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Jointness in Sites: The Case of Migratory Beekeeping

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Abstract

This paper formulates a bio-economic model that specifies the sequentiality of allocative choice on a migratory beekeeping farm in discrete form. It is assumed that the modeled farm operates in conditions of certainty and, allocating an apiary to forage sites, produces only two marketable outputs: commercial pollination service and honey. The biological connotation of this model is derived from the fact that the apiary outputs are specified as functions of the number of adult bees active on the pollinated sites.

The bio-economic model determines revenues, variable costs, gross income and profits of a migratory beekeeping farm for each sequence of forage sites to be pollinated, i.e. for each practicable site-chronological regime.

The bio-economic model allows the existence of jointness in sites to be tested, i.e. to ascertain if the sequential allocative choices are independent. The jointness in the forage sites can arise on the side of the revenues, on that of the variable costs or on both sides simultaneously.

This bio-economic model formulated for migratory beekeeping farms is convertible to other farming activities involving transhumance, such as the grazing or rearing of livestock.

1. INTRODUCTION

To support crop yield and improve harvest quality, growers can resort to a commercial pollination service[1]. This service takes the form of an input which is inserted into the production process according to a precise timing dictated by the blooming of the crop or spontaneous vegetation to be pollinated.

Many studies on the pollination service markets (Cheung 1973, Sumner, Boriss 2007, Burgett *et al.* 2010, Rucker *et al.* 2012) reveal that beekeepers rent out the same hives more than once in the course of a year following repetitive schemes. Cheung (1973) indicates the number of allocations of commercial pollination service of beekeepers in Washington State. Sumner, Boris (2006) report the pollination periods of some crops in California and discuss rivalries and complementarities of allocations in these different periods. Burgett *et al.* (2010) discuss the migratory aspects of beekeeping and report that the U.S. national migration calendar starts with the movement of the colonies in California during the months of December and January in anticipation of the pollinating of almond trees in February and March. Rucker *et al.* (2012) describe the sequence of allocations of the itinerant beekeepers of the States of Oregon and Washington who cross the U.S. on truck trailers loaded with hives.

Economic studies on pollination service markets therefore recognize the sequential timing of pollination service allocation to crops. The sequential nature of the allocative choice of pollination service has repercussions on ecological modeling and on beekeeper management.

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[1] *Pollination service involves: 1) a strictly commercial component exchanged on the market, consisting of the renting of the hives to farmers; 2) a pseudo-commercial farm use component with the pollinating of personally-owned crops; and 3) an ecosystem component generated by the pollination of spontaneous vegetation.*

Beekeepers offer pollination services and also produce honey. On a global scale, the value of the pollination services generated by beekeeping has been estimated with different methods, and is in the 1.5-14.6 billion dollar range (National Research Council 2007, p. 23), which is greater than the value of world honey production which was $ 1.25 billion in the same period (van Engelsdorp, Meixner 2010, p.580). In the U.S., the only component of pollination service traded on the market, measured by the fees for the hives, passed from about $ 150 million in 2000 to around $ 350 million in 2009 (Rucker *et al.* 2003, 2012a); this latter value being higher than the total U.S. honey production that, in the same year, was $ 215.6 million (NASS 2011).

When pollination service is considered as a marketable output, the beekeeper's managerial model needs to be revised. The beekeeper, as well as producing honey, may rent out hives to farmers, use them to pollinate his own crops, or allocate them to sites covered by spontaneous vegetation, usually forest sites. These are alternative allocations from the static point of view, but may become complementary if projected in a chronological sequence. Consequently the number of rented hives (always the same) diverges from the number of their allocations to the sites.

For the migratory beekeeper, the choice of allocating pollination service to the forage sites becomes strategic (Pilati, Boatto 2013). The apiary is moved from site to site according to the flowering periods of the crops.

The specific characteristics of the site to be pollinated, especially the type of crop (or spontaneous vegetation) growing on it and its location (Potts *et al.* 2003), all influence the allocative choice of the pollination service.

This paper formulates a bio-economic model that determines revenues, costs, profits and gross earnings of a migratory beekeeping farm for each sequence of sites arranged in chronological order. The technical unit of production taken as reference in the formulation of the model is an apiary managed in conditions of certainty. To simplify the specification of the bio-economic model, it is assumed that the apiary produces only two marketable outputs: the commercial pollination service and honey[2]. A third output, constituted by pollination of spontaneous vegetation, is produced free of charge in the form of a positive externality of honey production. On the basis of the gross income of the sites belonging to each site-chronological regime, the conditions will be specified for discriminating the existence of jointness in sites (Pilati, Boatto 2013).

2. SEQUENTIAL DISCRETE CHOICES AND SITE-CHRONOLOGICAL REGIMES

The annual biological cycle of the apiary is divided into two phases, one of production and one of dormancy or inactivity. The production phase is composed, in the case of the migrant beekeeper, by a sequence of allocations of the pollination service to the forage sites.

In the production phase the apiary obtains revenues from honey sales and/or the pollination fees for the hives. In the dormancy phase, the apiary does not generate any revenue but is still subject to costs.

The duration of each allocation for each pollination service depends on a series of site-specific characteristics, first and foremost of which is the type of crop and/or spontaneous vegetation present on the site.

[2] *An apiary can jointly produce a variety of physical goods: honey, wax, royal jelly, pollen, propolis, bee venom, queen and worker bees. Merging all the physical goods into the production of honey involves an explicatory loss because it cancels some management regimes of the beekeeper, first of all the specialist production of swarms and queen bees.*

The allocation of pollination service to an orange grove produces honey, but provides no advantage to the crop. The revenue of the apiary therefore derives exclusively from the sale of honey.

The allocation of pollination service to a site with a kiwi crop does not produce honey. The revenue of the apiary in this case derives only from the pollination fees. The allocation of pollination service to a site with a blueberry crop boosts the harvest of the grower and allows the beekeeper to produce marketable honey. The beekeeper's revenue in this case is derived from honey production and any pollination fees. However, the vegetation is only one of the site-specific characteristics that influence the allocation of pollination service.

The location of forage sites also plays an important role because the same crop and spontaneous vegetation bloom on different dates depending on the altitude and latitude. The site location also affects the transport costs of the apiary; it may become a source of negative externalities (Siebert 1980) and also positive externalities if other sites benefit from a free pollination service thanks to their proximity. Other site-specific aspects that influence the allocation of the pollination service are the nectar producing potential and the agronomic techniques practiced on the site.

Each forage site houses the apiary for a given period of time that varies according to the crop or spontaneous vegetation. Every sequence of sites therefore corresponds to a chronology of pollination periods. The total length of the production phase of the apiary is not prearranged. The starting and ending dates depend on the size of the area covered by its migrations. The production phase of the beehive may be anticipated and/or prolonged by the appropriate choice of sites. Again, pollination service may be allocated to sites covered by crops or, alternatively, by spontaneous vegetation.

In the case of the allocation of pollination service to a forage site covered by a crop, if the crop belongs to another farm (grower) then the beekeeper obtains revenues in the form of pollination fees and/or the honey produced. In this case, when the crop allows honey to be produced, the fee for pollination service is usually lower (Rucker *et al.* 2012).

If the pollinated crop belongs to the beekeeper himself, meaning the farm has its own hives, the revenue due to the commercial pollination service remains implicit, absorbed in the revenue of the pollinated crop. The estimate of this revenue is indispensable for accurately calculating the beekeeper's profit.

The value of the pollination service can be estimated in different ways depending on the spatial scale of the analysis (Heien 2010). When an analysis is conducted at the farm scale, the cost of replacement method (Allsop *et al.* 2008), although it has limitations (Bauer, Wing 2010), appears to be more appropriate. From the beekeeper's point of view, however, the revenue in the case of personal use of the pollination service corresponds to the fees that would have been received had it been offered on the market.

Let us now consider the allocation of pollination services to a forage site covered by spontaneous vegetation. These types of sites are generally common goods with free access and the allocation of pollination service to these sites does not entail any transaction. But allocation of pollination service to these sites boosts spontaneous plant production. The result is a greater availability of food which benefits wild animals and has widespread effects on the local ecosystem in terms of conservation of biodiversity and the rural landscape. The allocation of pollination service to spontaneous vegetation therefore produces honey but also a non-marketed output, an ecosystem benefit[3].

Site-chronological regime is a sequence of sites arranged in chronological order (Pilati, Boatto 2013). Site-chronological regimes differ from one another by at least one site; the chronological sequence of sites set out by the regimes is therefore always different and original. The site-chronological regime relates the space dimension, represented by the forage sites, with the time dimension, represented by the timing of the sequential allocation of the pollination service[4]. The beekeeper assembles the site-chronological regimes and compares them to select the most profitable one. The site-chronological regimes also assume an importance from the environmental point of view when they supply different levels of non-marketed ecosystem services (Pilati, Boatto 2013).

If every forage site requires the pollination service just once in the annual biological cycle of the apiary, then each site-chronological regime corresponds to just one pollination calendar.

From a botanical point of view the site-chronological regime identifies a sequence of crops or spontaneous vegetation present on the forage sites. In this sense, the site-chronological regime also identifies a cropping regime. However, the relationship between sites and crops is not biunique; a cropping regime results as being compatible with more than one site-chronological regime because a given crop can be grown on numerous sites

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[3] *The ecosystem value of the pollination service allocated to the spontaneous vegetation is important from the perspective of agricultural and environmental policy. Public interventions aimed at the conservation of biodiversity or the rural landscape. The apiary can also act as a detector of the biological quality of the site by gathering evidence of pollutants and general site-specific information on the quality of the environment.*

[4] *A map of the sites most suitable for bee foraging according to the plant species present provides a valid management support to the beekeeper only if it is accompanied by the pollination calendar of the sites.*

in different locations. The same crop can also often have early and late varieties.

3. THE BIO-ECONOMIC MODEL

The bio-economic model formulated below assumes that the migratory beekeeper manages one apiary formed by identical hives and with homogeneous outputs for each type of crop or spontaneous vegetation present on the forage site.

The beekeeper makes discrete allocative choices for the apiary in conditions of certainty. It is assumed that the following are known ex ante: the starting and ending dates of the pollination periods for each forage site; the number and productivity of adult bees for every sequence of sites.

The apiary produces a commercial pollination service measured (proxy) by the number of forager honeybees and the physical output, honey, measured in kilograms. The apiary also produces an ecosystem service free of charge when it is allocated to a site covered by spontaneous vegetation.

The HoPoMo model (Schmickl, Crailsheim 2007) simulates the daily dynamics of the population of a bee colony. It can be used, for some basic aspects, to clarify the dynamics of adult bee populations in an itinerant apiary[5]. Unlike what is proposed by the HoPoMo model, in this bio-economic model, the number of adult bees is not measured daily but just once per forage site stay in correspondence to the intermediate date for the period of the stay.

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[5] *The seasonal profile of the dynamics of the apiary population is captured in the bio-economic model by the starting and ending dates of the pollination period for the site. The forage potential of the site is instead approximated by the type of vegetation present.*

In the HoPoMo model, the worker bees are distributed in different cohorts that perform the duties characteristic of their age. One of the cohorts is composed of forager honeybees.

In our bio-economic model of the itinerant apiary, the size of the cohort of honeybees that directly produces the pollination service is specified as a fraction of the number of worker bees, as proposed by the HoPoMo model; and this fraction is in turn a fraction of the total number of adult bees.

The honeybees that produce the commercial pollination service[6] on every site are therefore a fraction of the number of adult bees. This fraction can change during the seasons.

Each site corresponds to a fraction of adult bees that perform the honeybee function.

The site-specific characteristics that influence the growth of the bee colony in the bio-economic model are: a) the starting and ending dates of the allocation period of the pollination service; b) the type of crop or spontaneous vegetation pollinated; c) the regime the site belongs to.

For the modelling of the honey production, the number of adult bees present in the apiary is taken as reference. It is assumed for the sake of simplicity that the number of adult bees in the apiary is a multiple of that of the single colony (one beehive).

The quantity of honey produced by the apiary on a site is calculated by multiplying the average number of adult bees by the average yield of an adult bee.

By virtue of the above assumptions, the revenues of the marketable outputs become functions of the number of adult bees active on the site on

[6] *Honeybees (foragers) collect pollen, nectar, water, propolis. Only a percentage of the honeybees perform a pollination service.*

the intermediate date of the pollination period. The biological factor confers a dynamic profile on the bio-economic model that is captured in a discrete form.

In reference to the site-specific characteristics it is assumed that:

- every site is mono-floral and therefore requires the allocation of the pollination service just once during the production phase;
- every site allows the optimal number of hives per hectare - namely stocking density (Rucker *et al* 2012, p. 959) - to be reached[7];
- every site produces just one variety of honey and a yield per adult bee is obtained that varies according to the regime the site belongs to;
- all the sites to which the pollination service may be allocated have already been identified on the basis of fixed factors equipment.

We indicate with j=1,2…s=forage site; i=1,2….m = site-chronological regime; d_{0j}, d_{1j}=dates of start and end of the allocation of the pollination service to site j.

The beekeeper works out the site-chronological regimes by extracting the forage sites, properly numbered, from a predefined list. Let E_{ij} be the function of site jth belonging to the ith regime:

$E_{ij} = 1$ if jth site $\in$ ith regime

$E_{ij} = 0$ otherwise

The variable E_{ij} assumes a unit value when the jth site (hereinafter site j) belongs to the ith considered regime, otherwise a nil value.

The sites with overlapping pollination periods (d_{0j}, d_{1j}) are alternatives. Each regime therefore includes only sites with complimentary periods of pollination.

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[7] *Apicultural techniques establish the optimal number (density) of hives per hectare for every crop to be pollinated (Cheung 1973, tab.1).*

The revenue of each site-chronological regime is formed by honey production (RH_i) and commercial pollination service (RS_i):

1) $R_i = RH_i + RS_i$

The revenue generated by honey production RH_i can be specified as the sum of the revenues from the honey produced on sites belonging to the site-chronological regime:

2) $RH_i = \sum_{j=1}^{s} RH_{ij} \cdot E_{ij} = \sum_{j=1}^{s} PH_j \cdot QH_{ij} \cdot E_{ij} = \sum_{j=1}^{s} PH_j \cdot B_{ij} \cdot rm_{ij} \cdot E_{ij}$

where: RH_{ji} = revenue from the honey on site j of the ith regime;

QH_{ij} = quantity of honey produced on site j in the ith regime;

PH_j = price of the honey produced on site j of each regime.

B_{ij} = average number of adult bees active on site j in the ith regime.

rm_{ij} = average yield of an adult bee active on site j of the ith regime.

In every site-chronological regime some values of RH_{ij} assume a nil value because it only includes some of the forage sites j=1,2…s; but RH_{ij} also assumes a nil value when site j, while belonging to the considered regime, does not produce honey, as in the case of site j=s.

However, the belonging of site j to the ith regime requires that at least one of the two outputs is not nil. If RS_{ij} = 0 and RH_{ij} = 0, site j does not belong to the ith regime with the only exception of dormancy or base site j=s , which is true for all regimes. In line with this, site j=s is the start of all regimes.

When the crop does not allow the apiary to produce honey, the revenue from honey on site j is nil for any regime.

The quantity of honey produced on site j can vary with the site-chronological regime, but not the price of the honey as this depends on the variety produced, i.e. by the crop or spontaneous vegetation that covers the site.

Assuming that each variety of honey is traded on a perfectly competitive market, the price of the honey produced on site j becomes an exogenous parameter with respect to the allocative choice of the apiary.

The average yield of honey from an adult bee on site j of the ith regime is calculated by dividing the quantity of honey produced by the apiary on the site by the number of adult bees B_{ij} active on the same site at the intermediate date of the pollination period. B_{ij} is a biological variable and configures the model of the migratory beekeeper as a bio-economic model.

Multiplying the number of adult bees active on site j of the ith regime by the average yield rm_{ij} of an adult bee, the quantity of honey produced is obtained ($QH_{ij} = rm_{ij} \cdot B_{ij}$).

The average yield rm_{ij} depends on the characteristics of the pollinated site, type of hive and species of bee[8], but as will be clarified below, also on the site-chronological regime to which the site belongs.

The second marketable output produced by the beehive is the commercial pollination service. The revenue from this service can be specified as the sum of the pollination fees paid for sites belonging to the ith regime:

3) $RS_i = \sum_{j=1}^{s} RS_{ij} \cdot E_{ij} = \sum_{j=1}^{s} PS_j \cdot BF_{ij} \cdot E_{ij} = \sum_{j=1}^{s} PS_j \cdot \alpha_{ij} \cdot B_{ij} \cdot E_{ij}$

where: $RS_{ij} =$ revenue of the commercial pollination service on site j in the ith regime;

[8] *The average yield of a honeybee depends first of all on technical/biological data: the species of honeybee (e.g. Apis mellifera), construction technique of the hive, etc. These data are exogenous variables of the bio-economic model.*

$PS_j =$ price of the commercial pollination service of a honeybee on site j of each regime;

BF_{ij} = average number of forager honeybees active on site j in the ith regime;

α_{ij} = average percentage of adult bees on site j in the ith regime participating in honey collection (forager honeybees).

The price PS_j of the commercial pollination service provided by a honeybee on site j is calculated by simply dividing the current market price for the bee colony pollination fee (allocation to the crop on site j) by the number of forager honeybees present in the colony on the intermediate date of the pollination period. If it is assumed that the market is competitive, the price of the commercial pollination service becomes an exogenous parameter, independent with respect to the allocative choice.

The number of forager honeybees supplying the commercial pollination service can be specified as a fraction α_{ij} of the number of adult bees ($BF_{ij} = \alpha_{ij} \cdot B_{ij}$).

Some values of $RS_{ij} = 0$ appear in every site-chronological regime because they include only some of the j=1,2…s forage sites; RS_{ij} always assumes a nil value for the dormancy site j=s.

Substituting equations 2) and 3) in equation 1) obtains the specification of the total revenue of the apiary in the ith regime as the sum of the revenues obtained from honey and the commercial pollination service on the sites that form:

4)

$$R_i = \sum_{j=1}^{s} PH_j \cdot rm_{ij} \cdot B_{ij} \cdot E_{ij} + \sum_{j=1}^{s} PS_j \cdot \alpha_{ij} \cdot B_{ij} \cdot E_{ij} = \sum_{j=1}^{s} (PH_j \cdot rm_{ij} + PS_j \cdot \alpha_{ij}) \cdot B_{ij} \cdot E_{ij}$$

The beekeeper chooses E_{ij}, i.e. determines the chronological sequence of the sites to pollinate and consequently identifies the parameters B_{ij}, rm_{ij}, α_{ij}. The parameters PH_j, PS_j are instead, as already mentioned, exogenous.

Because the apiary stays on site j for t_j days, the average daily revenue DRb_{ij} of an adult bee on site j of the ith regime will be:

5) $DRb_{ij} = R_{ij} / t_j \cdot B_{ij}$

where: $t_j = d_{1j} - d_{0j} =$ number of days the apiary stays on site j of each regime.

If the commercial pollination service is allocated to a site on a grower's farm, it will be necessary stipulate a contract and sustain a transaction cost (Rucker *et al.* 2012).

The total cost of the apiary TC_i in the ith regime is given by the sum of the production cost and transaction cost:

6) $TC_i = FC + \sum_{j=1}^{s} VC_{ij} \cdot E_{ij} + \sum_{j=1}^{s} TRC_j \cdot E_{ij}$

where: FC = fixed production cost;

VC_{ij} = variable production cost of the apiary allocated to site j in the ith regime;

TRC_j = transaction cost of the apiary allocated to site j in each regime.

The production cost of every regime includes fixed costs and variable costs. There is, in the short-term, only one fixed cost amount i.e. it is independent of the site-chronological regime; the availability of fixed factors in fact defines the list of accessible sites and, consequently, the practicable set of site-chronological regimes. The variable cost of the apiary corresponds, according to the scheme already applied on the side of the revenues, to the sum of the variable costs of the sites included in the ith regime.

The transaction cost can be specified as the sum of the transaction costs of the sites included in regime. Each site j has a transaction cost independent of the regime to which the site belongs. This is approximated to a fixed cost, even though a variable component of the transaction cost can be identified (Nigel *et al.* 2000).

The profit of the apiary for each regime corresponds to the difference between the revenues and total costs:

$$7)\pi_i = R_i - TC_i = \sum_{j=1}^{s}(PH_j \cdot rm_{ij} + PS_j \cdot \alpha_{ij}) \cdot B_{ij} \cdot E_{ij} - (FC + \sum_{j=1}^{s} VC_{ij} \cdot E_{ij} + \sum_{j=1}^{s} TRC_j \cdot E_{ij})$$

Equation 7) can identify:

- the ranking of the regimes based on the obtainable profit;

- the percentage of the revenue due to honey RH_i / R_i and to the pollination service RS_i / R_i for each site-chronological regime; this aspect sometimes has fiscal relevance.

To ascertain the presence of economies of scale in the ith regime it is necessary to simulate the variation of the average production cost of the apiary as the number of hives increases. Economies of scale are registered in the site-chronological regime if the average production cost of the ith regime decreases with the increase of the number of hives in the apiary.

To verify the presence of short-term economies of scope, with the same regime, i.e. revenues, the sum of the total costs of two specialists, beekeeper and farmer, must be compared with the total cost of the multi-output farm (Boatto, Pilati 1999) that integrates beekeeping and crops. Maintaining the site-chronological regime unvaried is necessary because the products (the scope) of the apiary could change with the sequence of sites. The condition of invariance in the site-chronological regime renders the empirical verification of the presence of short-term economies of scope extremely difficult.

3.1 - Jointness in sites

To verify the presence of jointness in sites the gross earnings GI_i must first be calculated for every site-chronological regime:

8) $GI_i = \pi_i + FC + TRC_i = \sum_{j=1}^{s}(R_{ij} - VC_{ij}) \cdot E_{ij} = \sum_{j=1}^{s} Gi_{ij} \cdot E_{ij}$

with: $Gi_{ij} = R_{ij} - VC_{ij}$ = gross income of the apiary allocated to site j in the ith regime.

The presence of jointness in sites can be verified by comparing the gross income Gi_{ij} obtained from site j in each regimes to which it belongs. There is no jointness in sites if:

9) $Gi_{ij} = Gi_j \qquad \forall$ j $\in$ ith regime, $\forall$ i

If the condition of equation 9) holds, the gross income of each site j is independent of the regime to which it belongs. The function of the gross income of each regime would in that case be separable and additive in the sites.

There is no jointness in sites on the revenues side if the apiary allocated to site j obtains the same revenue independently of the regime to which it belongs:

10) $R_{ij} = R_j \qquad \forall$ j $\in$ ith regime, $\forall$ i

Equation 10) is verified if (see equation 4) the following parameters are independent of the regime:

11) $B_{ij} = B_j \qquad rm_{ij} = rm_j \qquad \alpha_{ij} = \alpha_j \qquad \forall$ j $\in$ ith regime, $\forall$ i

There is no jointness in sites on the costs side if the variable cost of the apiary allocated to site j is independent of the regime to which it belongs:

12) $VC_{ij} = VC_j \qquad \forall$ j $\in$ ith regime, $\forall$ i

If equations 10) and 12) are not respected it is necessary to proceed to the identification of the sites responsible for the jointness.

There is jointness in sites if the gross income of the apiary allocated to site j changes with site-chronological regime. The comparison is made between the gross income of the same forage site observed in different regimes to which it belongs.

The analysis of the source of jointness in sites follows the same approach as that for no jointness.

There is jointness in sites on the revenue side if the revenue of the apiary allocated to site j changes with the sequence of the sites, i.e. with the site-chronological regime to which it belongs. This jointness is explained by the fact that parameters B_{ij}, rm_{ij}, α_{ij} depend on the sequence of site. Changing the regime of the site may, among other things, involve an early start to the production phase of the bee colony (Pilati, Boatto 2013).

There is jointness in sites on the side of the costs if the variable cost of the apiary allocated to site j changes with the sequence of sites, i.e. with the site-chronological regime to which it belongs. The simplest reason for this jointness in sites is due to the variable cost of transport; the distance to be covered to reach site j depends on the location of the forage site that precedes it in the site-chronological regime (Pilati, Boatto 2013).

4. CONCLUSIONS

The allocation of pollination service to forage sites during the production phase of the apiary is the largest factor in determing management choices for the migratory beekeeper. According to the crop or spontaneous vegetation present on the site being pollinated, the beekeeper obtains a revenue from the sale of honey, from pollination fees or from both. The discrete, sequential bio-economic model of the migratory beekeeping farm formulated in this paper specifies revenues, variable costs and gross income of site-chronological regimes as the sum of those of the sites belonging to them. This allows the site-chronological regimes to be ranked on the basis of obtainable profit.

Simulating variations of the average cost of production by varying the number of hives in the apiary, the presence of economies of scale can be tested within each site-chronological regime. Short-term economies of scope are instead difficult to test because the comparison between the production costs is conducted in the same site-chronological regime.

There is no jointness in sites if the gross income of each site j is independent of the regime to which the site belongs, i.e. if the function of the gross income of each regime is additive and separable in the sites.

Jointness in sites can arise on the side of the revenues, on that of the variable costs or on both sides simultaneously.

There is jointness in sites if the revenues or variable costs of the apiary allocated to site j change substituting the site-chronological regime to which it belongs. There is jointness in sites on the side of the revenues when the number of adult bees present on site j, the average yield of an adult bee, or the fraction of honeybees on the same site change with the regime. There is jointness in sites on the side of the variable costs when the variable cost of the apiary allocated to site j changes with the regime to which it belongs.

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