Competition in the Manuka Honey Industry in New Zealand

by

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Acknowledgments. I would like to thank Peter Bray, Robert Dixon, Linda Newstrom-Lloyd, Donald Maclaren and Kerrin Vautier for comments on earlier drafts of the paper and my colleagues Peter Bardsley and Tony Klein for assistance with the equations of the model.

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Abstract

This paper examines the problems of spatial competition in the beekeeping segment of the New Zealand manuka honey industry. Competition between two close apiaries results in negative reciprocal production externalities. A basic geometric model of spatial competition between two apiaries is developed. Various forms of possible management and regulation of the industry are explored, drawing on the experience of management and regulation of production activities with similar externality problems, particularly oil and gas reservoirs, and New Zealand competition policy.

Key words: manuka honey, spatial competition, production externalities, regulation

Competition in the Manuka Honey Industry

1. Introduction and Brief Profile of the Industry

As manuka honey[1] production in New Zealand has expanded very rapidly in the last seven years or so, a number of economic problems have emerged. These include the problem of setting product standards in the industry and adulteration, and that of protecting consumers from false or unsupported claims of medical benefits from the use of manuka honey. Consumer doubts about the quality of manuka honey products and their health benefits threaten the reputation of the industry. The New Zealand industry is also concerned about the use of the generic name of "manuka" honey (called the "geographical indication" in WTO trade law) in Australia. Another substantial problem is the unregulated aggressive competition among beekeepers for access to the limited stock of manuka bush hive sites.

In early 2017, the Ministry for Primary Industries released a 'scientific' definition of manuka honey as a part of its consultation with the industry to develop product standards (Ministry for Primary Industries, 2017c) and proposed new export requirements for all bee products (Ministry for Primary Industries, 2017d). Claims of medical or health benefit are a matter for separate government regulation through product standards and consumer protection law. In August 2017, New Zealand honey producers announced they had applied for exclusive trademarks on "manuka honey" in the major countries buying the honey in world markets, including Australia. By contrast, aggressive competition among beekeepers seems to have received little attention. It is an interesting problem in the economics of regulation and competition policy.

The manuka honey industry is a part of the honey industry.[2] Manuka honey sells at the top end of the market for honey types. It is marketed as an anti-bacterial agent and health food. The price for bulk manuka honey, which is the price paid to the beekeepers, is on average several times that of the prices paid to beekeepers producing other honey types (Ministry for Primary Industries, 20171, Table 5). Prices per kilogram for bulk manuka honey ranged from $12 up to $148.00 in 2016. Retail prices also range very widely, depending on the rating of the product and to a much lesser extent on the quantity purchased. For the highest rated products, that is, pure manuka honey,[3] retail prices range up to just over $1,000 per kilogram. With a wide gap between bulk and retail prices for manuka honey, large profits have been made by honey processors and packers downstream of the beekeeping operation, selling both on the New Zealand market and exporting. This paper deals only with the upstream beekeeping sector of the manuka honey industry.[4]

As a consequence of the rapid increase in international demand for manuka honey, especially in China, the bulk price for manuka honey has more than doubled in the last five years (Ministry for Primary Industries, 2017a, Table 1). Along with this, the volume of production of manuka honey has soared. Together these trends have made the industry very profitable. Fortunes are being made by the incumbents in the industry.

This in turn has attracted many new entrants into the industry. Some of them were established beekeepers who previously harvested only non-manuka honey types and some of them entrants into beekeeping. Foreign investors have entered the industry. Corporate enterprises, which are much larger than the industry average in terms of hive numbers, are increasing their share of the manuka honey production. Areas of manuka bush not previously harvested have been opened up; the Department of Conservation have greatly increased concessions on the Public Conservation Lands which it manages and Iwi production is being encouraged by Maori groups and the government. The Ministry for Primary Industries is working with the industry to trial manuka plantations in order to supplement wild harvesting from natural manuka blocks. It is hoped that large-scale high-performance science-based plantations will boost aggregate national output. The Ministry has said that the value of the New Zealand manuka honey industry could grow from an estimated $75 million in 2010 towards $1.2 billion per year (Ministry for Primary Industries, 2017b). New cultivars are being developed to increase hive yields.

As a consequence of these trends, manuka honey apiary[5] and hive numbers and annual production of manuka honey have all grown rapidly. Unfortunately, the statistics of apiary and hive numbers and annual production (Ministry for Primary Industries, 2017) cannot provide a breakdown of the totals for the manuka honey type alone because of the lack in the past of a consistent definition of manuka honey; sales of 'manuka' in New Zealand are sales of both the manuka and the kanuka species of tea tree as both are commonly called 'manuka', and sales of both manuka and kanuka honey vary in their purity. Consequently, there are no time series of annual production of manuka honey in New Zealand. Wikipedia (2017) gives a figure of 1,700 tonnes of manuka honey produced in New Zealand but this is only a rough calculation[6]and other industry sources give a figure of around 3,000 tonnes when kanuka honey is included.[7] (The total for all honey types was 19,885 tonnes in 2016.)

This paper provides an overview of the beekeeping sector of the manuka honey industry. It focuses on the nature of competition among beekeepers. The form of competition leads to inefficient production as well as conflict between beekeepers. Later sections of the paper examine the possibilities of management or regulation of the industry to resolve competition issues and to improve the efficiency of production in this industry.

2. Competition among Beekeepers

Competition in the beekeeping segment of the industry takes the form mainly of competition for hive sites. Given that the stock of manuka bush is fixed in the short run (which can be equated with one summer honey season), competition among beekeepers for hive sites has increased with the growth in apiary numbers. (There is also competition for wintering sites.) Apiary rentals for manuka sites have increased rapidly in the last two years and in 2016 rental fees were up to $1,000 per apiary (Ministry for Primary Industries, 2017a, Table 7). As an illegal form of competition, there have been instances of the poisoning and sabotaging and stealing of hives (Ministry for Primary Industries, 2017a, p. 12). There is growing concern that the increase in apiary and hive numbers may also reduce the aggregate production by all hives in some areas (see Newstrom-Lloyd, 2015 and McPherson, 2016 and 2017).

These problems arise because of the nature of the industry. It is one in which there is free entry because there are no entry barriers in the form of large scale or complex technology required for production and there is no government limitation on entry into the industry. The official statistics for 2016 show that there were 6,735 registered[8] beekeeping enterprises. Of these many were hobby farmers (defined as enterprises with up to 50 hives). At the other end of the distribution of enterprises by hive numbers, 29 were classified as “mega commercial” enterprises (defined as enterprises with more than 3,000 hives each). The largest of these had over 30,000 hives and in the aggregate mega commercial enterprises managed 34 per cent of all registered hives.

Commercial enterprises have many apiaries and their apiaries each have many hives. Long term commercial beekeepers know by trial and error over a number of years how many hives in one apiary will give them the best return for the apiary. This number varies from site to site, depending on the climate and the floristic resources of the location (Newstrom-Lloyd, 2015 and Department of Conservation, 2015, p.11). The national average for all apiaries and all types of honey is around 15 hives per apiary (Ministry for Primary Industries, 2017a, Table 4)

Moreover - and this is the central point - the production of one beekeeper affects the production of other beekeepers in the neighbourhood. For this purpose the neighbourhood of one apiary may be defined as the area surrounding the site which is visited by bees from hives on the site. The foraging range of bees is around three to five kilometres from the hive[9]. Customarily in New Zealand, beekeepers observed the rule that they would not locate apiaries of new hives within three kilometres of existing hives. In the recent past this distance was reduced to two kilometres. This custom has broken down and as a consequence there is an overlap between the foraging areas of some apiaries.

Interaction among beekeepers is a *production externality*. A production externality arises when one producer's activities affect other producers in a way or ways which do not operate through the market. A standard textbook example of production externalities are the effects of a steel mill releasing pollutants into a stream, which reduces the output of downstream fisheries. Most production externalities are negative, that is, the output of one producer reduces the output of another or others. This is true too of the manuka honey beekeeper problem in which a new entrant into the industry located within a few kilometres of an incumbent reduces the annual output of the incumbent.

3. Analysis of Production Externalities

Each externality problem is different because each has its own unique characteristics of the generation of the externality and the ways it affects other producers. Positive production externalities, in which the production activities of one producer have a positive effect on the output of one or more other producers, are rare. By a surprising coincidence, the standard example is actually from the bee industry again. This is the case of a beekeeper and an orchardist, made famous in the literature of economics by James Meade (1952).[10] It yields a double reciprocal positive externality: the orchardist has a positive effect on the beekeeper because his flowering fruit trees provide nectar and pollen for the bees and the beekeeper has a positive effect on the orchardist because his bees pollinate the fruit trees.

This beekeeper-orchardist case has attracted a large literature, mainly in the USA. The thrust of this literature is that the externality has been captured or "internalized" by the emergence of well-organized markets for pollination services (see the classic article by Cheung, 1973 and the recent survey by Rucker, Thurman and Burgett, 2014).

The manuka honey problem is a different problem. It involves a negative externality from the close proximity of two (or more) apiaries operated by two (or more) beekeepers. Usually the reporting of this case points to the entrant beekeeper who sets up a new apiary with no regard to the effects of bees in his apiary on the output of bees in a neighbouring apiary or apiaries.

Competition between any two (or more) neighbouring apiaries of bees is a case of spatial competition. The competition can be illustrated by some geometry.

4. The Geometry of Spatial Competition between Apiaries

To analyse competition among two (or more) beekeepers, one needs a model of competition based on the harvesting area of an apiary. The analysis of this competition is an exercise in Euclidean geometry.

Begin with a single isolated apiary of bees, located at a point L_1. The harvesting area is a circle whose radius is determined by the maximum distance that bees forage from the hives in the apiary. In reality this radius is not fixed as it will depend on the supply of nectar and pollen available, the weather and other factors. However, we may take it as an average over a period of time and therefore fixed. Further, the radius of the circle may be taken to be unity without any loss of generality. Consequently the area of the circle is π. We will take this to be the apiary of one beekeeper called Beekeeper 1.

Now consider that a second beekeeper, Beekeeper 2, establishes a new apiary in the neighbourhood. This is located at the point L_2. The two apiaries are sufficiently close that the harvesting areas overlap. This situation is depicted in Figure 1. The circle depicting the harvesting area of Beekeeper 2 is identical to that of Beekeeper 1 (i.e. it has the same radius and hence the same area). The area A is the intersection of the set of points within the two circles. It is the *area of competition* between the bees of the two beekeepers. This area may be expressed as a fraction of the area of the circle of Beekeeper 1, $c = A/\pi$.

Within the area of competition bees from the hives of the two beekeepers compete for the supply of pollen and nectar. The main negative externality effect of this competition is to reduce the actual manuka honey collection of Beekeeper 1 below the potential honey collections that exists within the radius of the circle if there is no competitor. A second negative effect is that the bees in the apiary have less food which compromises the colony reproduction and increases the risk of pests and diseases and of robbing between hives. In severe cases, this may result in the loss of colonies (hives).[11] These effects from the closeness of apiaries are known as “overcrowding”. From the point of view of efficient production, overcrowdding has the effect of increasing unit costs and may reduce aggregate output (Newstrom-Lloyd, 2016 and McPherson, 2017).

There is a second source of putting too many bees in a given area for efficient production, namely "overstocking". Overstocking is putting too many hives in one apiary. (Brown et al, forthcoming). This results in reducing the output of each hive and, like overstocking, may increase the risks of diseases, pests and colony loss. However, the reduced hive production affects mainly the beekeeper who overstocks rather than the neighbouring beekeeper. It is due to the inexperience of new beekeepers. Hence, the variable of the number of hives in an apiary is not included in the subsequent analysis.

While this competition has been viewed from the point of view of the first beekeeper, it should be noted that the area of competition applies equally to the second beekeeper. The proximity of two apiaries means that the hives of Beekeeper 1 lower the harvest of Beekeeper 2's bees and at the same time the hives of Beekeeper 2 lower the harvest of Beekeeper 1's bees. Thus, it is an example of a double reciprocal production externality where both production externalities are negative. This is the first example of a double negative production externality in the literature on externalities to my knowledge. Moreover, the reciprocal externalities are symmetric, that is, both beekeepers share the same area of competition.and their production is affected in the same way.[12]

Competition between two (or more) beekeepers also poses a societal problem. The social or economy-wide objective in this analysis is efficient production. This involves maximising the value of honey production net of production costs. In the case of this industry there is no need to add a concern over possible effects of competition among beekeepers on consumer prices. The beekeeping segment of the industry is fiercely competitive and individual beekeepers have no market power. Moreover, the price received by the beekeepers is a small fraction of the consumer price charged downstream. Any concern over overpricing to consumers should be addressed at the retail stage.

To achieve this objective of efficient production, there will be an optimal location of apiaries. A sub-optimal location will result in overcrowding, which will increase unit costs and may reduce aggregate output.

When the location of two neighbouring apiaries is fixed, the area of competition is fixed. If the two apiaries were to move closer together, the area of the intersection of the two circles would increase. However, the relationship between the distance between the two apiaries, *the* *separation distance*, on the one hand and the *area of competition* on the other is not a simple linear relationship. The precise relationship is derived in the Appendix and it is given by the function in Equation (2).

This function relating the separation distance to the area of competition is essential to understanding competition in the manuka honey beekeeping industry. It is also essential to the societal problem of locating apiaries so as to maximise the net value of honey production from a given area of manuka bush. (See Appendix for further discussion).

Besides beekeepers**,** there is another set of economic agents who play an essential role in determining the nature of competition in the manuka honey industry. These are the landowners who must grant permission for an apiary of hives to be located on their land when the honey producer is not the landowner. The right to locate hives at a location on his/her land is sold for a price, typically for one honey season, under a Land Use Agreement. Hive rentals in the industry are based on a fixed price per hive or a percentage of the crop or a combination of both.

Landowners too have sought to increase their income from hive rentals as the profits from manuka honey beekeeping have risen rapidly. Land Use Agreements reached between the landowners and the beekeepers will decide the extent of competition in the industry, including the areas of competition which give rise to conflict and overcrowding. Some landowners are known to have invited more than one beekeeper to put hives on their land. In such cases a landowner has an incentive to maximise the aggregate net production from the land as this will maximise their own hive rental income. Mistakes have been made in allowing overcrowding on the land of one landowner due to inexperience but such mistakes will tend to be corrected in the self-interest of the landowner. When a manuka bush stand can be accessed from the land of more than one landowner, however, the danger of overcrowding will persist.

5. Management or Regulation of Production Externality Situations

What I am calling the manuka honey competition problem has not received attention from economists in New Zealand or elsewhere to my knowledge. The last Apiculture Monitoring Programme report recognises the problem: “Tension between neighbouring beekeepers and/or landowners has in some cases led to hive theft and vandalism.” It then adds “Regulatory controls are being promoted by some, but industry, local and central governments recognise the legal and practical challenges of implementing and policing regulatory controls over apiary site placement." (Ministry for Primary Industries, 2017a, p. 12).

The manuka honey problem is a very different problem to the bee pollination externality problem which has received so much attention in the economics literature. The central issue in the manuka honey industry is how to manage or regulate the industry so that competition between neighbouring apiaries operated by different beekeepers is fair and the aggregate value of production of manuka honey from a given area of bush is maximised.

This manuka honey production problem is an example from the family of externalities known as the Problem of the Commons. This includes many well-known externalities such as animal grazing on Commons land, fisheries, water basins, irrigation schemes, oil and gas reservoirs, and climate change. All of these externalities arise because agents have access to common resources. In each problem a non-cooperative market solution is inefficient, that is there is a market failure.

Elinor Ostrom has analysed governance issues in common pool resources, especially irrigation systems and fisheries.[13] Her analyses show that government regulation in an attempt to improve efficiency usually does not produce an efficient solution and may be worse that the market solution. This is sometimes called government failure. Moreover, her analyses show that left to themselves the market operators on the commons in some cases produce a voluntary cooperative solution that eliminates conflict and leads to an efficient outcome. (See the survey by Aligica and Sterpan, 2017.) The foremost condition required for the emergence of a voluntary cooperative community solution is closed access, the ability to control access to the common resource (Ostrom, Chang, Pennington, and Tarko, 2012).

The manuka honey production problem has most similarity to one well-explored case of the Problem of the Commons, namely, that of production by multiple operators on a common (sub-surface) oil reservoir. In each case, competition occurs over a well-defined area. An oil reservoir is like a block of manuka bush. Several beekeepers may have access to this stand, just as several operators have access to a common oil reservoir; they share a common resource. Moreover, in the case of both an oil reservoir and manuka bush stand, access to the common resources is controlled by owners of the land.

Management and regulation of oil reservoirs has received huge attention, chiefly in the USA where the rights to extract oil (or gas) underground are held by the surface landowners or by leasors who have acquired the rights from the landowners. This is known as the 'rule of capture'; the situation in which 'the owner of a tract of land acquires title to the oil and gas which he produces from wells drilled thereon, though it may be proved that part of such oil or gas migrated from adjoining lands' (quoted in Kenyon, 2014, p. 2). US Courts have upheld this rule. Kenyon (2014, p.2) notes

> One effect of this ruling, among others, was the creation of a highly competitive practice of drilling in the US, with each landowner drilling as many wells on his land as possible in order to ensure maximum production from his part of the field, even going so far as to drill on the very edge of the lease line in the hope of extracting oil or gas which may have migrated from his or her neighbour's land.

This literature noted the inefficiency of competitive market access to a reservoir. Each of the producing firms has an incentive to maximise the economic value of its own lease rather than that of the reservoir as a whole. A competitive or non-cooperative outcome results in several inefficiencies. There may be too many wells resulting in excessive capital costs, wells may be located in the wrong places and the aggregate value of oil produced may be less than the maximum possible.

This oil reservoir case is of interest to analysts of the manuka honey problem. There is a market for access to manuka bush as beekeepers pay farmers and other landowners for the right to locate hives on their land, just as there is a very well developed market for land and leases on an area covered by an oil reservoir. As noted above, the unregulated market for manuka sites results, in some sites, in overcrowding of hives and excess costs and it may result in an aggregate output less than the maximum possible, as in the oil reservoir externality problem.

Our chief interest in the oil reservoir problem is in the remedies to the problem of inefficient production which have developed in the oil reservoir case. One remedy in the situation of oil reservoirs is unitisation. 'With unitisation, a single firm, often with the largest leased area, is designated as the unit operator to develop the field as a whole.' (Libecap, forthcoming). The unit operator has an incentive to maximise the output of the whole reservoir, with the individual rights holders sharing in the net profits of the field on an agreed formula. Unitisation makes optimal well placement and production possible. It is another example of a voluntary cooperative solution to the Problem of the Commons. In practice, there are difficulties due to the imperfect and uncertain knowledge of the properties of the field and the consequential difficulty of negotiating a unit agreement (Libecap, forthcoming and references therein). For this reason only a small fraction of reservoirs are managed by a unit manager.

A related remedy is for one operator to buy out all others. The negotiation of an agreed purchase price for each of the other leases faces the same valuation problems as that of negotiating a unit agreement.

Another possible remedy is government regulation. The markets for oil and gas are highly regulated in some countries.

6. Applying the Analysis to the Management or Regulation of Manuka Honey Production

Should the manuka honey industry be self-managed by the industry or regulated by the government?

The status quo is no regulation of the beekeeping industry. It allows any beekeeper to establish hives wherever it wishes. The market for hive site services then determines freely the location of hives and manuka honey production. (Legal remedies for sabotage and poisoning or interfering with the hives of other beekeepers remain, as do regulations relating to bee health and biosecurity).

In the case of manuka honey production, a voluntary solution by the industry itself through unitisation does not seem feasible in general. The chief difficulty is that the Ostrom condition of closed access is not met. There are typically many possible locations for hives inside and outside a manuka block on parcels of land owned by different landowners and the number and location of hive sites changes over time as beekeepers sign new agreements with landowners. There is, however, an exception. Manuka stands on Crown land or Maori land offer the possibility of a unitised operation. Similarly, if large scale manuka plantations are created in the future, they would have a unitised operation. At the present time, large single-ownership stands account for only a small part of total manuka honey production.

The next possibility is self-regulation by the industry. This could be by means of a code of conduct. A code could include a separation rule and other rules. Apiculture New Zealand, the peak bodies for the beekeeping industry since it began in April 2016, has recently developed a Beekeeper Code of Practice (Apiculture New Zealand, 2017). Clause 1.8 of the Code requires that members of the Association '…respect appropriate distances between his/her hives and another beekeeper's hives'. What distance is 'appropriate' is not specified.

A precise rule could specify the minimum distance between apiaries. With the knowledge of the relationship between the separation distance and the area of competition, the separation distance could be fixed so as to restrict the area of competition to some pre-set limit. For example, it might be decided that a new apiary must be located such that the area of competition is no more than a fixed percentage of the area of an established apiary. If competition conforms to the basic model in the Appendix, Equation (2) tells us that the relationship between the separation distance on the one hand and the area of competition on the other. Suppose we set the limit of overlap at no more than, say, 20 per cent of the area of an established apiary. Then, from this equation, the proximity distance (p) can be no more than 32 per cent of the distance between the established apiary and point of location of the second apiary which would produce zero competition between the two apiaries. (See Figure 2.). Hence, the separation distance (d = 1-p) must be at least 68 per cent of this distance If the bee harvesting distance is set at, say, three kilometres, this distance is 6 kilometres. That is, the two apiaries must be at least 4.08 (= 0.68x6) or roughly 4 kilometre apart if the area of competition is to be no more than 20 per cent of the harvesting area of the established apiary. As a part of its management of Public Conservation Land, the Department of Conservation (2015, p.11) assumes a foraging distance of 3km but it imposes a 6 km exclusion zone between apiaries. This rule results in zero competition between two neighbouring apiaries, which is very conservative[14].

One difficulty with a separation rule is that it gives priority to the incumbent producers. While this is the effect of the traditional customary separation rule, and seems to be a rule favoured by many in the industry today, protection of incumbents may lead to higher cost production and is inequitable. Moreover, the ease of entry and the past history of the industry suggest that a code will not be fully effective. Experience with self-regulation in other industries indicates that, when the conditions for a voluntary cooperative solution are not met, for some prducers, the profit incentives for producers will override consideration of collective benefits.

Since the passage of the Commerce Act 1986, the New Zealand approach to industry regulation has been to avoid regulation of an industry and to deal with competition problems in an industry by reference to competition law if and when they occur. (The exceptions are a handful of industries which present problems from the point of view of competition due to the presence of networks or other special features: telecommunications, electricity supply and the dairy industry. These are subject to special regimes under competition law.) Part 2 of the

Commerce Act lays down the condition under which the provisions relating to restrictive trade practices may be applied; these cover contracts or agreements or covenants which lessen competition in a market or take advantage of market power, and price fixing. For the purposes of competition law, a market is a well-defined product market and geographic area. The externality problems outlined in previous sections are local problems, involving mostly competition between two or a few apiaries and their beekeepers. To date there have been no investigations of competition problems in the industry by the Commerce Commission.

7. Conclusions

Spatial competition for hive sites has given risen to conflict between manuka honey beekeepers in a rapidly expanding industry and to some inefficient production. An approach to competition policy through competition law rules out regulation which would have the government or an appointed government authority decide who is permitted to establish apiaries and in what location and with how many hives. Self-regulation has not resolved the beekeepers' competition problems. The industry has been unable to agree on a precise separation rule and an industry rule is in any case not fully enforceable. Beekeeper competition problems seem likely to persist. This outcome resembles that of the similar situation involving oil reservoirs on private land in the USA.

In the longer term, competition problems may be ameliorated by the growth of large single-ownership manuka bush stands. Opening up new stands of manuka bush may have relaxed the constraints of a fixed supply of hive sites. On the other hand, the rapid increase in apiary numbers has exacerbated the competition problems.

More information about competition in the industry needs to be gathered. The manuka industry is now an important industry in its own right.[15]

When the definition of 'manuka honey' and the export requirements announced by the Ministry for Primary Industries in April 2017 are fully implemented, it will be possible to compile production, sales and export statistics for the manuka honey sector of the honey industry. It will also be possible to map the location of all apiaries which produce manuka honey. This can reveal the frequency of overlap in the harvesting areas of individual apiaries.

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Appendix

The Geometry of Spatial Competition between Beekeepers

We want to analyse how the area of competition between the two apiaries is affected as the colonies move closer together. To do this begin with the hypothetical situation in which two apiaries are just sufficiently far apart to avoid competition. This is depicted in Figure 2. The two (identical) circles here touch each other. The centre of the second circle is denoted by the Point L. There is zero intersection at this location point. Draw the line connecting the centres of the two circles.

Now we can consider what happens to the area of intersection, the area of competition (c), as the location of Beekeeper 2 shifts towards the fixed location of Beekeeper 1 along the line L_1L. Consider L_2 at an arbitrary distance along the line, say L^0. This point divides the line L_1L into the two sections L L^0 and L^0L_1. These may be called the *proximity distance* and the *separation distance* respectively, or P and D. The former measures how close the colony of Beekeeper 2 has moved towards the colony of Beekeeper 1 and the latter measures the distance remaining between. By construction, P + D = 2r = 2. Dividing both P and D by 2, we get p = P/2 and d = D/2, with p + d = 1. p and d are respectively the proximity distance and the separation distance measured on a scale from 0 to 1. When the two colonies are located so that the circles just touch, we have p = 0 and d =1. As the location of L_2 is moved towards L_1, the area of intersection, the *area of competition* (A), and therefore $c = A/\pi$ increase. At the unity end of the scale, the two colonies are at the same location and have the same circles as harvesting areas, i.e. p=1 and d = 0.

We seek the graph of the function c = f (p). It starts at the points (p =0, c =0) and ends at the point (p = 1, c=1). It is a continuous and strictly increasing function of p, but it is non-linear.

For any given p, the area of competition is given by intersection of the circle of Beekeeper 2 with the circle of Beekeeper 1. See Figure 4. Draw straight lines form the centre L_1 to the two points where the two circles intersect. This defines the angle θ. Given θ, the area of the segment of the circle defined by this angle ABEC is θ/2. The area of the triangle ABC is [sin (θ/2) cos (θ/2)]. A, the area of intersection, is then twice the difference between the area of the segment of the circle and the area of the triangle:

$$A = 2[\theta/2 - \sin(\theta/2)\cos(\theta/2)] \qquad (1)$$

As a fraction of the area of the circle, this gives

$$c = 2[\theta/2 - \sin(\theta/2)\cos(\theta/2)]/\pi \qquad (2)$$

where $d = \cos(\theta/2) = 1-p$ or $p = 1 - \cos(\theta/2)$

define the relation between the distance p and the angle θ.

The graph of the function $c = f(p)$ is in Figure 5.

As an example, take $p = ½$, the midpoint M on the line LL_2. This case is depicted in Figure 3. Note that the area A is less than the area of the semi-circle. Therefore $c < 1/2$. From Equation (2), it is in fact $c = 0.36$.

The line $c = p$ is drawn for comparison in dotted form. Note that the function $c = f(p)$ lies below the line $c = p$ throughout the whole range of $p \in (0,1)$. Thus, for any assumed value of p, $c < p$. The area of competition does not increase as rapidly as the proximity distance. This is an important property of the function.

The model depicted above is the basic model of competition. In this model, the area of foraging of bees from one apiary is simply the area over which bees from the apiary can collect honey (nectar and pollen). If the floral resources were distributed uniformly over the area, this map would also give the distribution of the actual quantity of honey which could be collected by one apiary alone. With two competing apiaries, it is assumed that the number of hives is the same.

This basic model can be extended in a number of directions. We need to know how overlapping areas of competition affects the output of the two apiaries and their combined output. With more information on the flight pattern of bees, the calculation of the competition between two close apiaries could be refined. It is more efficient for bees, in terms of collection net of the amount needed to fuel the bees' flight, to concentrate on the area close to the hive. If the quantity of honey collected decreases with distance from the hive, effective competition is concentrated when hives are close and the desired separation distances would decrease. The area may not be a full circle and floral resources may not be uniformly distributed over the area.

Figure 1. Spatial Competition between Two (Close) Apiaries

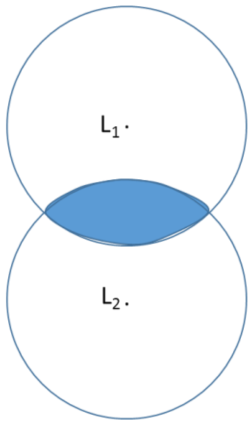


Figure 2. Proximity and Separation Distances

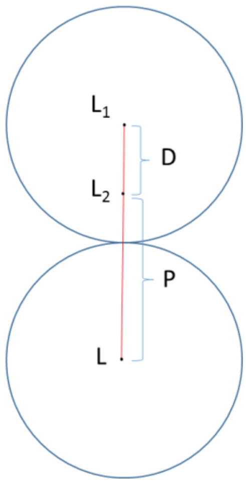


Figure 3. Mid-point (M) (p=1/2)

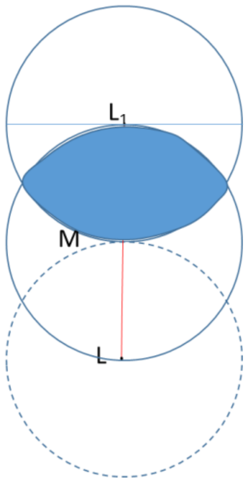


Figure 4. Derivation of Equation (2)

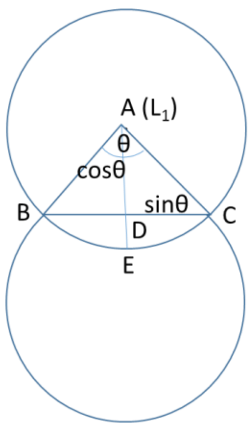
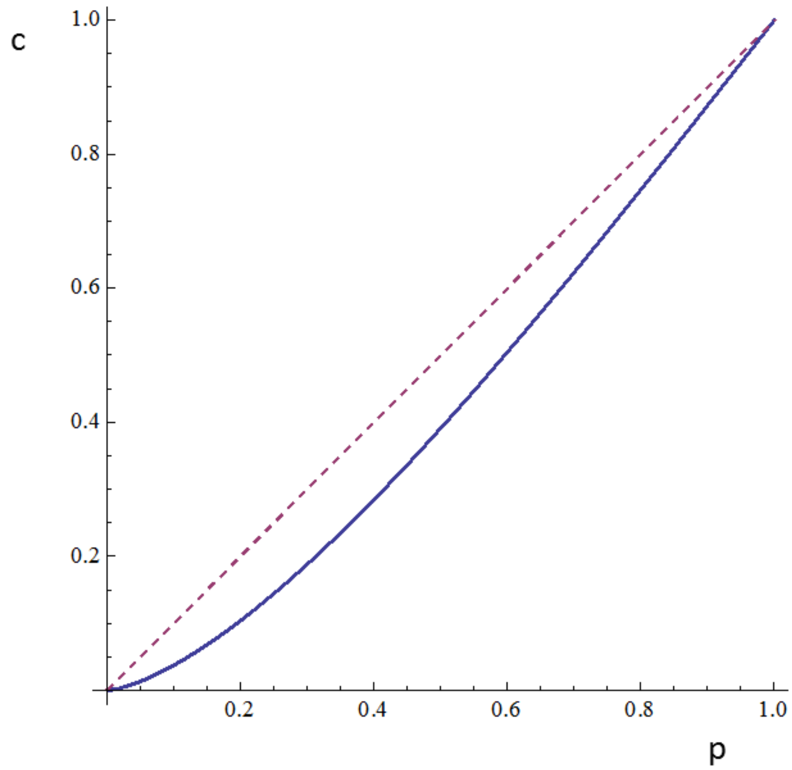


Figure 5. Graph of c = f(p)



[1] Manuka honey is a monofloral honey collected from Manuka (leptospermum scoparium) which is a species of tea tree that occurs naturally only in New Zealand and Australia.
[2] Income from honey production is only a part of the income of beekeepers. They sell other bee products such as beeswax and propolis. Some beekeepers receive substantial income from pollination services provided to fruit growers and growers of grain such as canola. New Zealand beekeepers get most of their income from the sale of honey whereas beekeepers in Europe and North America earn more income from pollination services than from honey.
[3] These prices are for online sales, based on a selection of online sites selling manuka honey made by the author on April 5 2017.
Two rating systems are used. One is based on the content of MGO (Methylglyoxal), which is the active ingredient believed to have therapeutic properties. The other is based on the UMF (Unique Manuka Honey Factor) used by the Unique Manuka Factor Honey Association members.
[4] Some of the enterprises have integrated operations which cover all stages of production of manuka honey, from apiary production to processing, packing and exporting.
[5] An apiary is a site for a colony of hives.
[6] This site reports this total as "representing almost all the world's production". There have been no estimates of total manuka honey production available in Australia but total manuka honey production is known to have grown very rapidly in Australia too. Recently Australia's largest honey company, Capilano, has estimated the Australian total to be over 500 tonnes a year. (Kingbee, 2017)
[7] This information was given to me by Peter Bray of Airborne Honey Ltd.
[8] All beekeepers have a legal obligation to register under the Biosecurity Act 1993. This measure is part of the American Foulbrood Management Plan. There is some double counting as some of the larger beekeeping enterprises chose to operate under multiple registration numbers (Ministry for Primary Industries, 2017a, Table 4). On the other hand, industry sources claim that there are many unregistered sites, totalling perhaps up to 30 per cent of the true total.
[9] Bees will forage further from a hive if there is good floral source of nectar and pollen. Beard (2015, n.1) states that bees may forage up to 10 kilometres from their hive 'although in a majority of cases 95% of foraging occurs within 6 kilometres'. A figure of 3-5kilometres is often used as a 'normal" range (Newstrom-Lloyd, 2015, McPherson, 2017, p. 47 and Department of Conservation, 2015, p.11)
[10] Meade was awarded the Nobel Prize in Economics in 1977 (but not for his work on externalities).
[11] Colony loss occurs mostly in overwintering sites. The Ministry for Primary Industries has commissioned an annual survey of winter colony loss since 2015.
[12] This externality is curious in that the externality is generated by the decisions of bees, not the beekeepers directly. Bees choose where they forage. The industry calls this 'bees without borders'. Of course, the beekeeper decides where to locate the apiary and the number of hives in an apiary and, consequently, the problem reduces to one of interaction between the decisions of beekeepers
[13] Ostrom won the Nobel Prize in Economics in 2009 for her analysis of these issues.
[14] There is an irony in that the strict control by the Department of Conservation of hive numbers and location in the lands under its management has not prevented other beekeepers from locating hives outside the border of Public Conservation Lands to gain access to the floral reserves within the PCL.
[15] Basic economic data should be collected for this segment of the honey industry, as for other major agricultural crops and products. Currently the main source of statistics on apiculture is the Apiary Database maintained by Asure Quality Ltd. This database was developed for the management of the American Foulbrood bacterium. It provides much valuable information on apiaries but it does not report many of the data series available for other industries; for example, there are no statistics of the value of production or employment or value added or wages paid in the industry.