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# Agricultural location theory: von Thünen's contribution to economic geography

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## I Introduction

It is generally acknowledged that the roots of agricultural location theory can be traced back to 1826 when Johann Heinrich von Thünen published his classic work, *The isolated state* (see Champion, 1979; Chisholm, 1979; Ponsard, 1983, for an interesting discussion of some antecedents to von Thünen's work). His goal was to uncover laws that govern the interaction of agricultural prices, land uses and distance, as farmers seek to maximize profit. Von Thünen has had a tremendous impact, not only on location theory but also on economic geography as a whole. While research based on his theory continues, many interesting problems prompted by this model await further progress. The aim of this article is to survey the important contributions to this area and draw attention to the opportunities for further research.

The von Thünen land-use model is adequately described elsewhere (see, for example, Grotewold, 1959, or Chisholm, 1962), so only a brief description will be provided here. In von Thünen's own words:

Imagine a very large town, at the centre of a fertile plain which is crossed by no navigable river or canal. Throughout the plain the soil is capable of cultivation and of the same fertility. Far from the town, the plain turns into an uncultivated wilderness which cuts off all communication between this state and the outside world. There are no other towns on the plain. The central town must therefore supply the rural areas with all manufactured products and in return it will obtain all its provisions from the surrounding countryside (Hall, 1966: 7).

This was von Thünen's isolated state. By holding all other factors constant, he set out to determine the influence of transport costs on the location of crop production. Given the importance of transportation costs, crops are arranged around the market in a concentric fashion. Summarizing the results, von Thünen stated: 'with increasing distance from The Town, the land will progressively be given up to products cheap to transport in relation to their value' (Hall, 1966: 8).

The location analysis questions raised by von Thünen's research are as follows. Given that a producer is faced with a number of alternative cropping activities, and given that the producer weighs up the economics of supplying these products to one of a number of alternative market centres, which activities are actually carried out? Where are these activities located? And which producers are allocated to which centres? The analyses of these questions is among the main contributions of von Thünen's agricultural land-use theory. The idea behind the von Thünen model is really very simple: various locations have different accessibility characteristics – some pieces of land are close to the market centre, and so they have an implied cost of transportation which is lower than the less accessible lots. A system of land rents for the property arises. Obviously, the actual owner of the best land can charge more rent for a property which has lower transportation costs, because those lower costs make the land very desirable and more profitable than the land which is further away from the centre. The key contribution of the von Thünen model is that he draws attention to locational attributes of the property as a source of land rent. To distinguish this source of rent difference from those owing to resources or 'fertility' (Ricardo's definition of land rent), we call von Thünen's type of rent 'location rent' (see Chisholm, 1962, or Ponsard, 1983, for a comparison of the Ricardian discussion of land rent with that of von Thünen).

Stevens (1968) has shown that programming models of optimal location generate equilibrium location rents. Duality allows von Thünen's theory to be modelled as either a problem in optimal location or a problem in equilibrium location rent. The dual nature of mathematical programming has also assisted researchers in the basic construction of the model. The interpretation of 'duality' in this context is entirely intuitive: activities which are included in an optimal linear programming solution make use of scarce resources, such as land and labour. The dual variables can be interpreted as the imputed prices (or values) of these scarce resources. In the case of land, the imputed price is quite naturally called rent (Stevens, 1968).

As argued by Chisholm (1962), von Thünen provided not only a theory of land use if the location of settlement patterns are taken as given but *also* a theory of the location of settlements given a land-use pattern. While this latter theme has not generally been explored by geographers, archaeologists have found it useful in the analysis of resource use and settlement location patterns.

This is not the first review of agricultural location theory. Indeed there have been several. For example, Norton (1979) reviews research that attacks the problem from a historical perspective, emphasizing both historical analyses and those of agricultural evolution. He argues that in order to comprehend the evolution of agricultural landscapes, an investigation of process, and of the variables which promote *change* in forms, is required. Calling for an integration of the economic and behavioural approaches, Hart (1980) provides a review of the agricultural location research within a behavioural framework. He contends that neither approach can provide a total explanation and each is dependent on the other. In a survey of the literature on von Thünen's intensity theory, Kellerman (1983) finds that most of the research has concentrated on the development of optimal intensity equations for a point in space under given conditions, rather than on the resulting theoretical 'intensity landscapes'. He calls for the formulation of operational hypotheses regarding the relationship between crop and intensity curves and the empirical testing of such hypotheses. Samuelson (1983) provides a thorough analysis of von Thünen's contribution to economic thought. In a more specialized review, Kellerman (1989a) carefully explains the basic von Thünen model and its mod-

ern versions. Kellerman (1989b) then goes on to examine research that has relaxed some of the assumptions underlying the basic model.

This article attempts to bring all these perspectives together, highlighting those contributions that open the door to further research. The goal is to stimulate research; not to provide a comprehensive and exhaustive review of the literature. Section II reviews historical studies of land-use patterns (and their dynamics). Then, in sections III–V, three sets of new ideas in economic geography that grow directly from von Thünen's concepts are reviewed: we deal with them here in the order of economic, behavioural and spatial analysis.

## **II Empirical evidence from historical studies**

A number of studies have directed attention to the investigation of agricultural relationships in a historical setting. These studies are interested in determining whether or not the von Thünen model assists in understanding the actual spatial pattern of agricultural production. While there is some interest in finding the predicted concentric zones of production, most research has concentrated on determining the influence of distance on land value, use and intensity. Simply looking for the existence of rings in the agricultural landscape will not provide evidence that the von Thünen model does, in fact, reflect reality. There could be several possible explanations for the existence of such rings.

### **1 Role of distance to market**

Norton and Conkling (1974) demonstrated the importance of distance for an area north of Toronto in 1861. They found that land values were closely related to distance from the market, Toronto. Land use was clearly demarcated into two zones: an inner zone of commercial production surrounding the market and an outer zone of subsistence production. Evidence also indicated that the main commercial crop, autumn wheat, exhibited an inverse intensity–distance (to the market) relationship in terms of both output per arable acre and yields per crop acre.

As transportation costs decrease and technology improves over time, it is expected that the influence of distance on agricultural production will also decrease. Leaman and Conkling (1975) hypothesized that this decline in the influence of distance over time would result in an increase in the influence of environmental factors on the determination of land use. They tested their hypothesis in western New York State for the years 1840 and 1860. When transportation costs are high, farmers cannot always grow the crops that the land is best suited for as they may be too expensive to transport to the market. As transportation costs decrease everywhere, they hypothesized, farmers would be to specialize in the production of crops that are better suited for the physical environment. Leaman and Conkling (1975) analysed two time periods using canonical correlation and found that the land-use pattern in 1840 was one of unspecialized general farming that bore very little relationship to the physical environment. By 1860, however, a number of specialized land uses were evident and the resultant land-use patterns revealed a much closer conformity to the environment. Specialization according to comparative advantage was seen as a result of improved inter-regional transportation. The idea of inter-regional price equilibrium has long appeared to be open to

generalization to include the pattern of land use surrounding each market centre. If a region/market specializes in 'corn' for export, where is the boundary of its growing region? How does this respond to changing inter-regional prices?

Historical studies have revealed the impact of transportation improvements on agricultural production over time. An empirical example of the changes that can be brought about by such improvements is provided by Irwin's (1954) historical study of the Illinois and Michigan Canal after 1848. By linking the Illinois River to Lake Michigan, the canal made the shipment of corn by water from central Illinois to Chicago economically feasible. Prior to the canal's existence, transportation was expensive as most grain had to be transported to Chicago via wagon or boat. Wheat was the predominant export crop. Owing to its higher transport cost and lower market value, corn was produced mainly for local consumption. When the canal opened, farmers promptly responded to the presence of a cash market for corn along the canal and the Illinois River (Irwin, 1954: 70). The canal was used mainly for corn, while wheat continued to be transported over land. As noted by Taylor (1917), wheat was grown too far from the canal for it to be an alternative to land transport.

Distance to market can play a role in crop allocation even when transport costs remain stable. In the eighteenth century, whiskey was produced in western Pennsylvania. Grain, used to produce the whiskey, was the outermost crop from the eastern market. It was the only crop that could be profitably grown at this distance from the market (Abler *et al.*, 1971). In 1794, the government levied a tax on inland whiskey, reducing the net profit to such an extent that its production was no longer possible. The zone of profitable farm production shrank eastward. Within the cultivated area, all other crops outbid whiskey for use of the land (Abler *et al.*, 1971).

## 2 Empirical evidence of von Thünen rings

In an attempt to show that the von Thünen crop theory provides an explanation of the overall organization of American agricultural activity, Muller (1973) utilized trend surface analysis to evaluate the empirical evidence. He analysed net income per unit area (a surrogate for economic rent) in 1376 counties of the USA in 1964. Muller (1973) used the results, along with dynamic economic integration theory, to discuss the evolution of the surface from the early nineteenth century onwards. He discovered that interdependent specialized farming regions developed and focused on the national market around 1800. These regions expanded westward over time. In addition, the eastern seaboard market grew and became the principal national market.

In an analysis of colonial Mexico, Ewald (1977) found that agricultural zones which accorded closely to Thünen principles were evident among both the Indian and Spanish economies. Throughout the colonial period, transportation costs were high and infrastructure was limited, and the influence of these factors was evident on the agricultural landscape. Ewald (1977) found distinct rings of crop production surrounding the built-up areas. While the Indians and the Spanish cultivated different crops, each had their own crop ordering as distance from the urban areas increased.

Empirical research on a microscale has also been conducted. Blaikie (1971) found in northern India that distance from the farmstead to the fields influenced the types of crops that were grown by individual farmers. Since farmers had to walk to their fields, intensive cultivation was only done in fields close to the farmsteads, and intensity decreased as distance from the farmstead increased.

The search for empirical evidence of the existence of von Thünen-like rings is not always successful. In an analysis of nineteenth-century London, Atkins (1987) concentrated on the location of market gardening and liquid milk production around the city. He concluded that the von Thünen model provides an inadequate explanation of the resulting spatial structure of land use. Around London, the spatial complexity of the agricultural zones was greater than predicted by von Thünen. In addition, Atkins (1987) found that milk producers and market gardeners exhibited dissimilar behaviour when displaced from their land. Market gardeners tended to move a shorter distance further out from the built-up areas while milk producers responded by moving into the urban area or at least by tolerating and adjusting to life in the city.

### 3 Changes over time

A number of studies have attempted to focus directly on change rather than on conditions at a given period (or periods) in time. One principal theme concerns the evolution of continental and world von Thünen systems with temporal demand increases, transport improvements and technological changes in farming practices. Schlebecker (1960) outlined a continental-scale von Thünen-type agricultural system that centred on the 'World Metropolis'. He noted changes in the location of the global market, over time, from Athens to western Europe to the eastern USA. Peet (1969; 1970/71; 1972) elaborated on this idea and observed that imports to Britain came from an ever-expanding but, nevertheless, logical von Thünen system. He noted that the von Thünen model suggests that an increase in demand in the market is necessary for the spatial expansion of agriculture. During the nineteenth century in Great Britain, demand for agricultural products increased greatly. In addition, technological advances lowered transportation costs, while technological advances in farming lowered production costs. As a result, Peet (1969; 1970/71; 1972) found that the margin of cultivation expanded outwards throughout the century. The supply of wheat, for example, came initially from within Britain, then from eastern Europe, then from North America by the 1870s and finally from western Canada and Australia. Peet considered three factors found in Great Britain to be critical for this process of expansion: increases in demand, declining transport costs and technological advances in farming. Modifying von Thünen's model by incorporating changing freight rates, Chisholm (1961) examined the change in land-use patterns in the UK from the late nineteenth century to the mid-twentieth century in response to growing transatlantic imports. He found that a decline in location rents is an important explanatory factor in the changing relative significance of agricultural land.

As distance to the market increases, von Thünen's model indicates that agricultural intensity should decrease at a decreasing rate. This function should steepen over time as a result of technological changes in agriculture. In an empirical study of USA agriculture from 1949 to 1969, Visser (1980) revealed that while agricultural intensity is a decreasing function of distance to the market, technological change did not alter these functions as such change was not uniform over all types of agriculture. Certain types of agricultural endeavours (such as irrigated farming or pastoral farming), though, did benefit from capital-using technological change. He concluded that von Thünen's model was still relevant for explaining the spatial structure of agriculture at a local scale.

An analysis of nineteenth-century hop cultivation in England also referred explicitly

to variable change through time and the consequences for land use and intensity (Harvey, 1963). He determined that the principal variables were changes in demand and technological developments. Although Harvey's analysis was based on more than just the principle of location rent, he found evidence of a decline in the density of hop acreage with increasing distance from the core area of production. This regularity in the land-use pattern over-rode physical differences in the environment. Harvey (1963) related regional expansion of hop cultivation to distance and suggested three distinct phases: 1819–26, rapid growth of core; 1826–46, rapid growth around core but stagnation in core; 1846–78, all-round expansion.

In empirical analyses of the von Thünen model, the time of the study is not as critical as the level of the technology (both in transportation and farming). Contemporary analyses in less developed economies, then, are comparable to historical analyses in certain respects. In many less developed countries, for example, the transportation systems resemble those of nineteenth-century Europe. Horvath (1969), in a study of agricultural land use around Addis Ababa, Ethiopia, found a von Thünen-like pattern of concentric zones around the city. Agricultural land use appeared to be organized in terms of the influence of transport costs on location rent. Vegetable gardening was found very near the city. As distance from the city increased, the land use switched to forestry and the outermost ring was used for subsistence agriculture. So, like von Thünen, Horvath (1969) found an inner zone of forestry around the city. This zone was wedge shaped, reflecting the greater accessibility to the city along the major roads. Between 1957 and 1964, this zone expanded. Transportation improvements in the area surrounding Addis Ababa permitted wood to be transported over increasingly greater distances. This, in turn, allowed more land near the city to be used for vegetable production (Horvath, 1969).

#### 4 Outlook and prospects

The empirical historical evidence clearly suggests that distance has been an important factor in the determination of agricultural land use, as predicted by von Thünen. While this pattern is no longer clearly evident in developed economies today, this does not mean that the theory is invalid, nor does it imply that location rent is no longer the basic allocating mechanism. The clearest evidence of von Thünen's model can be found today in less developed countries. Expanding populations and increasing population densities have put tremendous stress on the agricultural sector of the economies in these countries. Further research on the determinants of agricultural land use may lead to a better understanding of agricultural patterns in these countries and may assist them in optimizing their land use and agricultural productivity.

### III Economic aspects

Economic extensions to the von Thünen model cover a wide range of topics, though much of this research has concentrated on von Thünen's intensity theory with particular attention being paid to his assumption of constant fertility and production costs. An excellent, extensive review of this literature is provided by Kellerman (1983) and it will only be briefly summarized here.

## 1 Intensity

The first attempt to extend and relax von Thünen's assumptions was made by Dunn (1954), who utilized nonlinear production functions to show why more intensive forms of production (for the same crop) would occur nearer the market. The cost of land (rent), however, is a function of market access. This relationship makes it cumbersome to use Dunn's graphical method. A concise statement of this relationship was later made possible through the use of spatial equilibrium methodology and calculus. Using this approach, Garrison and Marble (1957) maximized rent as a function of intensity and showed that, given a single production function, intensity did decrease with distance from the market. Bannister (1977) later showed that their rent equation was in error as fixed costs were multiplied by the output. Correction of the error by Bannister (1977) did not alter Garrison's and Marble's conclusion. Despite an error found later (Visser, 1979) in Bannister's work, his fundamental results remain unchanged.

Arguing that von Thünen's model neglects to analyse the equilibrium of supply and demand while Dunn's (1954) fails to take scale economies in production into consideration, Webber (1973) develops a model where agriculture is placed into a two-sector economy such that supply and demand could be equilibrated between agricultural and city service production. This model determines the prices of output and the location of production and derives the density of population on the plain as a result of determining the intensity of production. Webber's (1973) model represented a considerable advance as it separated inputs into its labour and capital components.

Visser (1982) developed a model which showed that intensity decreases at a decreasing rate as distance to the market increases when there are diminishing marginal returns to intensity. Assuming spatially invariant costs and with the cost of one input decreasing as distance to the market increases, his model described the spatial structure of agriculture as viewed from the supply side. This model is a synthesis of previous work on the relationship between intensity and market access (see Casetti, 1972; Katzman, 1974) and supports their results. While further research is needed on the estimation of production function forms, this model brings us one step closer towards a general, modern theory of agricultural location.

Through his research of intensity patterns in India, Dayal (1978) developed a new index of cropping intensity which also considers the length of time a crop stays in the field. Later, Dayal (1984) extended his research by examining the regional variations in land, labour and aggregate agricultural productivity. Arguing that the commonly used measure of productivity is misleading, he utilized an index based on the value of crop output and not simply on yield per unit area and areal strength of crops. Although Dayal (1984) did not put his work in a von Thünen framework, his maps of land, labour and aggregate productivity reveal that productivity, in general, is highest near the markets and decreases with distance from the market. (It should be noted that for labour productivity, areas near some markets did have low productivity.)

Although most of the research on von Thünen's intensity theory deals with the specification of production functions, there have been detailed case studies of the effect of distance on farming intensity. Using a microscale approach, de Lisle (1978) looks at the effects of intrafarm distance on farm income in North America; actually a small Mennonite village in southern Manitoba where farmers work on fragmented farms and the fields are widely scattered about the village at varying distances from the farmhouse. De Lisle uses von Thünen's rent equation (as modified by Dunn, 1954). How-



ever, the market price is replaced by the farm-gate price and transportation costs are defined as the internal movement cost per acre per mile (rather than external transportation costs). By using the farm-gate price, the external transportation costs from the farm to the market are already deducted and allows de Lisle (1982), in a later article, to examine the effects of internal transportation costs on income. He did a field-to-field farm analysis and found that farmers made significant adjustments in the organization and intensity of their farming with increasing distance of fields from farmsteads. Crop production at greater distances was made feasible by cutting back on labour and capital inputs and decreasing the amount of movement to and from the fields. Although gross income declined with increasing distance from the farmstead, the adjustments in the organization and intensity of farming offset the effects of distance on net income.

## 2 Dynamics and equilibrium

An explicit approach to the derivation of a dynamic von Thünen formulation was taken by Day and Tinney (1969). Their model consisted of a series of linear programming models, described for a two-commodity and two-resource situation, which successfully produced an evolution towards the characteristic von Thünen equilibrium situation. The basic von Thünen assumptions remain, with the exception that the farmers do not know the market price their goods will receive beforehand and so use the previous year's prices to determine their expected profits. The market environment (demand) not only affects production decisions through price expectations but also affects the resources available for production. Day and Tinney (1969) show that the market can direct an economy to a competitive equilibrium through a sequence of successive adjustments and it can do so through the activities of rational (maximizing) but ignorant (forecasting) decision-makers whose *ex post* performances differ from their expectations all the way to their final efficient solution. At equilibrium the model indicated a positive rent value even for the remotest area which is not in accord with the von Thünen proposals. Interestingly, Day and Tinney (1969: 150) noted that 'while von Thünen's spatial equilibrium can come to pass, it can do so in a great variety of possible ways and with a great variety of rings of final specialization and mixed farming'. Historically, this has important implications for it suggests that a given spatial form may result from a number of different evolutionary sequences.

Since crops are normally produced once a year, supply is inelastic with respect to present prices. Okabe and Kume (1983) examine the dynamics of agricultural location by formulating a dynamic von Thünen model. Their model differs from Day and Tinney (1969) in that it explicitly takes a utility function into account (rather than an implicit utility function), and analytically examines the dynamic processes in the context of continuous land (rather than discrete zones). The model assumes that land is linear (extending in one direction from the market) and that only two types of agricultural goods are produced. Under these assumptions and assuming that farmers decide what crop to plant based on last year's market prices, this dynamic model shows that land use will reach an equilibrium when initial prices take specific values. However, this equilibrium is generally unstable and there is apt to be a fluctuation in land use over the years. The authors also note that if only one good is produced on all the land over the years, the area in which that good is produced always changes cyclically with two-year intervals.

### 3 Rent and surplus

While it is known that a relationship exists between land rent and consumer surplus, the nature of this relationship was not treated explicitly until recently. O'Sullivan and Ralston (1980) use influence curves to show that, in a von Thünen framework, consumer surplus is equal to location rent. However, consumer surplus is generally measured as the area under the demand curve above the price line. O'Sullivan and Ralston (1980) show that rent does equal this area but only when the marginal utility of money is constant (as in the von Thünen model). Macmillan (1982), however, argues that the consumer surplus concept, itself, is unnecessary and actually causes both theoretical and practical problems. Later research by O'Kelly (1988) reinforces the important connection between consumer surplus and aggregate land rent.

Other researchers have focused on the effect of transportation improvements on the von Thünen model. Ralston and Barber (1982) examine the impact of a new road on the supply and demand of a port hinterland's product (the agricultural good grown in the area around the port). The expansion of a transportation network in developing countries is important for economic growth. However, the authors note that research in this area is hindered by the interdependencies that link the transportation network with the economic system. The transportation network 'both affects and is affected by the operating conditions and constraints determined in other sectors of the economy' (Ralston and Barber, 1982: 201). While most research in this area is of a descriptive nature, there have been some breakthroughs using an analytical approach. Further research in this area must consider two main inter-related features. First, the nature of the interactions between the economic system and the transportation network needs to be specified. Secondly, the operating conditions of the government authority in charge of network development must be defined. Ralston and Barber (1982) develop a recursive version of a dynamic road investment problem. The government authority's objective is to maximize the net benefits of the road (i.e., total incremental rent minus expenditures on construction and maintenance). They must determine both the optimal long-run equilibrium (how long should the road be to maximize benefits) and the best path to equilibrium (the 'best' construction schedule for the given road length). Even when maintenance costs are set to zero, the authors find that the optimal road length is not its maximum length (owing to the fact that the objective is to maximize benefit not production). Their analyses also indicate three possible scenarios when there would be no construction at all. If the maintenance costs are too high, no construction will occur (marginal costs exceed marginal benefit). If the demand curve is too steep, there will also be no road built (markets are too sensitive). Finally, if the transport rate for the old transportation ( $b$ ) is much larger than the rate for the new form of transportation ( $a$ ), then no construction will occur (i.e., the ratio of  $b$  to  $a$  is too large). In this case, the technological differences are too great for the long-range goals to be attainable.

In another article, Ralston and Barber (1984) examine the impact of three different taxation schemes on road development and on the supply and demand of a port hinterland's production. The taxes are used to finance road extension. They found that each scheme gives rise to a different spatial pattern of development around the port. In addition, each taxation scheme leads to different levels of benefits and different equilibrium conditions. Only the benefits that accrue to the producers (farmers) are considered in this model. The first method of taxation is an incremental tax. This tax has no effect on the extent of the cultivated area. It also has no effect on transport costs or on market

prices. The second method is a ton-mile or vehicle-mile tax (e.g., a fuel tax). This type affects agricultural land-use development. For some farmers, using the new road would no longer be cost-effective (and it must be implicitly assumed that using the old mode of transport is not cost-effective either) and, therefore, the amount of land under cultivation decreases. The third type of tax is a commodity sales tax. This increases net price to buyers at the port, and, therefore, will also lead to an impact on agricultural land use and rents. Note that this tax is not spatially biased. The objective of the government authority in charge of transportation development is to maximize the net benefits (to farmers) of road construction. At the same time, they must anticipate the effect of any road extension on commodity supply and on market prices. Net benefits refer to rent. However, rent in this article is defined as the port price minus the transport cost. The authors find that for a short road and when production occurs on a narrow strip along the new road, a fuel tax provides the largest net benefits. For long roads, a sales tax provides the largest net benefits.

In the basic von Thünen model, aggregate location rent and producers' surplus are equivalent. O'Kelly (1988) examines how transportation improvements impact agricultural crop production in a simple von Thünen model. The homogeneous transportation cost assumption is relaxed. In addition, it is assumed that crop prices adjust in order to balance supply and demand. O'Kelly (1988: 188) notes that 'rural road improvements tend to produce increases in farm gate prices, while decreasing market town prices'. If transport costs decrease (e.g., as a result of road improvements), the longer-term equilibrium market price should decrease as a result of increased supply, assuming demand remains constant.

O'Kelly (1989) also examines the impact of an improved transportation corridor on a two-crop agricultural system. The von Thünen assumption of homogeneous transportation costs is relaxed. In addition, it is assumed that crop prices adjust to balance supply and demand. This article differs from previous research in that it 'emphasizes the endogenous determination of the boundary of production between two competing crops, while allowing for differential freight rate impacts on each of the crops' (O'Kelly, 1989: 385). O'Kelly notes that there are two sources of differential transportation impacts. The transportation improvement may have route-specific (as opposed to system-wide) impacts only. For some farmers, then, the improvement will provide no savings. The second source is quite interesting from a research perspective. The transportation improvement may have differential effects on each crop. To determine transportation costs with the improved route, an analysis of both the distance and angular location of a farm is required. O'Kelly (1989) finds that the slopes of the location rent lines vary with angular location and owing to this, the boundaries between the two crops occur at different distances from the market centre at various angular locations. Note that this finding is the result of the nonhomogeneous transportation costs.

#### 4 Outlook and prospects

Research studies into the economic aspects of von Thünen's model have been numerous and far-reaching. Still much work remains to be done. In order to understand more fully the relationship between intensity and the spatial structure of agriculture, the proper forms and parameters of the production function must be investigated. The effects of technological change (both in agriculture and in transportation) on the spatial structure of agriculture also need to be explored in more detail. Finally, these economic

models must be simulated on a realistic transport network, and the location of infrastructure (such as grain terminals, trans-shipment points and mills) needs to be integrated in an overall synthesis. In the following sections we move on to behavioural and optimization models which begin to consider such a synthesis.

#### IV Behavioural aspects

Behavioural geographers contend that the assumption of a perfectly informed and economically rational farmer, typically used in the economic research, is unrealistic and should be relaxed. This assumption neglects the fact that the agricultural decision-making process is full of uncertainty. For example, short- and long-term weather variations, uncertain markets and other factors prevent farmers from obtaining prior knowledge of either prices or yields. Behavioural geographers also argue that noneconomic factors, such as personal preferences or the age and experience of the farmer need to be taken into consideration, as they play an important role in the farmer's decision-making (Ilbery and Hornby, 1983; Ilbery, 1985).

Simon (1957), realizing that most farming decisions are made by farmers with inadequate information, outlined the satisficer concept. His idea of 'bounded' rationality suggests that decision-makers seek decisions which yield satisfactory, rather than optimal, outcomes. This concept works well if there is only one satisfactory option known to the farmer. However, it is likely that farmers will be aware of more than one feasible option and Simon's (1957) idea of 'bounded' rationality does not clearly demonstrate how the farmer will choose among options. It is possible that the farmer will select the first satisfactory strategy the farmer is aware of. This, however, introduces a large element of chance into the determination of agricultural land-use patterns. At the other extreme, the farmer may compare all the available options and select the one that is the most satisfactory. This, though, is little more than a slightly modified version of the economic rational model (Hart, 1980).

Wolpert's (1964) research indicates that behavioural characteristics may provide valuable information about agricultural decision-making behaviour. He relates these characteristics to both the availability of information and attitudes towards uncertainty. He proposes that the primary determinants of the uneven flow of information and the variations in knowledge are the uneven spatial distribution of farmers according to farm size, membership and proximity to other farmers. For example, Wolpert's (1964) work has shown that older farmers tend to choose strategies with a lower level of risk than those chosen by younger farmers.

##### 1 Game theory

Agricultural economists (e.g., Agrawal and Heady, 1968; Found, 1971; Low, 1974) have long used game-theoretic approaches to introduce risk and uncertainty, while geographers, such as Cromley (1982) and Jones (1983), have only recently focused on some spatial implications of uncertainty. Game-theoretic approaches are appealing because they provide a normative theory of behaviour while recognizing the existence of uncertainty in the decision-making process. Basically, game theory involves the use of a pay-off matrix depicting the outcomes of the various strategies available to the farmer under

each of a number of possible outcomes (Gould, 1963). The decision that is best for the farmer may then be selected according to various criteria.

Cromley (1982) uses game theory to examine the differences that could occur in the spatial pattern of agricultural land use under environmental uncertainty. The pattern of land use can vary according to the goals of the farmer (i.e., profit maximizer or risk averter). Most of the basic von Thünen assumptions still hold while, in addition, it is assumed that weather conditions vary from year to year. However, it is assumed that farmers have no prior knowledge of weather conditions for individual years. Weather affects production costs, crop yields, market prices and hence, rent. Cromley (1982) found that long-run maximizers (who grow only one crop and grow that crop every year) could outbid the short-run maximizers for the use of the land. One interesting observation is that if all farmers were short-run maximizers (which could occur if short-run fluctuations were very high), then rent would not necessarily be a decreasing function of distance from the market.

Jones (1983) also examines the spatial pattern of risk in a von Thünen framework. Market price is assumed to be the only source of risk and since total transport costs are the only costs that are allowed to vary with distance in this model, income (or rent) is found to be riskier as distance from the market increases. Risk, then, is measured as the coefficient of variation of net farm income, and it increases as distance from the market increases. Jones (1983) finds that in a 'perfect capital' market, the expected rate of return on net farm income will differ spatially because of crop production and risk characteristics. If the net farm rate of return remains constant over distance as the net farm income falls, the increasing coefficient of variation will move the farmer's crop mix which gave that constant rate of return, off the efficient portfolio frontier. If the maximum attainable rate of return rises over distance, the standard deviation of the rate of return could stay the same or rise; if the rate of return must fall, its standard deviation must fall in compensation. Jones (1983) concludes that farmers shift their crop mixes to reach these efficient points of covariance risk and return. This article differs from the usual von Thünen model in that stochastic returns, as well as transport rates, influence crop locational patterns, especially at more distant locations. Therefore, zones of multiple cropping can be introduced without fundamentally altering the spatial structure of the von Thünen model.

It is not uncommon in game theory for different selection criteria to result in different optimal decisions, since these criteria are based on how risk prone the farmer is. This difference may depend on whether a short-term or a long-term view is taken. In the short run, it may be advisable to choose a less risky strategy for fear of large-scale losses in the first few years. Conversely, a farmer may be financially able and willing to withstand possible early losses in the hope of making greater profits in the long run. The particular circumstances of the farmer may help to resolve this anomalous situation. For the subsistence farmer in the less developed world, the luxury of being able to plan on a long-term basis effectively may not exist. Crop failure in the first year could be disastrous in survival terms alone. As a result, as Norman (1969) has shown, optimal decisions must be based on the short-term view, with the maximization of security rather than profit as the primary goal. For highly capitalized farms in parts of western Europe and North America optimality may be better associated with long-term profitability. However, between these two extremes occur a number of other situations in which factors such as the farmer's tenure, age and the degree of dependency on agriculture for income affect the farmer's view of the optimal decision.

## 2 Strategic risk reduction

Risk and uncertainty can be added to a model without the use of game theory. Jones (1982) incorporates risk into a von Thünen-like model of farm tenure choice. Land tenure is a strategy available to farmers for reducing risk. The riskiest strategy is to own the land you farm. One can reduce the risk by renting out farmland for a fixed rent. This places all the risk on the tenant and leaves the landowner with a steady income. Share-cropping divides the risk between the landowner and the tenant. Jones (1982) hypothesized that share-cropping would decrease relative to fixed rental as access to the market improved and that owner operation would increase with access to the market relative to tenant operation. To test his hypothesis, he analysed tenancy choices for over 200 USA counties in 1880, using multiple regression. The spatial patterns he uncovered were quite similar to the expected patterns and Jones (1982) concluded that they appear to derive from the hypothesized behaviour.

In another article, Jones (1984) identifies three ways a farmer can reduce risk: 1) obtain off-farm employment; 2) diversify crops; and/or 3) engage in different forms of land tenure. Analysing the use of off-farm employment as a risk-reducing strategy, Jones (1984) hypothesizes that off-farm employment will initially increase as distance to the market increases but will eventually decrease with distance. Off-farm employment allows the farmer to combine income from two sources with different risk characteristics; but at the expense of what could be earned on the farm. He found that while the demand for off-farm employment increases with distance, the cost of taking this employment initially falls sharply with distance and, eventually, begins a net rise which he attributes to commuting costs. He concludes that von Thünen's model can be used to derive the benefits from, and costs of, off-farm employment.

Using a mean-variance portfolio model, Cromley and Hanink (1989) show how risk affects the spatial pattern of land use in the von Thünen model. A farmer's utility function, then, is more than either pure profit maximization or pure risk aversion (i.e., the utility function is no longer discrete). Multiple spatial cropping patterns are expected when the basic von Thünen model is extended to incorporate portfolio theory. Other researchers have also obtained these multiple spatial cropping patterns by relaxing the assumption of a single market centre and considering spatial interaction (see Wilson and Birkin, 1987). By incorporating the portfolio model, crops have a more extensive range of locations than in the basic von Thünen model. One interesting aspect of this is that it is possible for crops to be grown at distances where they generate negative expected returns because the total efficient portfolio generates a positive return. Cromley and Hanink (1989: 957) explain that 'this situation creates greater stability of return in extreme years, when the odd crop has a positive return whereas the others have negative returns'.

Macmillan (1992) also incorporates risk into a von Thünen model by utilizing a portfolio-theoretic approach. He extends the Cromley and Hanink (1989) model by expressing the bid-rent function as a continuous function of distance. By demonstrating how agricultural production changes with increasing risk-taking or risk aversion and by evaluating long-run equilibrium conditions, Macmillan (1992) argues that competition will lead to risk neutrality and, therefore, the classic land-use pattern. Although the model has some limiting assumptions (for example, it is assumed that farmers have unlimited free credit facilities), it represents a major step towards integrating the portfolio approach and the mathematical programming models discussed below.

### 3 Outlook and prospects

Several reasons have been suggested for the apparent incompatibility between the economic and behavioural approaches (Hart, 1980). One of the major differences lies in their initial assumptions which are in direct conflict with one another. In the economic approach, decision-making is a parameter; while in the behavioural approach it is highly variable. Most economic models assume that farming takes place in continuous space. Behavioural models, on the other hand, concentrate on individual farms. Hart (1980) suggests that the two approaches might be united within a probability framework. Within this framework, economic models could be used to determine the optimal strategy available to farmers. The results of the economic models could then become the starting point for behavioural models, which could indicate the degree to which decision-makers are willing or able to conform to the optimal strategy.

## V Ideal or optimal spatial organization

While the original von Thünen model operates in continuous space, mathematical programming can be utilized to define discrete space versions of a similar structure. The use of mathematical programming is a natural and obvious extension of the von Thünen model. Its main advantage is that it allows for the explicit determination of which activities (crops) appear in an optimal solution and which of the large set of possible inequalities forms the set of equations to be solved for equilibrium values. An inherent difficulty in determining the location of agricultural land use is the order of activities out from the centre. If the rent gradients or bid-rent curves can be ordered by slope, this problem can be solved external to the model with the result that the land use with the steeper bid-rent curve will locate close to the market. However, if such ordering is necessary to the solution, this problem becomes very difficult to solve using classical methods of marginal economics whenever the model is altered (such as by introducing scale economies or variations in land quality) by factors that affect the slope of the bid-rent curves. However, these variations on the basic model can be handled quite easily with mathematical programming.

### 1 Mathematical programming for relaxing von Thünen's basic assumptions

Mathematical programming frameworks have made it quite easy to relax the assumptions in the basic von Thünen model. Despite development of this extension by location theorists, the greatest strides in the use of mathematical programming (especially linear programming) have been made by agricultural economists (see Fleisher, 1990, for a summary of the advances made by agricultural economists in this area). They have developed regional linear programming models in which all the constants of the basic von Thünen model have been carefully specified and have also introduced the factor of time. Unfortunately, agricultural economists have not made explicit the ties between agricultural programming models and the von Thünen model. Integration of these two approaches is a much needed avenue of research for economic geographers.

Researchers who use mathematical programming argue that a von Thünen-type model, cast in a programming framework with the basic assumptions relaxed, will better represent the spatial variation in agricultural production than will the basic

model. Specifying the model as a linear program facilitates numerical solution and can assist in answering practical policy questions (see, for example, Henderson, 1959; Heady and Egbert, 1964). It is also an aid to description or representation of real-world patterns. Most importantly, however, it allows one to extend rigorously the scope of the original problem.

Jones (1976) places a macro-Thünen model into a linear programming framework to see if it represents the spatial variation in USA agricultural production in 1954 better than the basic von Thünen crop model. Utilizing a two-crop model, three different scenarios are developed. The first is the basic von Thünen model with all its assumptions, which results in concentric crop rings. The second is the basic model cast in a linear programming framework. This model, though, does include constraints on factor supply and on crop demand. The final model extends the second one by incorporating multiple markets into the model. Each market has its own transport rates, market price and demand. Also, yield and production costs vary among the different producing regions. Jones (1976) found that there is the appearance of a recognizable ring pattern in the basic Thünen programming model which corresponds to that existing in reality. In fact, it is almost as predictive of the actual pattern (in 1954) as the model which allows for multiple markets.

## 2 Operationalizing economic theory

One of the first applications of linear programming to the von Thünen model was by Stevens (1968). He attempts to show that an assumption of demand varying linearly with price may be used to generate a class of quadratic programming problems. In his model, he includes elastic demand, variable transport rates and nonuniform land fertility. Stevens (1968) demonstrates that the axiom of von Thünen's model, where each and every piece of land will be occupied by the crop which can offer the greatest non-negative bid rent, is expressed only in the primal-dual relationships between variables and constraints. The role of the objective function is to 'force the variables and constraints into the proper equilibrium configuration' (Stevens, 1968: 32).

Macmillan (1979) extends Stevens' (1968) work by deriving the agricultural location problem as a special case of the Walras-Wald model of general economic equilibrium. He argues that, unlike Stevens' linear and quadratic formulations, the partial equilibrium approach will yield a 'system of statements' (Macmillan, 1979: 956) which are internally consistent with certain assumptions on the behaviour of individual economic agents. Macmillan (1979) notes that Stevens' (1968) formulation and his interpretation of the objective function ignore the individual producer (let alone the consumer). He contends that the confusion over Stevens' model is the result of the use of the bid-rent concept. According to Macmillan (1979: 957), 'if farmers offer bids for the use of land, then the markets for land services cannot be perfectly competitive'. The approach taken by Macmillan drops the bid-rent assumption and, according to Macmillan, this allows for the existence of perfectly competitive profit-maximizing farmers.

Mathematical programming and the von Thünen model have also been extended to areas outside agricultural location theory. Using a Cobb-Douglas production function and a Vickrey transportation cost function, Kanemoto (1976) constructs a von Thünen-type model with traffic congestion and two production inputs (land and labour). A flat homogeneous plain with a central business district (CBD) at the centre is assumed. The CBD is surrounded by a production zone which consists of factories and roads.



Traffic congestion is assumed to exist and the transport rate is assumed to be a function of traffic density. The problem is to determine the allocation of urban land between production (factories) and transportation (roads) use. Two models are considered and compared. The first determines the optimal land use. Kanemoto (1976) shows that the optimal solution can be obtained competitively if congestion tolls are levied and the road is built so as to make the marginal transportation cost savings from widening the road equal to the land rent. In the second model (the market city model) congestion tolls are not levied, resulting a suboptimal allocation of land use. The market land-use pattern is defined as the allocation that takes place when congestion tolls are not levied and the road is built so as to make the marginal savings of transportation costs from widening the road equal to the market rent. Kanemoto (1976) found that the market city is more congested than the optimal city and that the market city is much larger than the optimal city.

### 3 Outlook and prospects

One of the problems with the linear programming models is that they usually imply a pattern in which all flows go to the nearest market. This is almost always unrealistic, and spatial interaction models with their associated overlapping market areas provide a more flexible basis. Wilson and Birkin (1987) build on this observation and generate a dynamic model of agricultural location which can be used to generate equilibrium patterns. One interesting twist is that they allow rent to be endogenous in one of their models. They assume that rent is a function of land-use intensity and that there is a land-use constraint for each agricultural zone (i.e., there is a finite amount of land in each zone), but capital (or labour) can be substituted for land. Below a certain threshold, extra land is freely available and rents will only be raised relatively slowly as the demand increases. Beyond the threshold, increases in output can only be supplied at a great expense which can only be met by rapid increases in rent (which is, therefore, no longer a simple surplus or economic rent).

Mathematical programming models are an excellent vehicle for integrating the behavioural and economic approaches. Agricultural economists have long recognized this by incorporating uncertainty into many mathematical programming models. Quadratic programming may be used to represent farmer behaviour under uncertainty. Currently this integration is lacking in most geographical models (exceptions include Macmillan, 1979; Cromley and Hanink, 1989). The results of agricultural economists' models show optimal production plans much closer to the actual ones than those which emerge from linear programming. Freund (1956) was the first researcher to apply the Markowitz (1952) mean-variance portfolio model to the study of risk in agriculture. By introducing risk into these models, researchers were able to explain diversification as a rational choice of expected utility maximizers. The inclusion of risk and uncertainty into a model allows the assumption of the economic human to be relaxed and the models are able to resemble reality more closely. Since Freund's application in 1956, quadratic risk programming has been applied in countless studies to evaluate optimal crop allocation under conditions of risk and uncertainty. By introducing risk into future von Thünen programming models, geographers would be able to complete the important and vitally needed integration of the behavioural and economic approaches to agricultural location theory.

## VI Conclusion

This article has provided a synthesis of research which derives from the von Thünen model. The first section has shown the model to have some interesting historical and empirical 'realism'. Over the years, the model has attracted attention from some of the most well recognized names in geographical research. Our claim is that the model is worthy of continued study and appraisal because: 1) it teaches us about the duality between land rent and proximity to the market; 2) it necessitates a connection between the neoclassical and behavioural paradigms; 3) it models an economic system in which risk and uncertainty cannot be assumed away; and finally 4) the model provides a means of understanding actual land-use practices. Among the interesting research problems that await further progress, we select the following as a summary of the discussion in the article:

- 1) The dynamics of land-use changes in response to changes in exogenous conditions must be modelled as a system of differential (or difference) equations.
- 2) Although the relationship between various notions of 'surplus' and the von Thünen model has been the topic of some controversy, the usefulness of 'surplus' measurement in practice makes it imperative that a comprehensive treatment of this issue be made by economists and geographers.
- 3) The interaction between transport system changes, and other forms of technological change, and land-use changes is a long-standing concern for geographers interested in development. The von Thünen model has many interesting insights to offer to this analysis, and once the realism of a network-based transport system and a geographical information system for land cover is integrated, we realize that the theoretical foundations needed to guide such an analysis come from the von Thünen model.
- 4) Allowing farmers in these models to possess a realistic 'risk' aversion would be a major breakthrough in this arena: whether or not distance would play a key role in the rent gradient under conditions of farmers assembling a portfolio of crops in response to their uncertainty about future prices, is a worthwhile extension of the basic model. Although the review has indicated that good progress has been made on this problem, it remains a very challenging research problem to combine the role of noneconomic factors into an optimization model for land-use allocation. It is at this level that the models meet the reality of everyday farming practice. Recent micromanagement tools and measurements have given farmers unprecedented information about the soil, slope and productivity of their land, and their decisions about the allocation of these scarce resources play a key role in their own profitability, and in aggregate, determine the macrostructure of land use.

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# Networks and embeddedness in the dynamic types of new industrial districts

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## I Introduction

In recent years there have been intensive debates on the changes in the spatial organization of industrial activities, including the emergence of 'new industrial spaces' mainly in western economies. Some of the most critical issues in these debates are related to the localization and globalization of industrial activities in the context of networks, embeddedness and production systems.

It has been argued that economic development will itself increasingly be manifested in 'new industrial spaces', new 'high-tech locations' or 'innovation milieux' (Tödtling, 1994). Piore and Sabel (1984), among others, emphasized the importance of flexible specialization as a post-Fordist mode of production in the formation of new industrial spaces. In a similar vein, vertical disintegration has been emphasized as a major change in the production system, which has resulted in the emergence of new industrial clusters or ensembles (Scott and Storper, 1987; Scott, 1986; 1988a; Storper and Scott, 1989). In particular, studies on the 'third Italy' contend that flexible specialization, based on co-operation networks of small and medium-sized enterprises, successfully competes with the mass production of large enterprises (Goodman and Bamford, 1989; Capecchi, 1990). In the flexible specialization school, the local environment is seen to be especially important, and intensive networks clustering small and medium-sized firms within the local environment lead to the concept of the 'industrial district'. In other words, it has been argued that firms are becoming increasingly 'embedded' in local and regional networks of firms and institutions (Tödtling, 1994).

However, there has also been an increasing trend of globalization in the interfirm relations of production. The largest international and global firms are deliberately sourcing globally, and are globally co-ordinating basic research, applied research, development, production, marketing, distribution, service and financial functions (Dicken, 1992). Amin and Robins (1990; 1991) criticized the concepts of localization based on flexible specialization. They emphasized the forces of globalization and the