEC - Censo Nacional Agropecuario 2002 and 2018

Figure 2 shows estimated values for σ_{KL} as a function of changes in the relative price ratio between labor and capital. The horizontal axis spans the lower (20 percent) and higher (60 percent) bounds of the increase in the price of labor with respect to capital. The formula used to calculate σ_{KL} is a hyperbola. As such, "errors" in estimating $\%\Delta(w/r)$ have a larger impact on estimated σ_{KL} at low as compared to high values of $\%\Delta(w/r)$. Using the average between the lower and higher bounds of *%Δ(w/r)* shown in the graph, estimated σ_{KL} ranges from 1.0 in the pampean to 2.0 in the non-pampean region, averaging 1.5 for the country as a whole. If somewhat smaller values for *Δ% (w/r)* are used for calculations (e.g. 30 percent) elasticity values range from 1.4 to 2.8, with 1.9 for the country-wide average.

Figure 2: σ_{KL} as a function of *% Δ(w/r)*



Source: Own calculations

Empirical estimates of capital-labor substitution (Wei, 2013) show values for the elasticity of substitution ranging from 1 to 7 for Brazil and from 2.0 to 3.5 for the U.S. These cases are of interest, as agriculture in both countries shares similarities with that found in Argentina. Substitution values reported in Table 3 appear therefore "reasonable", at least as compared with those reported in Wei's paper.

A further comment may be made on the calculations presented so far. Strictly speaking, the σ_{KL} construct refers to movements along a given isoquant – output is kept constant. We have sidestepped this issue here: output increased significantly between the two time periods analyzed. However, if output increases are "neutral" in the sense of not changing the marginal rate of substitution for all *K/L* ratios, estimated σ_{KL} will not be affected. Additional comments on possible "non-neutrality" of technical change are presented below.

Summarizing: the observed increase in the price of labor with respect to capital is a strong candidate towards the explanation of the reductions observed in the use of the labor input in Argentine agriculture. While this is valid for the country as a whole, it is particularly important for the non-pampean areas of the country.

II.2 H2: Labor-saving technical change

For the period analyzed here, the adoption of reduced and zero-tillage is a plausible candidate for the observed reductions in labor use: for cereals and oilseeds, this technology reduces the number of operations during the cropping season. Adoption of reduced and zero-tillage increased from less than 5 percent of planted acreage in the 1990's, to 55 percent in 2002 and 90 percent in 2018 (Nocelli Pac, 2018). Extensive use of this technology was possible by the introduction of herbicide resistant seeds, in particular in the soybean and corn crops.

The "net" effect of reduced tillage systems can be expressed as the sum of a "substitution" effect resulting from lower labor requirement per unit of area of reduced as compared to conventional tillage, plus an "expansion effect" that results from changes in crop area induced by the reduced tillage technology.

The substitution effect ΔL^S represents the impact of reduced tillage as of t = 2002. It is calculated as the difference between labor requirements that would result if only conventional tillage were employed, and labor requirements given the shares of conventional and reduced tillage existing in 2002. In turn, the expansion effect ΔL^E is the difference between the extra labor resulting from expansion in the crop area and the reduction in labor resulting from the reduction in livestock numbers that occurred as a result of re-allocation of land from livestock to crop production.

Table 4 shows total crop area, and area under conventional and reduced tillage systems in the two time periods considered here. Estimates are presented on labor-hours per unit of land for both systems. As shown, reduced tillage results in about half the number of hours per hectare (soil preparation, planting, weed and pest control, excluding harvesting).

As relates to the substitution effect ΔL^S, adoption of reduced tillage (55% of planted area in 2002) allowed a reduction in the labor (as compared to the conventional tillage scenario) of some 26.000 workers, or some 3.2 % of the *reported* (permanent workers + contract work) agricultural labor force for that year (801.000). In turn, the expansion effect ΔL^E results in an increase of 27.000 workers from additional crop area, minus 26.000 from reduction in animal stocks during the period. The net figure for $\Delta L^S + \Delta L^E$ is 25.000 less workers in 2018 as compared to 2002. This figure represents 3.1 percent of existing agricultural labor force in 2002, and 7.5 percent of the reduction (331.000 workers) in ag labor force occurring from 2002 to 2018.

In conclusion, observed reductions of labor use between 2002 and 2018 are only partially explained by the adoption of reduced tillage systems. Even allowing for errors in the technical coefficients used in calculations (many of them crude estimates), it is highly unlikely that reduced tillage systems per-se are responsible for the large falls in reported labor in the primary agricultural sector.

Table 4: Changes in labor use resulting from Reduced Tillage

		2002	2018
Planted area	million hectares	25.0	35.0
Share Conventional Tillage	%	0.45	0.10
Share Reduced Tillage	%	0.55	0.90
Area Conventional tillage	million hectares	11.3	3.5
Area Reduced Tillage	million hectares	13.8	31.5
Labor requirement Conventional Tillage	Hrs/ha	3.5	3.5
Labor Requirement Reduced Tillage	Hrs/ha	2.0	2.0
(A) Substitution Effect	Person-years		-26000
(B) Expansion Effect (1) (additional labor from additional crop area)	Person-years		27000
(C) Expansion effect (2) (reduced labor from reduced livestock)	Person-years		-26000
Net Effect = (A) + (B) + (C)	Person-years		-25000

<u>Sources:</u>
Planted Area Ministerio de Agricultura
Technical coefficients: own calculations based on trade publications

II.3 H3: Scale/size relationships

Increasing returns resulting from consolidation of resources from a larger to a smaller number of farms can account for increasing output from a given stock of resources. However, it cannot explain decreasing use of farm labor: the "scale" concept refers to equi-proportional changes in input (including labor) use. Economies of scale would result in a reduction in the number of farm units, but not in the outflow of resources (labor in particular) from the agricultural to other sector of the economy. This is particularly true if sector output is tradeable, and thus increased volume of production resulting from farm consolidation does not result in a fall in output prices. Analysis of the impact of farm size on labor use therefore requires attention be focused on input proportions and not pure "scale" effects.

In the 1988-2002 period farm numbers in Argentina fell by 1.7 percent per year (Table 5). Reduction in farm numbers increasing slightly to 1.8 percent between 2002 and 2018. Reduction in numbers was somewhat higher in "non-pampean" that in the "pampean" region. As a result of these changes, in the 2002-2018 period farm size (measured in area per farm) increased some 35 – 40 %. Increased farm size results from optimizing decisions, in particular reductions in costs with resulting improved perspectives for profit and further firm growth. While several factors may result in a negative relation between firm size and average costs, an important one to be considered are the savings associated with higher capacity machines.

Increased farm size facilitates (and in turn is the result of) changes in the types of capital used, and in particular, in the ratio between the capital and the labor input. Moreover, different types of capital may allow an increase in the *K/L* ratio without a corresponding increase in the amount of *K*. Instead *K/L* may increase due only (or mostly) to a reduction in *L*.

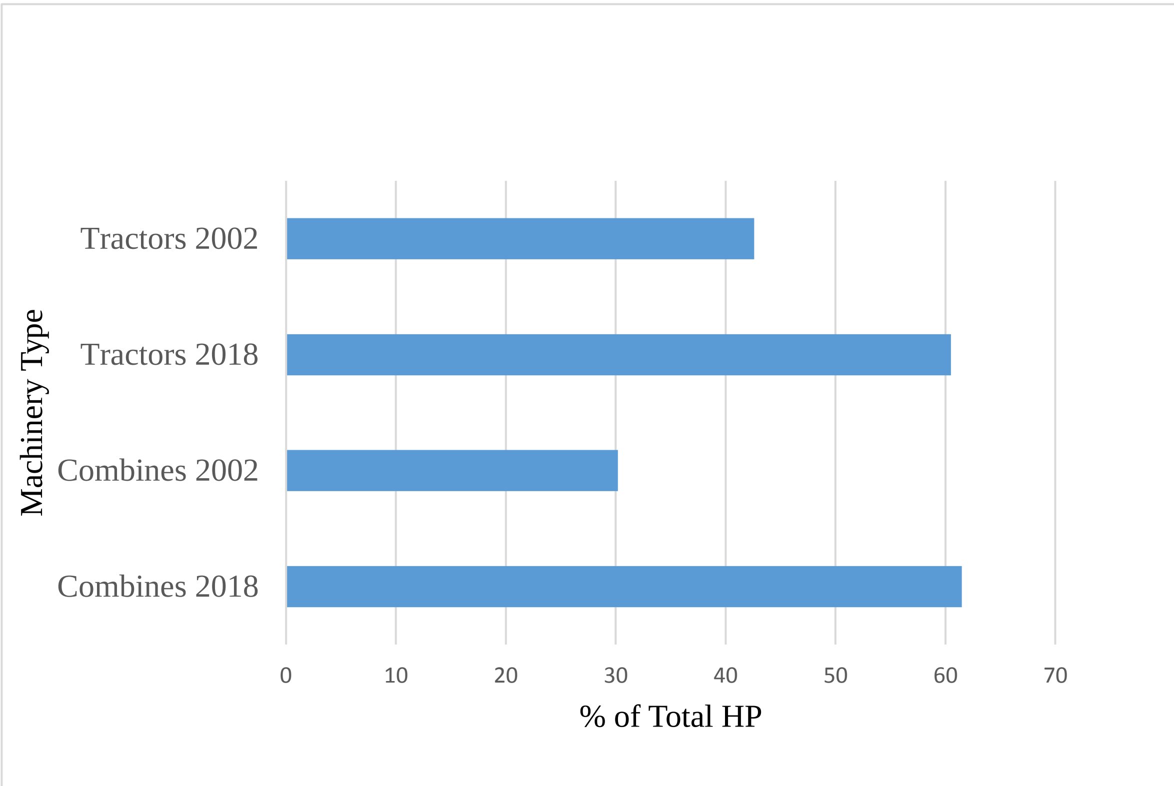
Let each unit of farm machinery K^A be twice as large and costing double as machinery K^B. If a farm substitutes one unit of K^A for two units of K^B, total capital remains unchanged. However, labor use under K^A will be half as that of $2K^B$ if K^A "requires" only one worker, the same labor requirement of each of 2 units of K^B it replaces. Formally:

$$Q^B = \min[L/2, K^B/2] = Q^A = \min[\mathrm{L}, K^A] \text{ where } K^A = 2K^B$$

The issue here is thus not capital/labor substitution, but differences in the organization of production. The trend towards larger machinery may be catalogued as "technical change" if machinery is not only larger, but incorporates features not found in smaller versions. A good example of this is reduced-tillage planters, sprayers as well as computerized monitoring systems that are only cost-effective in high-output agricultural machines such as tractors and combines.

Figure 3 shows (2002-2018 period) the percentage of total tractor and combine horsepower stocks accounted by the largest two categories of each of these types of machines (see Appendix for details). Results indicate that "large" tractors accounted for 43 percent of total HP in 2002, increasing to 60 percent in 2018. In the case of combines, "large" units accounted for 30 percent of the total in 2002 and 62 percent in 2018. Higher capacity machines thus allow reductions in labor costs without necessarily increasing the capital-labor ratio (a smaller number of "large" machines replaces a larger number of "larger" ones). In summary: in contrast with the inconclusive evidence resulting from hypothesis H2, H3 appears to reasonably explain observed reductions in labor use that have occurred in Argentine agriculture.

Figure 3: Changes in Machinery Size
(% of Total HPs accounted for by largest-sized machines)



Source: Own calculations based on CNA 2002 and 2018

III. CROP YIELDS AS A DETERMINANT OF MACHINERY SIZE

As suggested by the discussion presented above, not only the "amounts" of capital but the specific forms this capital takes affect cost-minimizing input combinations. The last decades have witnessed a virtual revolution as relates agricultural machinery. Improvements have not only occurred in basic design (e.g. reduced tillage planters allowing higher planting speed, improved precision, fertilizer placement) but also in the introduction of real-time monitoring of crop conditions, soil fertility and other aspects. These technologies are not scale neutral, but involve fixed costs both as relates to hardware, software (where applicable) as well as technological know-how on the part of the farmer.

The case of modern harvesters illustrates some of the issues involved. A steady trend towards higher output machines has been evident: in the early 1970's engines of harvesters produced by major manufacturers averaged some 140-150 HP. In the following decades, these increased averaging 400 HP in 2010 (Méndez, Velez and Scaramuzza, 2014). Larger combines allow increased throughput and reduced labor costs.

The question may be asked on what limits exist on machinery size. In relation to this, technical limits exist on both the "practical" width of cutting platforms and (in particular) the speed at which the machine can travel over ground. Higher speeds result in higher harvest losses, thus effective use of higher-capacity combines increases with higher as compared to lower crop yields as more grain is processed for a given speed over ground of the machinery.

Differences in yields are expected to vary according to both technical (*TE*) as well as allocative (*AE*) efficiency at the farm level. *TE* will increase yields as a result of higher output levels per unit of input. But an upward shift in the production function (increased *TE*) will generally increase input marginal productivity as these shifts result also in changes in the slope as well as in output for every input level. This will trigger higher input levels and thus and additional yields independent of those resulting only from increasing *TE*. The result is improved conditions for better quality and higher-capacity machines, larger farm size and reduced labor for a given amount of capital. The pattern that seems to emerge is thus one of higher crop yields allowing higher-capacity machinery (in particular combines) to work efficiently, and higher capacity machines allowing reduction in labor inputs.

The implications of the above are the following. First, labor-savings may be achieved by the use of "larger" capital inputs (tractors, combines, planters, forage equipment) as these allow a given capital stock to be combined with a reduced level of labor services. Second, cost-efficiency of larger machines increases with farm size: even if the farmer contracts machinery services instead of purchasing equipment, coordination costs are reduced – at least up to a point - when a given contractors supplies services to a smaller number of clients. Of course, if the farmer purchases instead of renting equipment, the case for a larger farm unit is even stronger.

Lastly, interactions exist between farm-level productivity and choice of machinery size: higher yields reduce average operating costs of higher output harvesters. Similarly – and given all else equal – more frequent or higher-volume fertilizer or pesticide applications, or the need for more timely production practices increase optimum machinery size, and thus indirectly, farm size as well. "Technical change" interpreted as increased volume from a given stock of resources is thus an additional factor pushing machinery size upwards and, as a spinoff of these changes, reducing the demand for labor services.

FINAL COMMENTS

Evidence presented here suggest a "best guess" for the elasticity of substitution between capital and labor inputs ranging from 1 for the pradera pampeana to 2 for the extra-pampean zone, and averaging about 1.5 for the country as a whole. These values are in line with those resulting from studies made, for example, in the Brazil and the U.S. Although substitution possibilities between capital and labor appear quite high, they probably do not account for all of the observed reduction in labor use that took place in the 2002-2018 period.

Labor-savings allowed by reduced tillage are a potential determinant of additional shifts in the demand for labor. In the case analyzed here, however, reduced tillage while saving on labor on a per-hectare basis, has its effect dampened due to increase in crop area that resulted from this technology: even abstracting from this issue, per-hectare labor savings alone cannot account for the large reduction in labor input observed in the Argentine agricultural sector. Other factors are operative.

Increased capacity of agricultural machinery seems to be the most important variable explaining falling demand for labor. In Argentina, total capital – at least as measured by a "horsepower index" appears to have experienced relatively modest increases – in particular as compared to decreases in the use of labor (the increase in the use of capital was where 4.5 percent country-wide, 7.6 percent in the "pradera pampeana", and 10.3 percent in the non-pampean provinces analyzed here). The important reduction (-20.9 percent) of the capital input in the provinces not analyzed here explains country-wide capital increase being lower than that for the pampean and non-pampean provinces included in the study.

Evidence is then not in favor of a substantial increase in "conventional" (i.e. horsepower index) of capital, but on the types of capital employed: the share that machines of larger capacity represent of total capital stock has increased significantly during the last decade and a half. As argued above, larger machines allow labor savings as – at least in some size ranges – as labor input per machine does not change proportionally with the output capacity of the machine.

It should be emphasized that larger machines (in particular newer ones) incorporate features not present in the same degree in ones of smaller size. "Technical change" in capital inputs is therefore an additional factor that adds to the "conventional" labor saving resulting from machine size per se.

This paper argues that linkages exist between production per unit of land and optimal machinery size: higher yields increase the cost efficiency of higher output machines (in particular, harvesters, but probably also planters and other pieces of equipment). A causal chain then exists linking better management with higher yields, and thus larger machine size. Larger machines, in turn act as a catalyst for increase in farm size.

APPENDIX: DATA AND CALCULATIONS

Labor Input

Data source is the *Censo Nacional Agropecuario* (CNA) 2002 and 2018. Census data does not report labor flows (e.g days worked by family and hired laborers per year), but stocks of "permanent" labor. This measure is an imperfect estimate of actual labor supplied due to: (a) varying degree of labor utilization, (b) not including seasonal labor (of particular importance in labor-intensive activities such as fruits and vegetables) and (c) not including labor supplied by custom contractors. The approach used adds to permanent labor figures an estimate of labor supplied by contractors:

(1) $L^T = L^{CNA} + L^{Co}$

Where:

L^T = Total labor input (persons/year)
L^{CNA} = Labor input (persons/year) reported in CNA
L^{Co} = Estimate of labor from contracted services reported in CNA

And:

(2) $L^{Co} = [A^{Co} \text{ x } t_2]/t1$

Where:

A^{Co} = total land area (hectares) receiving contract work
t_1 = estimate of effective (e.g. "net on the machine") hours of labor per worker
t_2 = estimate of per-hectare labor hours of labor used in contract work (per-hectare average of different implements)

Coefficients used were $t1$ = 1320 hrs, $t2$ = 0.96 hrs/ha,. S^H was obtained from the CNA. Identical procedure was used for the 2002 and 2018 censuses.

Capital Input

The capital input was derived by a (weighted) sum of tractor plus combine (harvester) horse-power. The following correction was used for age (vintage) of tractors and combines: $0.80^{(t-1)}$ where:

Machine age (years)	t	Correction factor
<5	1	1.00

5 – 9	2	0.80
10 – 14	3	0.64
>15 and +	4	0.51

The above hyperbolic decay function was used in order to capture advances in "quality" (sensors, GPS, automatization). After adjustment for vintage, total capital was then calculated as the weighted sum of tractor and combine horsepower:

K = Adjusted Tractor Horsepower x (1/0.5) + Adjusted Combine Horsepower x (1/0.30).

The weights attempt to approximate the "expansion" of machinery horsepower to total capital associated with each machinery: i.e. total cost of a combine + ancillary equipment used for harvest is 4 times the cost of the combine's engine.

<u>Relative Labor/Capital Price Ratio (w/r)</u>

Two alternative data sources were used to obtain estimates. Index 1 and Index 2 as discussed in the text were obtained from the Margenes Agropecuarios publication. Index 3 was obtained from the Agroseries Online data bank of the Asociación Argentina de Grupos CREA (AACREA).

Index 1: Ratio [per-hectare labor costs/ price of a tractor (120 hp)]
Index 2: Ratio [per-hectare labor costs/ non-labor per-hectare machinery operating costs]
Index 3: Ratio [monthly labor wage and non-labor/per-hectare machinery operating costs]

<u>Impact of reduced tillage on labor use</u>

Substitution Effect:

(3) $\Delta L^S = \{A_{t0}[L^C - (S_{t0}^C L^C + S_{t0}^{RT} LR^T)]\}/t1$

Expansion Effect:

(4) $\Delta L^E = \{[A_{t1} - A_{t0}][(S_{t1}^C L^C + S_{t1}^{RT} LR^T)] - [LU_{t1} - LU_{t0}] L^L / t1$

Total Effect:

(5) $\Delta L^T = \Delta L^S + \Delta L^E$

Where:

ΔL^T = change in labor use resulting from reduced tillage
$A_{t = t0}$ = Crop area at t = t0
$A_{t = t1}$ = Crop area at t = t1
L^C = labor per unit of land conventional tillage
L^{RT} = labor per unit of land reduced tillage

LU = livestock units
L^L = labor per LU
$t1$ = effective hours per year = 1320 hrs

Crop area in 2002 and 2018 were obtained from Ministerio de Agroindustria. L^C, L^{RT} and L^L from trade publications and personal communication by farm advisors:

L^C (hrs/ha) = 3.5
L^{RT} (hrs/ha) = 2.0
L^L (hrs/ha) = 1/250 = 0.004

Labor-hours were transformed to "person-years" assuming 1760 potential working hours per year per person, of which 75 % are transformed into actual labor input flows: 1760 x 0.75 = 1320 hrs/year per person. The assumption of 75 % "efficiency" of labor use was based on lost days due to weather, travel, overhead and other factors.

Estimation of reduced labor due to reduction in livestock numbers (L^L) was done by dividing reduction in animal stocks ("Livestock Units", LU) by an estimate of LU per unit of labor input (250 person-years per LU).

Data for LU was taken from the CNA:

Animal stocks (millions):

	Beef	Sheep	Pigs	Total LU
2002	48.5	12.6	2.18	40.7
2018	40.4	8.8	3.10	34.3
Change	- 8.1	- 4.0	1.4	6.4

Source: CNA 2002 and 2018

Total LU equivalents was calculated as 0.80 x Beef + 0.10 Sheep + 0.30 x Pigs [9]. Change in labor use was calculated dividing the change in LU by 250, an estimate of LU/person-year.

[9] See https://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Livestock_unit_(LSU)

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