Dialogues on Nature, Class and Gender: Revisiting socio-ecological reproduction in Past Organic Advanced Agriculture (Sentmenat, Catalonia, 1850)

I. Marco[a], R. Padró[a], E. Tello[b]

[a] *Barcelona Institute of Regional and Metropolitan Studies, Autonomous University of Barcelona, Plaça del Coneixement, edifici MRA, planta 2, 08193, Bellaterra, Spain*

[b] *Department of Economic History and Institutions, University of Barcelona, Faculty of Economics and Business, Av. Diagonal 690, 08034, Barcelona, Spain*

* Corresponding author. Phone: 34-676505388. E-mail: ines.marco@ub.edu

Abstract:

The concept of socio-ecological reproduction allows linking some fundamental approaches and methods of Ecological, Feminist and Sraffian Economics. By accounting reproductive flows we highlight the material and time efforts required to maintain ecological funds (i.e. soil fertility and livestock) and social funds (i.e. labour force) of farm systems, as well as the role of social appropriation of the surplus that went beyond them in preindustrial class structures. Through the methodology proposed to estimate time, energy, nutrients and cash balances at household level we can infer relevant insights in terms of social organisation of labour and social distribution of produce in past organic advanced agricultures. Results show that the productive capacity of farmland and labour were quite similar across farms, while the farmland hoarding exerted by a wealthier ruling class defined the unequal distribution of produce. The match between subsistence needs and wages shows that nearly the whole potential surplus per labour unit was extracted. Dependence on reproducible funds implied the reinvestment of large amounts of renewable flows that constrained the amount of surplus appropriable. Finally, we deem that technical change and increase of total produce along socio-ecological transitions might have been affected by the social class structure of preindustrial societies

Keywords: Social Metabolism, Inequality, Surplus appropriation, Female labour, Socio-ecological transition

1. Introduction

1.1 Socio-Ecological reproduction as an integration of perspectives

> 'A society can no more cease to produce than it can cease to consume. When viewed, therefore, as a connected whole, and as flowing on with incessant renewal, every social process of production is, at the same time, a process of reproduction'
>
> Karl Marx (1867, *Capital*, Vol I., Part VII, Chapter 23, on Simple Reproduction).

When we analyse economic processes from the point of view of an integrated system, it is difficult to distinguish those processes that can be considered 'productive' from those that can be considered 'reproductive'. The standard definition of *production* is the transformation of inputs into outputs (goods and services) (O'Hara, 1997), while *reproduction* is defined as a dynamic process of change linked to the perpetuation of social systems (Benería, 1979). Starting from the statement that the ultimate requirement of the social reproduction process is to meet the material and social needs of human communities (Polanyi, [1997]209), we could base the distinction between producing and reproducing on the question of '*what structures have to be reproduced in order that social reproduction as a whole can take place*' (Edholm et al., 1977:105). We seek to answer this question for the case of advanced organic agricultures.

Ecological economics highlights the link between basic human consumption and the permanent access to available energy and materials, thus revealing the very process of society-nature interaction (Georgescu-Roegen, 1971; Fischer-Kowalski, 1997, Martinez-Alier, 2009). This means that '*the real material bottom line of any social metabolism is its ecological integrity—a recursive web of self-regulating matter/energy flows signified by metabolic value*' (Salleh, 2010:212). From the Social Metabolism approach, and its fund-flow perspective (Georgescu-Roegen, 1971), it is stressed that the reproduction of the capacities of *ecological funds* is the basic condition on which the processes of social reproduction can occur.[1] We consider funds as the *agents of production* (O'Hara, 1997:145), the structures with capacity to transform the inputs flows into output flows (Giampietro et al., 2012). From this, and in order to analyse agricultural systems from a Social Metabolism approach, ecological funds were broaden including associated biodiversity, soil fertility, and livestock (Tello et al., 2015, 2016; Galán et al., 2016). But, what did reproducing the capacities of ecological funds imply for advanced organic agricultures?

Preindustrial agricultural societies were mainly based on renewable material and energy sources, within an agrarian socio-metabolic regime which relied on the energy conversion provided by plant biomass (Sieferle, 1997; Fischer Kowalski and Haberl, 2007; Krausmann et al., 2008; González de Molina and Toledo, 2014). According to Krausmann et al. (2008) in many cases biomass accounted for 95% of the primary energy supply. These energy sources were mainly converted through human labour, animal work and burning firewood (Gales et al., 2007; Kander et al., 2013). In these past organic agricultural societies, the main sustainability challenge regarding the ecological funds was linked to soil fertility maintenance (González de Molina, 2010; Corbacho, 2017). The maximum amount of output flow per unit of land was limited by ecological constraints, and its intensification and maintenance were directly linked to the maintenance of soil fertility through significant reuses of biomass within the prevailing farm systems.

Nevertheless, social reproduction was not only dependent on the energy and material flows that came from the agroecosystems. It also depended on the physical, emotional and spiritual support necessary to reproduce the society. This is what has been grouped under the name of 'domestic and care work', which includes '*the care of the maintenance of the spaces and domestic goods, as well as the care of the bodies, the education, the formation, the maintenance of social relations and the psychological support to the members of the family*' (Picchio, 2001:2). Historically, women have principally performed this work (Mellor, 1992; Sanday, 1981). As Feminist Economics revealed, domestic and care work were defined as *activities* or *tasks*, and such activities have been perceived as

[1] Although we acknowledge that we need to recognize ourselves as a particular form of nature, thus of ecology, we think it useful to distinguish between ecological and social funds in order to better understand their links, conflicts and integrated functioning.

simply falling outside the conventional definition of work (Beneria, 1999).

The omission of domestic and care work from the economic framework contrasts with its relevance within the social reproduction processes (Brenner and Laslett, 1991; Picchio, 1992; Bhattacharya, 2017). As we consider labour capacity as a fund, '*these* [domestic and care] *services are particularly important to maintaining flows and services provided directly by labour inputs or indirectly by those labour services maintaining capital funds and land*' (O'Hara, 1997:147). Domestic and care work allows the reproduction of labour force in at least two different ways, between which we will differentiate intergenerational reproduction (through childbearing and childcare) and daily maintenance of current active workers (Carrasco and Rodríguez, 2000; Picchio, 2003). The key role of domestic and care labour led feminist economists to highlight the material basis of women's oppression and its deep links with the political economy (Delphy, 1984).

Finally, ecological sustainability and Domestic and Family Work (DFW) are not enough for social reproduction to happen.[2] As mentioned, human beings reproduction directly depends on the available materials and energy, that is to say through the 'production process'. Due to the indivisibility of human beings reproduction and labour force reproduction, each social reproduction process is at the same time a labour force reproduction process. This last link will be closing the (re)productive economic system, a system that can be better understood 'as an endless spiral' within a circular conception of the economy, where reproduction can be understood as '*the more or less similar repetition of a series of productive and distributive processes that allow the cycle to be restarted again and again*' (Barceló, 1981:37). Observing the three processes of (re)production –ecological funds, domestic care, and nutritional and basic human needs of the labour force— allows us to describe the process in an integrated way, including both the reproduction of the funds usually defined as 'ecological' as well as the 'social' funds, in what we will call a process of socio-ecological reproduction (Hollingsworth, 2000).

Definitely, the distinction between production and reproduction does no give us a very useful information, given that any 'productive' process is only a way to consider a fraction of a wider

[2] In accordance with the abbreviations and definitions used in Marco et al., (*forthcoming*), we will define these works as Domestic and Family Work (DFW). We decided to maintain the original concept used by the historical source from which we estimate the flows of DFW (Le Play, 1877).

'reproductive' cycle. As an example, what has been historically identified as 'productive' (the farming labour sphere), could also be considered 'reproductive' as well at least in two ways. First, because of its role as a necessary step for labour force reproduction. And second, because although we can say that agricultural labour is 'productive' given that the end result is the generation of biomass for human and animal consumption, it is also true that some of the tasks performed by agricultural labour have a clear 'reproductive' sense (i.e. fertilising practices and livestock feeding). Therefore, there is a thin line in the definition of both. As a matter of fact, Marx's quote in the beginning of this section expressed this idea in a very clear manner.

1.2 Surplus and inequality: A Socio-metabolic and Sraffian approach

The approach described above shares several common roots with the Sraffian perspective, which highlights how the productive forces of a given year must guarantee the productive process of the following year. From a fund-flow analysis of preindustrial agricultures, this means that the output flows (Total Produce; TP) provided by the main agroecosystem's funds should be able to reproduce these funds. Within advanced organic agricultures, each fund reproduction process could be associated with two reproductive flows, one of them being of matter-energy character and the other one being a labour-time flow. With regard to matter-energy flows, soil fertility maintenance was associated with fertiliser biomass (Farmland Biomass Reused; FBR) and Livestock reproduction required feeding and stall bedding (Livestock Biomass Reused; LBR).[3] Both flows were driven by Agricultural Labour (L_A). The reproduction of the Farming Community was associated with the generation of enough biomass for reproduction (Final Produce for agricultural population; FPa), and required both Agricultural Labour (L_A) and Domestic and Family Work (DFW). For these advanced organic agricultures, manufactured capital played a minor role. In this case, we associate the reproduction of manufactured capital with the

[3] As has been explained in detail in previous works (Tello et al., 2015, 2016; Galán et al., 2016, Marco et al., 2017), we cannot specifically define the reproduction processes of Associated Biodiversity. Despite this, we know that above-ground biodiversity would be related with Unharvested Biomass (UhB) and habitat heterogeneity, while below-ground biodiversity would be related with fertilizing practices and soil quality management. For the purposes of this work, we decide to exclude this fund reproduction from the analysis. As well, regarding soil fertility, also Livestock Services (LS) are fundamental for closing the nutrient cycles. In this case, they are excluded in order to avoid double counting them through Livestock Biomass Reused and then through LS.

Final Produce (FP) allocated to feed and fuel non-agricultural population working on clothes, footwear, tools and infrastructure reproduction (FPt).

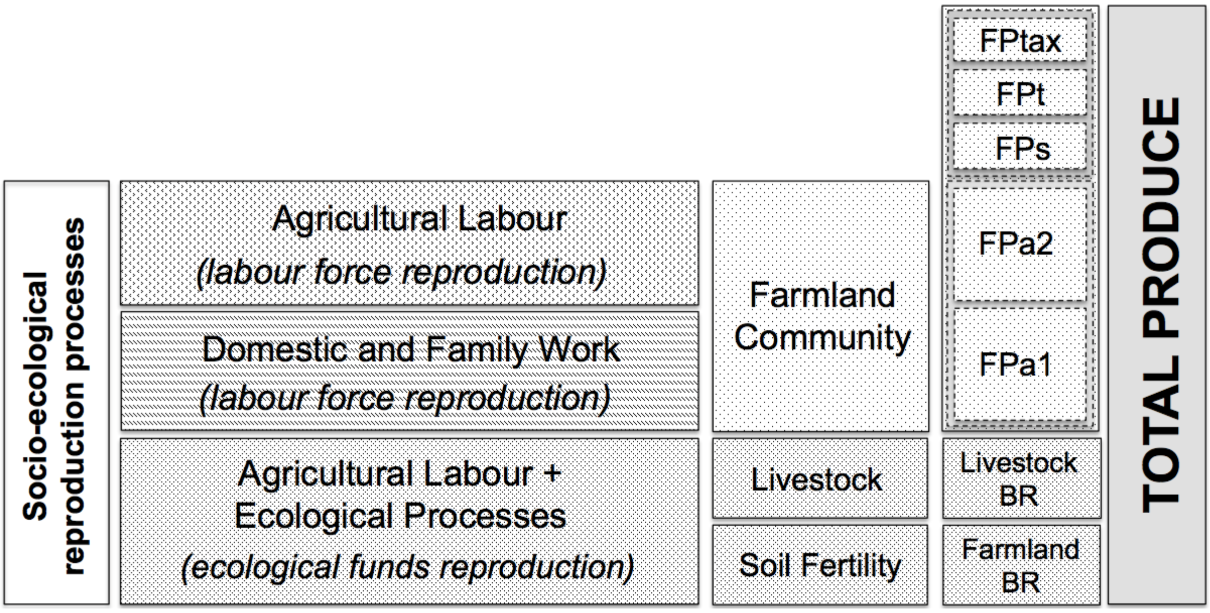
The difference between the total productive capacity (Total Produce; TP) and the total reproductive flows (FBR + LBR + FPa + FPt)[4] is the surplus, which we understand as *‘[t]he set of products that remain after the deduction from the total output of the means of production necessary to continue the cycle at the same level and the consumable goods essential to restore the workers so that they can supply the same amount of workforce’* (Barceló, 1981:78-79). Surplus can be expressed as a part of Final Produce (FPs). The emergence of surplus entails some social rules to define which social groups would appropriate it, and how, thereby potentially leading to the emergence of social hierarchies. Although part of this surplus would be used for sustaining the non-agricultural population of the society which was not related to the agricultural system, there could also be other social groups with the capacity to appropriate and accumulate this surplus. Therefore, for analytic purposes we make a simple division of Farming Community in two sections: those that had no systemic capability of appropriating surplus (smallholders; 1) and those with capacity to appropriate surplus (landowners; 2). In particular, this means splitting labour flows (L_1 and L_2), the associated consumptions (FPa1 and FPa2) and the corresponding domestic and family work (DFW_1 and DFW_2). Our last remark is linked to that part of the Final Produce that went to pay taxes (FPtax), which had a double function. Although it could be defined as a reproductive flow, because it was necessary to reproduce some physical and non-material infrastructures, it could also become part of a non-agricultural process of surplus accumulation by an elite. For this work, we decided to explicit mention FPtax (Figures 1 and 2), but we set aside a deeper analysis of it. In sum, we can describe the breakdown as follows:

$$\mathrm{TP} = \mathrm{FBR} + \mathrm{LBR} + \mathrm{FPa1} + \mathrm{FPa2} + \mathrm{FPs} + \mathrm{FPt} + \mathrm{FPtax}$$

Figure 1 provides us with a clear scheme of the listed basic components of socio-ecological reproduction processes in advanced organic agricultures. This figure also helps illustrate our main conclusions about the production-reproduction distinction.

[4] As Labour could be considered the same as FPa, all labour would be excluded from the equation.

Figure 1. Basic scheme of socio-ecological reproduction components



Source: Own elaboration.

Sraffa (1960) pointed out that there exists a maximum feasible profit rate (R), determined by ecological, technical and social aspects of the socio-ecologic system, especially by (*i*) the 'development of the productive forces' (i.e. Total Produce) and (*ii*) the different reproduction flows required to maintain the 'productive agents' working (i.e. FBR, LBR, FP). As it has been shown earlier, in preindustrial agricultures there were two main reproductive flows that limited the possibility of appropriating the 'natural' produce or Total Produce: (*i*) the metabolic rate that must be respected to maintain and reproduce the 'ecological' funds (BR), and (*ii*) the physiological subsistence level of the (whole) labouring force (FP). From here onwards we assume that the actual profit rate will depend on the result of the conflict between land, capital and labour, or the conflict over the distribution of produce. Therefore, an increase of productive capacity of the economy (TP), mainly through technical change, could give chances to lower the social-class conflict (Barceló, 1994). In order to assess the surplus distribution and its effects on social inequalities, we followed Milanovic's analytical tools, which can be linked to the basic Sraffian approach:[5] (*i*) the *maximum feasible inequality*, which corresponds to the situation where only one individual appropriates the entire attainable surplus and the rest live at the physiological subsistence level, and (*ii*) the *Inequality Extraction Ratio (*IER*)*, which measures how

[5] Although Milanovic did not explicitly refer to Sraffa.

close the actual inequality is to the maximum feasible inequality (Milanovic, 2006; Milanovic et al., 2011).

From this basic framework, we propose a new approach that, for the first time, combines a Fund-Flow Socio-Metabolic accounting of farm systems with a reproductive Sraffian standpoint. This, in turn, is linked to the household analysis developed in Feminist Economics and the Inequality Extraction Ration (IER) put forward by Milanovic et al. (2011). Our methodology (Socio-Ecological Reproductive Analysis; SERA), detailed in Marco et al., (*forthcoming*), seeks to quantify the socio-ecological reproduction processes in order to understand its structure and dynamics. We will apply this novel approach to a small farming community in Sentmenat (Catalonia) in the mid-nineteenth century as a test bench. Here we will describe the main results for the whole municipality including 244 households (HH). We start by focusing on some methodological issues and the characteristics of the municipal funds (see Section 2 and 3). We then summarize the results, including the main features of the social organisation of labour (Section 4.1), the social distribution of produce (Section 4.2), the Inequality Extraction Ratio (see Section 4.3) and the subsistence wages (see Section 4.4). Discussion and Conclusions seek to enter into a dialogue with diverse ecological-economic debates and to discuss the main relevant aspects of the results obtained.

2. Methods: Socio-Ecological Reproductive Analysis (SERA)

As a first step, Socio-Ecological Reproductive Analysis (SERA) reconstructs the socio-ecological funds of every agricultural household through historical sources. Household size and sex-age composition, available in municipal censuses, allow to estimate total available labour, food and fuel needs, and required Domestic and family work (DFW). Diets, adapted to sex and age, were estimated from diverse historical local and regional sources, as well as from secondary sources (Marco et al. forthcoming). DFW estimates are based upon the data collected by Wall (1994), on the basis of the European studies of Le Play (1877-79). In addition, Le Play data was contrasted with contemporary sources (Pastore et al. 1999; Gomiero and Giampietro 2001; Grünbühel and Schandl 2005; Fischer Kowalski et al. 2010). Cadastral records offer data on farmland size and livestock population and composition. These estimations allow to estimate, on the one hand, the required farmland and livestock labour, and, on the other hand, farmland and livestock produce (Total Produce), manure availability and ~~available~~ draught power availability.

SERA benefits from the biophysical analysis of agricultural systems developed by Social Metabolism approaches to farm systems (González de Molina and Toledo, 2014; Tello et al., 2015). These works contribute with a large proposal of coefficients and qualitative data that allow to estimate several information that was not recorded in ~~the~~ historical sources (e.g. by-products yields, and biomass recirculation~~) (~~; Guzmán et al., 2014). Farmland Biomass Reused (FBR), mainly for fertilising purposes, are estimated through nutrient balances (NPK), and Livestock Biomass Reused (LBR) through livestock feeding balances and stall bedding requirements. Remaining biomass (Final Produce; FP) is split into one part directed to self-consumption (estimated trough food and fuel requirements) and another to markets. Maintaining the qualitative information on the produce allows to check consumption requirements with produce availability, thus defining food and fuel self-consumption flows.

Commodities and labour markets introduced cash flows, but also tax payment and other farming or social expenses (e.g. tools maintenance, clothes, housing rents). Agricultural surplus generated income, while those products required after self-consumption were bought. Labour markets appeared in two cases. First, when labour availability was not enough to meet farming labour requirements. Second, when the combination of self-consumption flows and biomass flows obtained through commodity markets were not enough to meet consumption needs. The process might generate several different final situations, depending on the ability to get cash surplus, the integration on labour markets (as a demander or supplier) and the integration on commodity markets (increasingly dependent on cash flows), among others. Furthermore, the impossibility to match these balances would imply the temporary break of the reproduction processes described here. This would affect ecological funds (i.e. fertility losses, livestock starvation) or social funds (i.e. human starvation). At the same time, funds overexploitation would affect their productive potential.

Even if there were some social coefficients that might have broader ranges to move in, such as labour requirements per hectare, they also worked within biophysical constraints. Being a multivariable model, which includes energy, nutrients, time and cash flows, helps to combine historically recorded data with estimated data to compound a reliable set. As a result, this set of coefficients work as a ‘biophysical skeleton’ that allows to compound a good match between the recorded data and reasonable assumptions, while leaving enough flexibility to introduce cultural variability (Marco et al., 2017). In historical terms, this reproductive methodology, especially the link among the different balances, helps to control the estimated ~~several~~ flows that were not available in historical sources. Relying on this ‘biophysical skeleton’ we are able to estimate, on the one hand, the need to hire or sell labour~~,~~ in the cases of labour deficit or cash deficit respectively. On the other hand, we estimate the societal capacity to generate a surplus.

2.1 Productivity indicators

Our multi-balance approach uses different energy productivity indicators, depending on the output and the inputs analysed. All the productivities are measured in energy terms (GJ_{ECB}). First we analyse the productivities with respect to the Final Produce in Equivalent Consumption Baskets (FP_{ECB}), and we relate it with the major two inputs, land (hectares of farmland) and labour (agricultural working days). Thus, we obtain the *Final Productivity of Land* (FPLan) and the *Final Productivity of Labour* (FPLab). Then we add the *Social Productivity of Labour* (SPLab). The output measured in FPLab is the biophysical basis for the subsequent social appropriation of the produce, once the final distribution of consumable products after the exchanges made through labour and commodity markets has been accomplished. Social appropriation of produce includes the minimum consumption of each HH (food, fuel and housing) for all of them [FPa1 for smallholders and FPa2 for landowners], and surplus for landowners [FPs]. The input is the quantity of working days of the family members of the HH. Note that, from this perspective, FPLab shows the primary distribution of produce independently of the funds’ ownership, while SPLab accounts for the social distribution once the retribution of each of the funds or *agents* get their socially-determined part.

2.3 Inequality Extraction Ratio (IER)

For the analysis of the *maximum feasible inequality* and the *Inequality Extraction Ratio (IER)* we first calculate the Gini coefficient for inequality in the *social appropriation of the produce.* This was FPa1 in the case of smallholders and FPa2+FPs in the case of landowners. Second, we calculate the Gini coefficient for the maximum feasible inequality, where all the population would live at the subsistence level, except one household (Milanovic, 2006; Milanovic et al., 2007, 2011). For our case study this means maintaining the basic distribution of produce (food, fuel and rental housing), while only one HH appropriated the whole surplus. Comparing both coefficients we obtain the IER:

$$Inequality\ Extraction\ Ratio\ (IER) = \frac{Acual\ inequality\ (Gini\ coefficient)}{Maximum\ feasible\ inequality\ (Gini\ coefficient)} * 100$$

Still, differences with Milanovic's methodology are based on two issues; (*i*) the way of estimating the minimum subsistence level, and (*ii*) the scale of the analysis. Milanovic estimates the minimum subsistence level at $PPP 300 in 1990 Geary-Khamis dollars. This means adopting a general baseline supposedly valid for any time and place. Instead, our approach uses a bottom-up analysis to assess this subsistence baseline in biophysical and site-specific terms, where the household structure (size, age and gender), diet patterns and fuel consumption are taken into account (Marco et al., *forthcoming*). Concerning the scale, the case studies compared by Milanovic et al., (2011) refer to national level, including all economic sectors. Our analysis is scaled at municipal level, and is restricted to the agricultural sector.

3. Case study: Labour, Farmland and Livestock

3.1 Basic soil and climate features

The Vallès County is situated between the littoral and pre-littoral mountain ranges of Catalonia (northeast Spain). Sentmenat is located 25 km North of the city of Barcelona. Olarieta et al. (2008) describe in detail the edafoclimatic features of Sentmenat and the four municipalities surrounding it. We could define two different climate and soil zones within the County. First, a plain area on its southern half with altitudes ranging from 130 to 250 m, a mean annual rainfall of 600–650 mm and a mean annual evapotranspiration (Thornthwaite) of 770–800 mm that meant water shortage. Second, a more mountainous area on the northern half, with altitudes between 250 and 815 m, a mean annual rainfall of 800 mm and a mean annual evapotranspiration of 700 mm, which allowed for a small runoff that fed small creeks used for irrigating the plain.

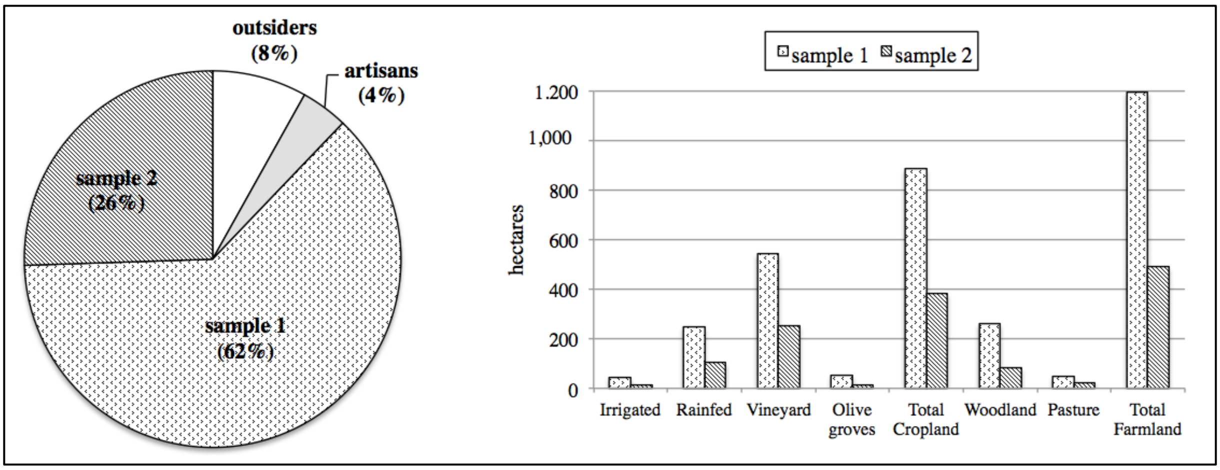
3.2 Land uses: Total and sampled farmland

The land tax register called *Amillaramiento* (1850) registered 1,917 hectares, of which 77% were cultivated. The vineyard represented 65% of this cropland. Our sample includes a smaller part of the farmland area and of the agricultural population (Sample 1). We were able to build 194 complete biophysical, labour-time and cash balances for which we have information about the characteristics of the HH and of the farms. To these, we added 52 HHs with no access to land. Thus, our sample accounts for 65% of the total area registered, 64% of the cultivated land, and 89% of the agricultural population registered in the population census. Although Sample 1 is smaller than the total farmland in the municipality, the land use pattern of Sample 1 was similar compared with the whole land use pattern in the *Amillaramiento*.

Within those who were excluded from Sample 1, we can differentiate various groups, the non-agricultural population who owned some plots (4% of the total area), and the non-resident landowners whose HHs were not included in the local population census. Among the latter, we can distinguish two types of outsider landowners; (*i*) small vineyard tenants from nearby villages (100 plots) which represent 8% of the total area (labelled as outsiders in Figure 2), and (*ii*) those of which there is no record of their origin and whose ownership was much more diverse. This second group, outsider landowners that were not identified as living in the nearby municipalities, conformed Sample 2.

We are interested in Sample 2 because, as explained later in Section 4.1, results suggest an imbalance between labour supply and labour demand of Sample 1. Thus, we assumed that part of the outsider landowners included in Sample 2 needed to hire local labour force, which enlarges labour demand. However, it should be specified that Sample 2 will only be used in Section 4.1, while the results and conclusions will focus on Sample 1.

Figure 2. Sample subdivisions and landuse patterns (Sentmenat, c. 1850)



Source: Own elaboration based on the *Amillaramiento* and population censuses.

3.3 The different nature of funds

'Human time is a limited resource but –in the short run— evenly distributed among the members of a social system: everybody has 24 hours at his/her disposal'

Singh et al., (2010:5)

We can establish the following characteristics of an average farm: 7.8 hectares of farmland, and 0.8 Livestock Units 500 (LU500), which entails 83 draught power working days and 1,483 kg of manure per year.[6] In Sample 1, 84% of the HHs were below the above farmland access, 70% were below the average threshold of livestock ownership (LU500), and 62% had no access to draught power of their own.

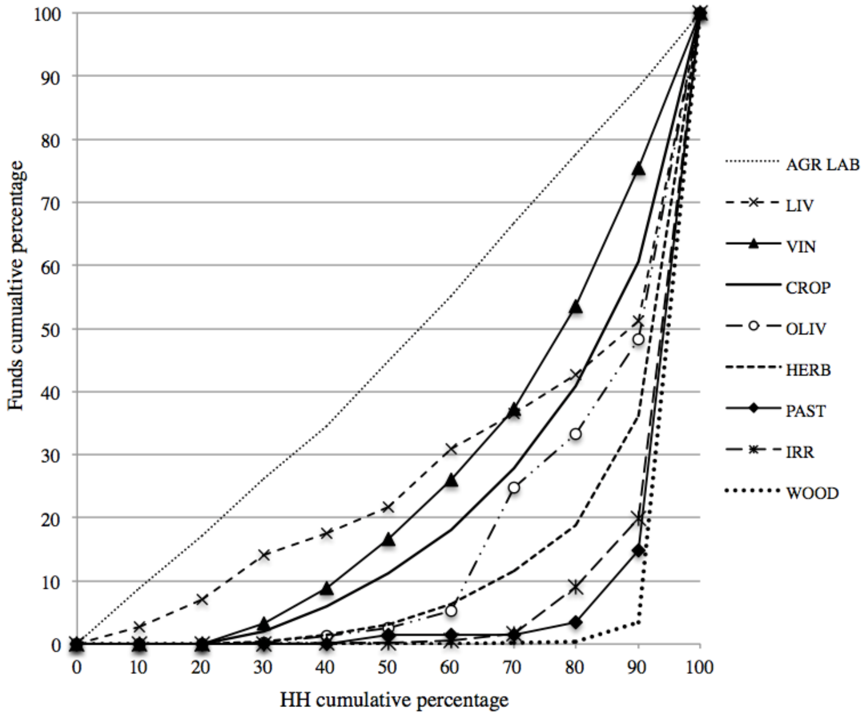
Figure 3 shows the main features of the distribution of funds, through Lorenz curves and Gini coefficients. We indirectly infer access to water from access to the irrigated land, which was the most

[6] Livestock Unit 500 is used to standardize livestock weight, and is calculated adding the total live weight of all the livestock heads of different types and dividing it per 500 kg.

unequally distributed along with the woodland and pastures. On the other side, vineyards were the most equally distributed land use. Indeed, Figure 3 shows the unequal pattern of distribution between funds, especially between labour and farmland. While the amount of available agricultural labour (after deduction of domestic and family labour) by HH varied steadily regardless of the farm size (Gini coefficient 0.07), the ability to absorb this labour force depended on the access to the farmland area (Gini coefficient 0.65).

Figure 3. Lorenz curves and Gini coefficients for farmland and livestock ownership and labour availability

FUNDS	GINI
AGR LAB	0.07
LIV	0.46
VIN	0.47
CROPLAND	0.58
FARMLAND	0.65
OLIV	0.69
HERB	0.76
PAST	0.86
IRR	0.86
WOOD	0.93



Source: Own elaboration based on the *Amillaramiento* and population censuses. Note: 'AGR LAB' refers to available agricultural labour, 'VIN' to vineyard, 'LIV' to livestock (LU500), 'OLIV' to olive groves, 'RF' to rain-fed grain growing, 'PAST' to pastures, 'IRR' to irrigated land, and 'WOOD' to woodland.

4. Results and Discussion

4.1 Social organisation and sexual division of labour

Out of the 83,226 days of agricultural work required to maintain the agroecosystem (297 Annual Working Units; AWU), 62% could be covered by self-employed workforce (184 AWU).[7] The rest of

[7] Out of that total, 75% destined to cropland labour, 21% to livestock labour and 3% to woodland labour.

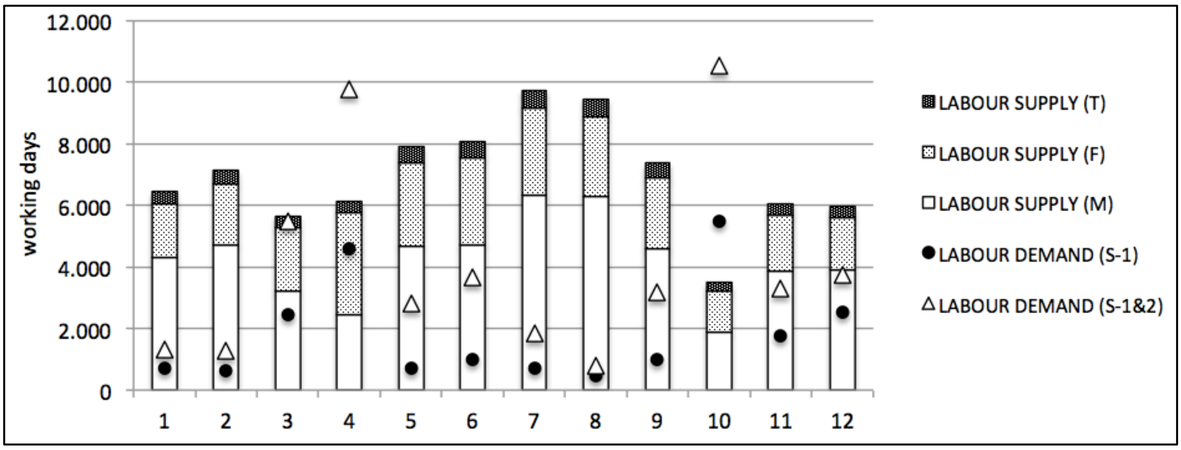
the necessary workforce (38%) had to be hired (113 AWU). Of these hiring needs, 35 AWU were covered by permanent contracted workers (with cohabitation within the same HH). The rest, 79 AWU, can be considered a proxy for temporary labour demand of day labourers. Regarding the characteristics of the HHs with labour deficit, all farms with more than 5.5 hectares (21% of the HHs) would be responsible for 82% of the total hiring. For further sections, we will take this reference (5.5 hectares of farmland) as a representative of the HH's size that could start to accumulate surplus through labour hiring. This is consistent with the values found by Padró et al. (2019) for the same municipality as the minimum surface area for the self-subsistence of a representative HH.

The need of the HHs to be hired in the labour markets to ensure reproduction (Necessary Labour Supply; NLS) was 32,820 working days (117 AWU), higher than labour demand. We obtain that proletarian HHs (without access to land; representing 21% of the total HHs) could contributed to 39% of the working days, and together with the semi-proletarian HHs of up to 3 hectares (representing 57% of the HHs) accumulated 80% of the temporary labour supply.

Given the strong seasonality of agricultural tasks, we observe limits in the potential of the monthly male labour supply which is considered the first to be provided (see Figure 4). This results in an estimate of the minimum participation of women in paid agricultural activities, between 22% (Sample1) and 18% (Sample 1&2) of total agricultural hired work. Including the effect of seasonality, the maximum annual hired work for the local population amounted to a maximum of 21,257 working days (80 AWU), which supposed 65% of the Necessary Labour Supply (NLS). If we include the potential labour demand of the excluded area (Sample 2), the total temporary demand for wage labour increases to 36,999 working days (132 AWU), which would cover 113% of the NLS (see Figure 4).[8] Although we cannot assure that all the work of Sample 2 was covered by wage work, we use it as a proxy. In sum, total agricultural labour would be 336 AWU, including self-employed labour (55%), permanent hired labour (10%) and temporary hired labour (35%).

[8] Although Sample 1 covers a large percentage of the agricultural population (89%), it is not as representative in terms of farmland (65% of the total farmland area).

Figure 4. Monthly Labour Supply and Demand



Source: Own elaboration. Note: Teenager (T), female (F) and male (M) work are indicated in parentheses.

At the municipal level, Domestic and Family Work (DFW) represented 35% of the total work of the agricultural HHs (184 AWU). The average weight of domestic work on the total work performed was 38%, and it remained quite stable among the HHs despite a slight decrease observed for the largest farms, mainly due to the increase in total work. On average, 62% of the available female work was devoted to DFW (CV = 35%). Although it is a very tentative estimate, bringing to light female participation in agricultural labour is one important contribution of this work. Overall, women's work represented at least 18% of all agricultural work (including wage and self-employed agricultural labour), and 47% of the total societal necessary work. Results are consistent with the few similar analysis made for other case studies. Based on local sources, Colomé (2000) estimates that women performed 18% of the total required labour for one hectare of vineyard c. 1861 (San Sadurní d'Anoia, Catalonia). Van Nederveen Meerkerk and Paping (2014) compare male and female wage work of labourers not living in the farms for some farms in Groningen (Holland) between 1773 and 1904. The share of women working days over male ones was around 30% (Van Nederveen Meerkerk and Paping 2014:462), while the same indicator for Sentmenat was between 23% (Sample 1) and 28% (Sample 1&2).[9]

Almost all the research studies on female labour participation exclude DFW, mainly for the

[9] We remind that due to our methodological assumptions the results might be underestimating the weight of agricultural female labour participation, as well as the overall female labour participation (see Section B.3 in Annex).

difficulties to obtain credible estimations. We emphasize the need to include DFW in order to (*i*) better understand the total labour required for socio-ecological reproduction (which would be around 54% underestimated if not included); but also ~~to~~ (*ii*) to understand the sexual division of labour and the lower percentage of female agricultural activity. Considering both DFW and agricultural labour, and even taking into account the minimum of agricultural work participation, female and male labour share within the total labour required was almost identical. The labour performed over the available labour capacity was around 77% per both sexes. This challenges the understanding of women as economically inactive in agriculture, when it is perceived as waged, permanent and continuous labour force. Female agricultural participation was complemented by DFW, which makes difficult the interpretat~~ion of~~ what *agriculturally active female* meant in this context.

4.2 Social distribution of produce: Consumption and Surplus Accumulation

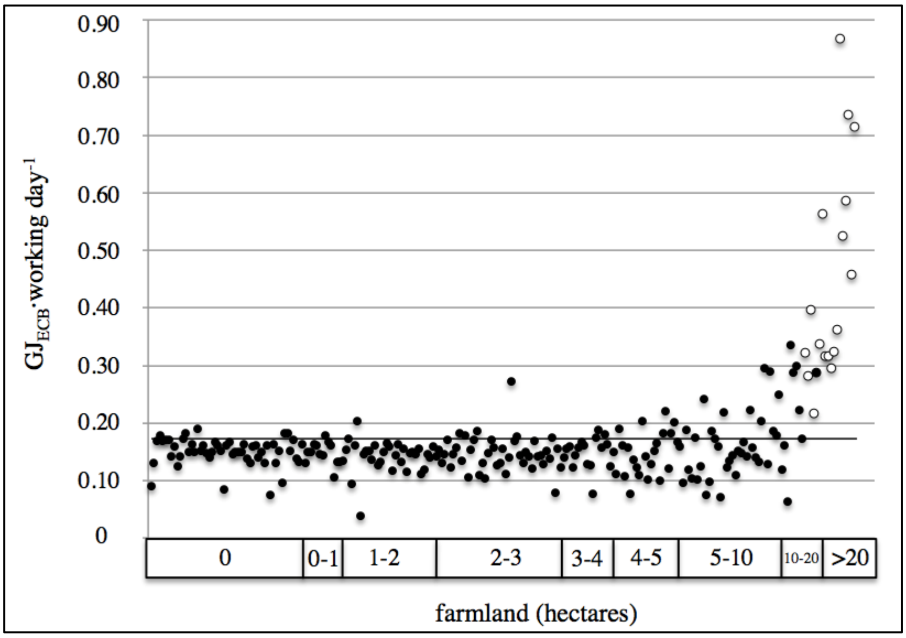
At the municipal level, Biomass Reused (BR) accounted 52% of Total Produce (TP), while the biomass that could be used for final consumption (Final Produce; FP) accounted for the remaining 48%. BR was shared between biomass reused for fertilising (21%) (Farmland Biomass Reused; FBR) or for animal feed (31%) (Livestock Biomass Reused; LBR). Final Produce of biomass (FP_{ECB}) was 28,232 GJ_{ECB}. Average energy productivity per HH was 116 GJ_{ECB}, although 75% of the HHs were below this threshold. The average value for Final Productivity of Land (FPLan) was 23.8 GJ_{ECB} per hectare of farmland (CV = 57%) and for Final Productivity of Labour (FPLab) was 0.34 GJ_{ECB} per working day (CV = 19%). The stability of both indicators, independently on the farmstead size, confirms the results raised by Marco et al. (forthcoming), which reached the same conclusion through the analysis of five representative households.

FPLan and FPLab inform us about the relative productive capacity of both funds (land and labour), but do not inform us about the final situation of the HHs, which would be defined by the total access to farmland, in other words, to absolute produce. A first consumption-production balance (before labour markets) shows that 67% of HHs had a shortfall in produce to cover their basic consumption requirements (summing 123 ECB), while 33% of the HHs were in a surplus situation (summing 208

ECB). The distributional role performed by labour markets allowed most of the HHs to cover their family expenses through additional labour incomes, while at the same time labour expenses reduced the cumulative surplus to 80 ECB.[10]

The Social Productivity of Labour (SPLab) displayed in Figure 6 shows an average of 0.17 GJ_{ECB} per working day. Here there appears an absolute change in the frequency distribution of SPLab, with a sharp increase concentrated in largest farms. In order to highlight this, we divide the series into two sections, depending on whether the access was lower or higher than 5.5 hectares (see Section 4.1), and we obtain that the average for the first sections (less than 5.5 hectares) was 0.15 GJ_{ECB} per working day (CV = 19%), and the average for the second section (more than 5.5 hectares) was 0.26 GJ_{ECB} per working day (CV = 66%).

Figure 5. Social Productivity of Labour (SPLab)



Source: Own elaboration. Note: The figures display all the HHs included in the sample.

[10] Although we will not present the details here, we point out that still 18 HH had a cash deficit higher than 0.25 ECB and 8 HH had deficits higher than 0.5 ECB. An initial explanation points towards HHs with a high dependency ratios, or highly dependent on female wages (which was half of the male wage). Note that part of the Labour Supply was absorbed by Sample 2. Therefore, labour income (155 ECB) and labour expenses (140 ECB) reflected here do not coincide.

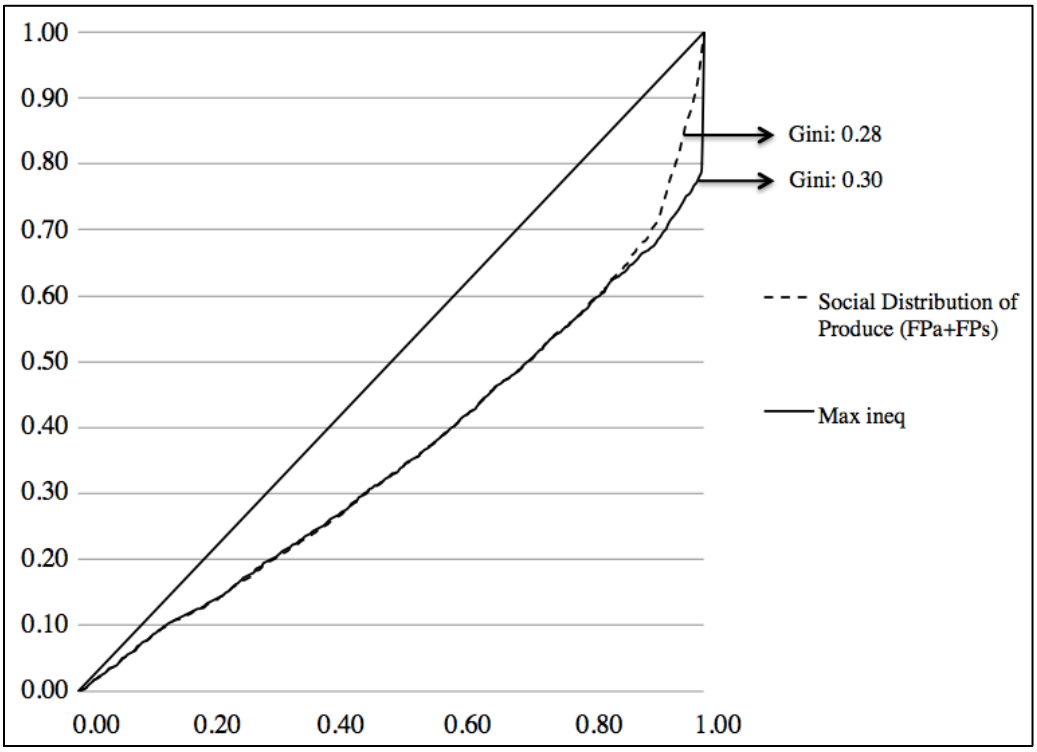
Differences between FPLab and the SPLab are very meaningful. While the rough appropriation per unit of labour (FPLab) is stable, inequality emerged during the social distribution of produce, thus after labour markets. The HHs with a higher SPLab coincide with those who accumulate profits. Indeed, 80% of the profits were concentrated in the last 18 HHs, all of them larger than 18 hectares of farmland (white dots in the figures), which coincides with the threshold of surplus accumulation.

4.3 Inequality Extraction Ratio

IER analysis allows to analyse the features of the maximum feasible inequality proposed by Milanovic (2006). Final Produce (491 GJ_{ECB}) had to reproduce the current agricultural labour, on the one hand, and the domestic and care labourers and dependent population on the other hand. In order to keep the agroecosystem producing, the intergenerational reproduction of the labour force was imperative. If we account for the basic needs requirement, 283 ECB were needed to cover the food and fuel consumption, and 74 ECB for the clothing and housing rent. Only this flow of basic needs would make a total of 358 ECB, or 73% of the FP_{ECB}. Taxes absorbed 52 ECB, reducing the total surplus to 81 ECB, 16% of the FP_{ECB}. Even if the surplus represented a smaller part of the FP_{ECB}, it still meant that 81 HHs (with 4 people and 2 dependents; see Section B.4) could be feed and fuelled, which represents 23% of the agricultural population held in the municipality.

The size of the surplus affected the maximum feasible inequality. Figure 6 depicts the inequality of produce and surplus distribution. The first inequality line shows the distribution of the final human-appropriated produce (Social Distribution of Produce; FPa+FPs), and the Gini coefficient for this distribution was 0.28. The maximum feasible inequality (Max. ineq. 1), where all the population would had lived at the subsistence level except one household, raised Gini coefficient up to 0.30. Accordingly, the Inequality Extraction Ratio was 95%, which meant that 95% of the maximum possible inequality was registered. Milanovic observes a similar pattern for preindustrial economies c. 1820, where global IER was 97% (Milanovic, 2011:8).

Figure 6. Social Distribution of Produce and Surplus Distribution



Source: Own elaboration.

4.4 Subsistence wages

Finally, we analyse the results of the estimation of reproduction-subsistence wages, as a proxy of reproduction cost of labour force, for an average household. We will compare it to labour productivity and historical wages to show which part of the labour surplus was appropriated by the wage labourer and which part by the landowner. An adult male worker annually needed 5.8 GJ of food consumption (equivalent to 147 pesetas) and 11 GJ of fuel consumption (equivalent to 24 pesetas). Thus, the total annual reproduction cost is estimated in 16.8 GJ or 171 pesetas. If the average worked days a year was around 180, the individual subsistence wage should had been 0.95 pesetas per day.[11] Comparing with the male daily wages recorded in historical sources (2.5 pesetas), this would be 260% of the subsistence wage.

If we include the basic consumption of the children (for intergenerational reproduction) and the basic consumption of the wife (who ensured the DFW), the consumption of the HH increased up to 57.5

[11] This represents 64% of the yearly available labour, the observed average of agricultural worked days of the total available.

GJ or 499 pesetas. The household subsistence wage should be 2.8 pesetas per day, slightly higher than the salary registered in historical sources. This might imply a subsistence gap which coincides with the potential female income if we apply the 18% of female agricultural labour (40 female working days) (see Section 4.1) and female daily wages (1.25 pesetas per day). In energy terms, if the annual basic consumption was 56 GJ, and we estimate 220 days of hired annual work (180 of male and 40 of female), it was necessary to obtain 0.25 GJ_{ECB} per working day.

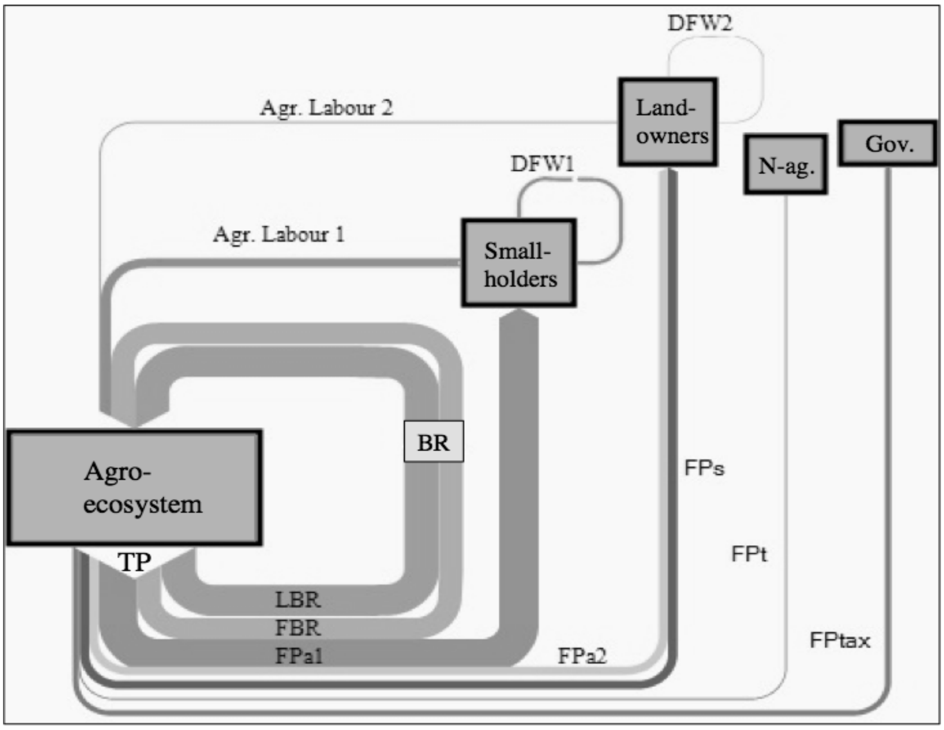
Finally, when comparing the average FPLab (0.32 GJ_{ECB} per working day) and the 'natural price' of work or subsistence wage (0.25 GJ_{ECB} per working day), the difference between the two would be the potential appropriation of surplus during the process of contracting the labour force in the market (22% of labour productivity; 0.07 GJ_{ECB} per working day). The match between daily wages and reproduction cost means that the totality of the potential surplus per labour unit was extracted.

5. Discussion

The methodology proposed brings to light the links between the distribution of agroecosystem funds (farmland and livestock), the social organization of labour and the appropriation of surplus. Although HHs were diverse, we observe that we can roughly establish thresholds to distinguish between those who were dependent on the existence of labour demand (below 3 hectares) and those which were able to accumulate (above 18 hectares). These thresholds would be relatively independent of the heterogeneity of farmland (in terms of farmland qualities or land uses). Therefore, both labour or land markets would be central elements to articulate the match in terms of land/labour capabilities of the different social groups, connecting them. At the same time, markets would be working as bioconverters through which the social distribution of produce occurred (Marco et al., *forthcoming*).

Results also show the biomass flows required at every stage of the socio-ecological reproduction process. 50% of Total Produce was required to reproduce the ecological funds (soil fertility and livestock), while 27% was required to meet the basic needs of the farming community. Although this percentage would be lower if we only include the active agricultural population, their need for domestic and care labour, and for intergenerational reproduction of labour, increased this reproductive flow. Thus, results highlight that the agroecosystem reproduction was based on agroecosystem funds, which needed a permanent recirculation of a large part of the produce to maintain its productive capacity. The 'cost of sustainability' can be accounted in terms of the required territory to maintain the reproduction flows (Land Agricultural Cost of Sustainability, LACAS; Guzmán and González de Molina, 2009). Our methodology and results highlight the Time Cost of Sustainability (TICAS), which includes not only the labour required to maintain ecological funds, but specially the domestic and family work required to maintain the labour force. Figure 7 displays the socio-ecological reproduction scheme described in this section for our case study (Sentmenat, 1850). The scheme shows a clear loopy structure, where different reproductive processes were interwoven.

Figure 7. Analytical socio-ecological reproduction scheme for the village of Sentmenat (1850)



Source: Own elaboration with the sources mentioned in the text. Note: All labour flows are expressed in working days. All other flows are energy flows expressed in GJ_{ECB}, except of LBR and FBR that are expressed in GJ (see section 2.2). '*N-ag.*' refers to Non-agricultural population which provided goods and services to agricultural population; 'Gov.' refers to Government.

Milanovic stated that '*as the average income grows, the constraint on the maximum Gini is relaxed*' (Milanovic, 2011:9). This could be better understood noting that when the surplus was larger, the maximum feasible inequality increased too. Sraffa posed a very similar proposal with the so-called '*fundamental Sraffian equation*' (Barceló, 1994). As has been widely acknowledged, biophysical and economic growth limitations of agrarian socio-ecological regimes, represented in this case by preindustrial agricultures, were due to its dependence on the harvest of solar energy converted by plants that set a limit to the flow of energy carriers available (Wrigley, 1988). Indeed, dependence on human and animal bioconverters compelled to a low overall efficiency of the conversion of primary into final and useful energy, which has been estimated at less than 5% (Krausmann et al., 2008). We consider that preindustrial agricultures had lower capacity to generate surplus because they relied on live reproductive funds (farmland, human and animal labour) that had high reproductive requirements. We include here the need to consider the total costs of labour force reproduction, including intergenerational reproduction. Once these flows of matter-energy had been commodified, we found a strong adjustment between reproduction wages and wage labour productivity (78%). The thin margin between labour productivity and reproduction requirements of labour force limited the capability of landowners to increase the appropriation of produce. In fact, this potential surplus per labour unit (22%) would be depicting the very same idea that IER shows at municipal level. Hence, the increase of this surplus appropriation had to be obtained mainly through an extensive growth.

We found two relevant implications of the processes unveiled above. First, they lead to understand social inequality as an 'ecosystem disease': i.e., the fact that higher produce appropriation by the elites (i.e. through lower wages) meant higher pressure on ecological funds reproduction (i.e. trough agricultural intensification in order to get higher output flows per land unit), as has been already stated by González de Molina and Toledo (2014). If we consider that in our case study the pressure exerted by an increase of surplus flows would entail a necessary reduction of the rest, like in a zero-sum game, this could imply (*i*) a reduction of fertilising biomass (FBR), (*ii*) a reduction of livestock feeding (LBR), or (*iii*) a reduction of human food or fuel consumption (FPa1). This process was similar to the one exerted by demographic pressure on land as Boserup (1965, 1981) stated. As Padró et al. (2019) point out for the same case study c.1860, demographic pressure was not the main driver towards the jeopardizing of ecological funds reproduction and could probably be better explained by social inequality.

Second, this leads us to reconsider the role of social inequality as one of the main driving force of socio-ecological transitions. Increases in total produce, particularly through technical change (or the development of productive forces), would increase total surplus. This process would be a shock absorber of potential social conflict ensuing the unequal distribution process between labourers and landowners (Barceló, 1994). If we consider that technical change might suppose to shift from renewable towards non-renewable energy sources, this meant to transfer internal tension to external and inter-temporal tension. And, last but not least, discovering these links opens the door to a deeper analysis of reconsidering the role of social inequalities within socio-ecological transitions. Might social inequality had been a powerful driver of agricultural technical change?

6. Conclusions

We have proposed and tested a novel methodological approach to reconstruct socio-ecological reproductive structures of advanced organic agricultures. This methodology of multidimensional-interlinked balances (biomass, energy, labour and cash flows) allows to build up a framework where ecological, feminist, Marxist and Sraffian perspectives can be easily related. Through the concept of socio-ecological reproduction we interlink ecological (un)sustainability, invisibility and relevance of domestic and family work, and class inequalities formation through land and livestock hoarding. The results obtained confirm the robustness of our methodology and the coefficients used. From a historical point of view, this methodology has demonstrated its explanatory capacity, and its potential to reveal several aspects of preindustrial agricultures that are difficult to assess from the available historical sources using more conventional approaches to rural inequality. Thus, biophysical and monetary socio-ecological integrated accounting through our Socio-Ecological Reproductive Analysis (SERA) can be used to get new insights on some ongoing ecological-economics, feminist and historiographical debates about how different forms of social inequality interact among them and with Nature.

The methodology used has been able to reveal different and relevant aspects of the joint socio-ecological reproduction processes by setting the links that existed between energy, material, labour and cash flows of farm units. Its application at municipal level c.1869 confirmed the hypothesis posed by Marco et al. (*forthcoming*), that trough land hoarding large landowners assured the required wage labour supply and surplus extraction at the same time. Due to the lack of enough land at its disposal, a significant share of total agricultural labour (40%) could not be performed as self-employed work and the mismatch had to be adjusted either through labour or land markets. DFW revealed itself as a substantial flow too (35-38% as a minimum). Finally, surplus analysis shows a small capacity to extract rent from agricultural work, and this reproductive limit led to the need to accumulate at least 18 hectares of farmland to start accumulating a significant surplus. The low development of productive forces entailed a huge Inequality Extraction Ratio (95%), which depicts the strong social conflict over land entitlements and social distribution of produce. Finally, we ask ourselves whether this social conflict could had set in motion a dynamics that lead to technical change.

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APPENDIX

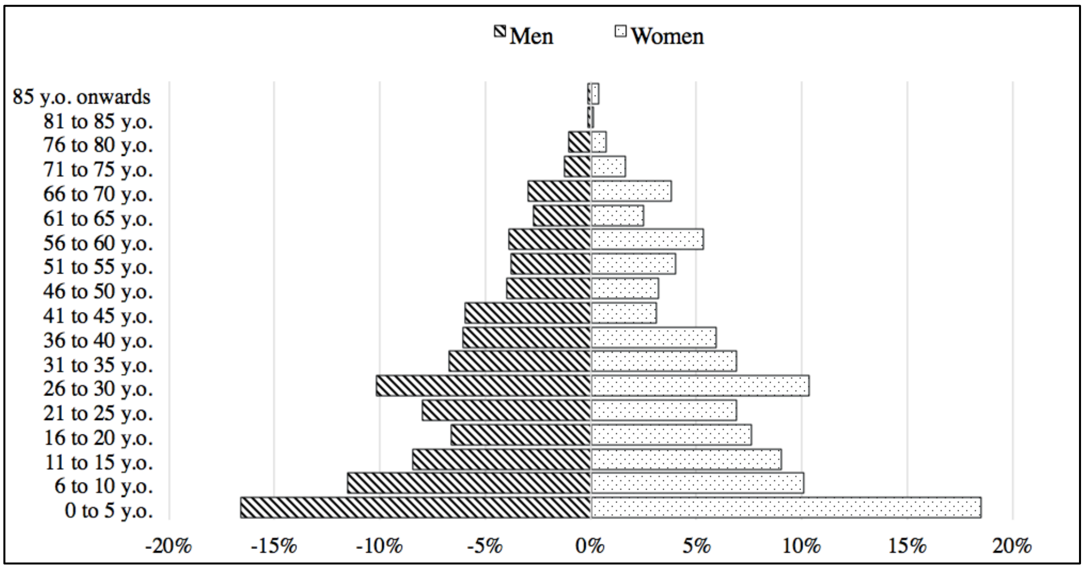
This Appendix provides information about the main socio-ecological funds at municipal level (Section A) and explains several methodological issues (Section B).

A. SOCIO-ECOLOGICAL FUNDS

A.1 Labour Force

The population registered in Sentmenat (1850) was of 1,718 inhabitants, grouped in 328 households (HHs). Population density was 65 inhabitants per km^2 (according to the Cadastral map area, 87 according to the *Amillaramiento*'s one). The population structure showed a certain balance between female (51%) and male population (49%), and the working-age population was around 63% (see population pyramid; Figure A). The potential labouring time for the whole society was 252,830 working days per year (903 Annual Working Units; AWU), an average of 770 working days per HH (2.8 AWU). 76% of the total population was considered to be agricultural (e.g. being part of a HH defined as agricultural). The total labour available for agricultural households was 208,593 working days per year (745 AWU).

Figure A. Population pyramid (Sentmenat, c. 1850)

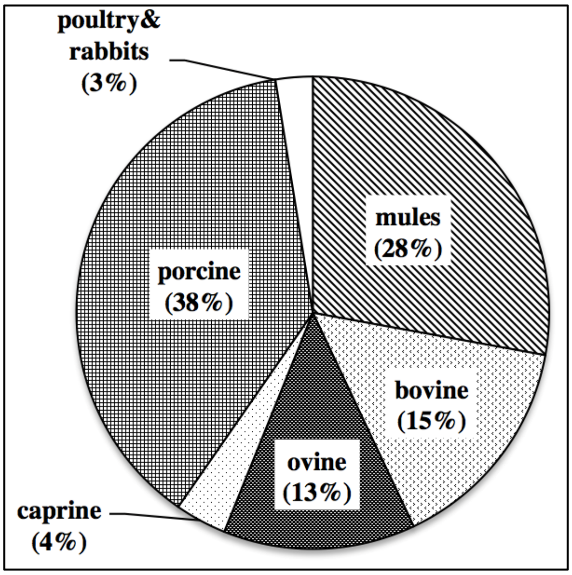


Source: Own elaboration from population census (Sentmenat, 1850).

A.2 Livestock-Barnyard Complex

Based on the cross data of the *Amillaramiento* and Cadastre (1848) and including estimates of small livestock per HH (Marco et al., *forthcoming*), the livestock weight was 195 LU500 and livestock density accounted for 16 LU500/km^2 of farmland. The livestock composition was balanced among draught animals and cattle for milk, meat and fibre. The availability of draught power was around 20,170 working days per year (16 working days per hectare), and the availability of manure was of 360 tonnes (dry matter) which meant an average availability of 382 kg per hectare of cropland.

Figure B. Livestock composition (Sentmenat, 1850)



Source: Own elaboration based on the sources mentioned in the text.

B. METHODOLOGICAL ISSUES

B.1 Data and methodology shortcomings

As it has been frequently pointed out by agrarian historians, the municipal scale entails some biases. Due to the large atomisation of plots, which despite forming part of a same farm unit they could be sometimes located in different municipalities, the distribution of the farmland recorded may be biased (Garrabou et al., 2014). For the case of non-resident landowners living in surrounding municipalities (see outsiders in Figure 3), the 'fragmentation of small farmsteads in various municipalities results in a certain overestimation of the number of smallholders and the weight of petty property' (Garrabou et al., 2014:63). To this, we might add the limitations of the historical sources to distinguish between landowners and sharecroppers, an aspect that highly affects our case study.

In addition to the limits of the historical sources, pointed out here and in previous works (Marco et al., *forthcoming*), we acknowledge that the development of this novel methodology is in an initial stage. Particularly, we could not include the likely differences in the management of farmland and livestock funds between smallholders and landowners. Labour requirements and yields do not change depending on the farm size, and only differences between soil qualities, irrigation and land use composition could be taken into account. Second, labour organisation has been inevitably simplified. We did not include the familiar and community networks that could partially supply labour interchanges outside the markets, or through other mechanisms like debt. For instance, Colomé (2000:294) notes that '[landowners] could also put pressure on the *rabassers* and/or wage labourers through monetary or in-kind loans (…) in exchange for the wages that a certain working time may require'. Finally, we could not include other ways of access to biomass flows through informal sources, like gathering, hunting or thefts. Despite these limitations, we consider that the results obtained are robust and very revealing. The aim of the current work is to reveal some basic structural functioning of this epoch, more than to address some short-term historical changes. The following quantitative estimates need to be understood as a first test of the application of the methodology, and not as an exercise of local history.

B.2 Rights on the land: owners, tenants and vine-growing sharecroppers (*rabassaires*)

The interpretation of available historical sources presents some problems to distinguish between landowners who work their own land, land-tenants and those who had a long-term sharecropping contract for planting the vines they grew (called *rabassaires* in Catalan). *Amillaramientos*, one of the sources most used by agricultural historiography, has been under debate due to the difficulties of clarifying which was the relation of each registered person with the land subject to taxation. The 1850 *Amillaramiento* of Sentmenat, unlike the one from 1860, explicitly established a distinction between plots whose taxpayer was (i) 'owner and tiller', (ii) 'owner who rents', (iii) 'owner with a tenant', or (iv) 'another owner'. In spite of this, both the number of cases that were not registered as 'owner and cultivator' (33 out of 454 cases) and the area they represent (4.4% of the total area and 4.7% of the cultivated area) make us doubt that a rigorous monitoring of the land tenure regime was carried out, especially with regard to the presence of *rabassaires*. For this purpose, we have resorted to the Mortgage Registry of Sentmenat, which registered 225 long-term tenure settlements between 1790 and 1844, representing a total near to 293 hectares. We have identified 143 of them (185 hectares). We also confirmed that in the 1850 *Amillaramiento*, those *rabassas* were registered analogously to the farms in full ownership. Although we are not including this element as a relevant one in the current work, it is necessary to mention that our database does include them.

B.2 Crop rotations

Crop rotation data was mainly obtained from the *Estudio Agrícola del Vallés* (EAV) (Garrabou and Planas, [1878]1998). The irrigation rotation (wheat-maize-hemp-bean) is mentioned both in the EAV and in IACSI (1879). These rotations were made in periods of two years, to two crops per year. We found the same rotation in irrigation in the cadastral survey of Castellar del Vallès (1850), so we assume that it remained stable during the second half of the 19th century.

For the rainfed rotations, we basically base upon those that appear in the EAV, which established a sequence of wheat and beans (in 1st and 2nd soil quality), and rye and wheat mixture (*mescladís*) and beans and vetches (3rd class). We considered it necessary to partially modify rainfed rotation to include two relevant crops mentioned in the same historical source. Firstly, fodder, described as a mixture of wheat, lupins, vetches and barley or oats. Secondly, EAV does not include rainfed potatoes, apart from the ones appearing in the crops associated with olive groves (described below). However, this historical source clearly mentioned that rainfed rotation referred only to the most frequent one (cereal-legume). Given the importance of this crop, which was reflected not only in the diet of the population, but also other historical sources (*Reclamación al Catastro de Sentmenat*, 1879), we decided to include it. Therefore, our proposal for rainfed rotation for 1st and 2nd class includes both cereal cultivation and legumes and potatoes.

The rotation would be: wheat-beans-wheat-potatoes (1st class), wheat-fodder-wheat-potatoes (2nd class), and *mescladís*-vetches (3rd class). The information on olive groves where the trees were kept associated with other annual crops cultivated in between (wheat and potatoes [1st land class], maize and *mescladís* [2nd], and barley and lupins [3rd]) has been taken from the EAV (Garrabou and Planas, 1878:257).

B.3 Estimates of female labour force participation

Women's work, and especially domestic and care work, has been systematically excluded from a large part of socio-metabolic analyses with a historical perspective. The limited specific information on women in the main historical sources, as well as the systematic exclusion of women from land ownership, makes it difficult to register these works. Delphy (1984) pointed out the difficulty of distinguishing between the mix of paid work, subsistence jobs and domestic work as one of the causes of their exclusion from statistics, which at the same time facilitated the disparagement of their value. In addition, one of the difficulties of measuring these works, as has been observed in time budget studies, is that they can, and usually are, performed simultaneously (especially care work) (Carrasco et al., 2011). This is why sometimes it is difficult to attribute a single purpose to a complex activity that includes tasks that can be considered leisure and work at the same time (Fischer-Kowalski et al., 2010; Singh et al., 2010).

For estimates of female labour participation, we made strong assumptions. The assessment used in this work for Domestic and Family Work (DFW) has been detailed in Marco et al. (forthcoming). In summary, based on the information registered by Le Play for the 19th century (collected in Wall, 1994), we estimate the weight of Domestic and Family work (DFW) by the number of children in the household: 132 fixed-work days, with an increase of 26 annual working days for every son or daughter. We only want to remark here that we assumed the maximum participation of female in DFW, that is, that female performed all DFW within the HH. For agricultural labour, the main assumption was that male labour would have been prioritised before female labour, both for internal labour within the farmsteads and wage labour. Despite this, we assumed that within the HHs, farmer's wives and daughters were prioritised before male labour for some specific tasks (gardening, small livestock, weeding and legumes sowing).[12]

In the case of female wage labour, we use two criteria that must be met together: from the supply side and from the demand side. The first one refers to when male wage income was not enough to meet the HHs income needs (annually). The second one refers to when potential male wage labourers were not able to cover wage labour demand (monthly). This assumption is coherent with what has been noted by researchers; as 'during the periods when the demand for vine cultivation increased, so did the participation of the different members of the Peasant Family Units, especially women active in agriculture' (in addition to migrant workers) (Colomé 2000:295). Due to the characteristics of our methodology, the extent to which women assumed more or less agricultural work depended on (*i*) the load of DFW they had to assume, (*ii*) the features of the own farmstead (if it existed), and (*iii*) the capacity of male labour availability to cover the HH cash requirements.

Accordingly, we account for the minimum female agricultural labour participation, but the maximum participation for DFW. Both assumptions will affect our results. It is possible that agricultural female labour might be underestimated, while DFW might be overestimated. Overall, the smaller bias of the latter might imply that our results would account for the lowest female labour participation. Although for the moment this has been the best possible methodological way to get a valid proxy of the female agricultural participation, we accept that it cannot exhaustively reveal its importance. As qualitative historical sources suggest, female agricultural labour was probably more frequent:

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[12] Please note here that we refer to the work of who would had been prioritised. This means that in the case that internal agricultural required labour exceeded male potential labour, women's labour would be used.

'Thus, it is customary to see, even in the last period of gestation of the primiparous, that [pregant women] keep taking care of the heavy labours of the field, or beating the loom, according to their ordinary occupations; and nevertheless, the fruit of their loves arrives perfectly'

Pujadas and Serratosa (1888:144).

B.4 From Final Produce to Final Produce in ECB

To meet their basic needs, all families needed a consumption basket with a certain amount of food and fuel. Although we could account for the total energy content of this consumption basket in GJ, we should also bear in mind that firewood and coal could not be eaten, while burning food for cooking or heating at home would be foolish. We have to consider them complementary, non-substitutable flows. Therefore, in order to analyse land and labour productivity indicators we convert the energy content of Final Produce (GJ) (which includes the products that are self-consumed in the same HH or destined for sale on the market) through a transformation procedure that allows us to obtain the Final Produce in an Equivalent Consumption Basket (FP_{ECB}). Through this process we seek to avoid conflating the different energy qualities between food and fuel energy carriers (Giampietro et al., 2013). For this purpose, (*i*) we estimate the cash value of Final Produce through the prices established for each product; and (*ii*) we calculate the amount of the Equivalent Consumption Baskets (ECB) which could be obtained with that income. Therefore, this value could be expressed either in ECB or in GJ_{ECB} (one ECB corresponding to 57.5 GJ). This means that the composition of the FP_{ECB} in terms of food and fuel weights is equivalent to the composition of an ECB.

Table A depicts the structure of an annual Equivalent Consumption Baket (ECB) for a family with average characteristics, 4 people and 2 dependents (Marco et al. *forthcoming*). This data has been built from several historical sources, which are thoroughly detailed in previous works (see supplementary materials in Marco et al. 2017 and *forthcoming*).

Table A. Composition of the Equivalent Consumption Basket (ECB)

Basic Basket	Annual Fresh Weights (kg.)	Cost (ptas,)	GCV (GJ)	$GJ\cdot pta^{-1}$	$pta\cdot GJ^{-1}$
FOOD	1,866	401.8	15.2	0.038	26.4
FUEL	3,431	96.1	42.2	0.440	2.3
TOTAL	5,297	497.9	57.5	0.115	8.7

Source: Own elaboration.

One of the important reasons for the transformation from FP to FP_{ECB} is the totally different ratios between prices and Gross Calorific Values (GCV) of food and fuel. At the time of our study, there existed a huge difference between the ratio for food products (26.4 $pesetas\cdot GJ^{-1}$) and the ratio for fuel products (2.3 $pesetas\cdot GJ^{-1}$) (see Table A), so that one GJ of food was one order of magnitude higher than one GJ of fuel. For our case study, there was a second differentiating element, linked to the importance of vineyard specialisation and the low caloric content of wine. These two issues ([*i*] weight and energy composition between fuel and food products and [*ii*] weight of the wine [produced] within FP in the consumption baskets) are the ones that will determine most of the changes that occur from FP to FP_{ECB}.

Despite this, we acknowledge that this weight-energy transformation through prices means adopting an energy-focused view. However, as Table B shows, we found that at that time prices (exchange values) were mainly defined by the embodied labour, and not so much by the caloric content of the product itself. Indeed, we found that labour costs were a large part of the total production cost (see Section 4.2), which perfectly fits with this hypothesis. As Barceló (1994:24) pointed out:

'(...) from the approach of reproduction and surplus the thesis is held that the price of a good reveals the difficulty (or sum of efforts required) to produce it. And, at least as a schematic approach, it states that this difficulty can be measured by the amount of work embedded in said merchandise, an amount that is an autonomous techno-economic property in relation to the price of the merchandise. So, from this point of view any –structural— increase (or decrease) of a relative price is ultimately caused by the increase (or decrease) in the amount of direct and indirect work required to obtain it.'

We analysed the relationship between the labour requirements of each type of crop, its energy productivities per hectare and the prices per energy unit (see Table B). The results confirm the hypothesis that the lower price per unit of firewood energy, in comparison with the higher prices of the energy units in the form of food, was linked to the lower labour requirements per unit of product. In the case of wheat and firewood, each working day would be producing a similar monetary value (around 10 pesetas). In the case of wine, the higher price per unit of energy did not compensate for the lower energy yield per hectare, and with the necessary work intensity being similar, the yield per day remained below.

Table B. Embodied energy, labour and cash for different agricultural products (Sentmenat, 1850)

	WHEAT		**CORN**		**WINE**		**FIREWOOD**
	main product	**by-product**	**main product**	**by-product**	**main product**	**by-product**	
working days·hectare^{-1}	49.4		52.1		58.7		10.8
GJ·hectare^{-1}	18.0	41.8	17.4	26.3	4.6	36.5	45.5
GJ·hectare^{-1} (tot.)	59.8		43.7		41.1		
GJ·working day^{-1}	0.4	0.8	0.3	0.8	0.1	0.6	4.2
GJ·working day^{-1} (tot.)	1.2		1.2		0.7		
peseta·GJ^{-1}	19.9	3.1	18.2	0.1	42.3	0.9	2.3
peseta·working day^{-1}	7.3	2.6	6.1	0.1	3.3	0.6	9.6
peseta·working day^{-1}	9.9		6.2		3.9		

Sources: Own elaboration

According to these results (Table B), we consider that the energetic viewpoint assumed in our procedure does not introduce a bias contrary to the predominant characteristics of the markets at that time. This accountancy transforms the energy content of the production of each HH, depending on its composition, by means of ECB coefficients which keep a fixed proportion of food and fuel. Thanks to that, all products can be accounted by their energy content without conflating different energy qualities that are not substitutable. And it does so in a manner consistent with the relative labour incorporated into both types of products and, therefore, also coherent with their relative market prices.

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