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Von Thünen on the Bybanen

A spatial model of the commute in Bergen

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"I loved Thünen above all my other masters." – Alfred Marshall

Abstract

The spatial model presented in this thesis explains the existing structure of Bergen and foresees how the city could evolve with the development of the light rails network (Bybanen). Many researches and policies were aimed at discouraging the use of cars. The approach taken here is not to force conversion of present automobiles drivers into collective transport users, but to make sure **new commuters** will predominately choose more sustainable modes of transport in the future. The key aspect is the appropriate location of new dense residential developments. Monocentric "compactness" does not necessarily result in a higher energy efficient city. Considering that further densification of Bergen Sentrum is not a feasible political/physical option, a light rail networks could lead, accordingly to the least commuting principle, to a denser city along the Bybanen route. As a strong sustainable symbol and a serious financial commitment, the Bybanen has the potential transform expectations and attitudes. Ultimately the Bybanen is a proficient strategy that will reshape the city; an opportunity to reduce GHG emissions and increase the societal welfare through (green) mobility.

Johannes von Thünen, the founder of spatial economics, has been a major direct and indirect inspiration in the construction of this model. A thorough reading of his magnum opus, The Isolated State, unearthed parts of his theories that have been either neglected or either entirely forgotten. For example the Thünian concept of land rent, which is more nuanced than the Ricardian Rent, can explain how a permanent infrastructure such as the Bybanen affects the structure of the city differently than an flexible bus network.

This research led to the creation of a commuting model true to the spirit of von Thünen. In addition, important contributions of his successors in location theory, urban economics and New Economic Geography have complemented the model in order to address urban challenges of the 21st century.

Acknowledgments

This fantastic journey would not have been possible without the inestimable help, influence, and inspiration of several great people to whom I am eternally grateful.

I would like to especially thank Gunnar S. Eskeland, my supervisor, who has challenged my worldview like no one else through his teachings and our discussions, who has supported me in times of doubts, and who has set me on the trail of von Thünen in Bergen.

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Von Thünen

Norway

MC

Special thoughts for my grandparents: For Mémé who taught me countless things including arithmetic. For Fernand whose stubborn refusal of the concept of inflation sparked my interest in economics.

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1. Introduction

Climate Change is probably the biggest challenge facing humankind (Stern, 2006). Various forms of pollution are emanating alongside the economic development that has elevated the welfare and the possibilities of our civilization. Progress comes at a cost that is immaterial in the economic system. Invisible Greenhouse Gases (GHG) are threatening our planet's ecosystems by modifying the climate faster than the adaptation capacity of living species including the ingenious humans who numerously agglomerate in their (natural) habitat: the cities.

Cities are heterotrophic systems largely exceeding the carrying capacity of their bioregion (Newman & Jennings, 2008). Indeed, since the First Industrial Revolution, the most salient aspect of urbanization is the reliance on increasingly dense sources of energy harnessed in ever farther regions (Taylor & Cruz, 2013). An enormous share of GHG is released by both the production and the consumption of that energy.

The next frontier in emission abatement is the energy efficiency of the transportation sector, in particular the transportation of people which will experience a growth in demand for domestic and international travels as society becomes richer (Eskeland & Lindstad, 2015). The spatial structures of urban regions and specifically transportation infrastructures have a direct and tremendous impact on the use of energy, emission of pollution and ecological footprint.

The spatial organization of the economy becomes even more important as the world experiences a rapid urbanization. The United Nations estimates that by 2060, 66% of the global population will live in urban agglomerations up from 54% today (UN, 2014). Urban areas cover only 0.5% of the surface of the globe (EU, 2010) but will influence the entire biosphere; such is the reality of the *Anthropocene*. The spatial structure of the economy at the urban and regional scale is increasingly determining the configuration at the global scale; thus the growing necessity to consider (urban) space in economic analysis.

Johann von Thünen was the founder of spatial economics, a sub-discipline which encompasses "*all branches of economics dealing with the analysis of economic process and developments in geographical space*"(Masahisa Fujita, 2010) including urban economics.

Von Thünen developed a simple model to describe the location and intensity of (rational) agriculture. In his magnum opus, *The Isolated State*, he describes a flat uniform plain with a central market town in the middle. He showed theoretically and empirically how transportation costs and distance will shape agricultural patterns around that isolated town. Specialization would be organized following a concentric pattern, what is referred as Thunian Rings.

The Isolated State has been an unrecognized masterpiece in his author's lifetime and an underappreciated *chef d'oeuvre* since. Von Thünen remained virtually unknown to Anglo-Saxons economists (with the notable exception of Alfred Marshall) for almost a century because it was not translated. This partially explains why spatial economics remained a German hegemony until the 20th century. But generally, and especially in mainstream neoclassical economics, space was dismissed as a secondary aspect.

Nevertheless, the legacy of Von Thünen is colossal and his theories experienced a renewal with the rise of urban economics. While, innovations in transportation technologies have rendered his model obsolete in the context of agriculture, a concentric model is still valid to describe commuting patterns. Inspired by *The Isolated* State, the Monocentric City has become a foundational framework in urban economics. Usually these models assumed a unimodal transport technology and focused on land use not mobility.

Mobility is at the center of current environmental and social challenges. A special attention to the mode of transportation is required. Citizens evaluate the various characteristic transportation costs of alternative commuting options. Therefore, the consumption of energy in commuting is the result of a large amount of decentralized decisions which can be "nudged" with appropriate incentives (Thaler, 2008). Von Thünen proposed an approach to analyze transportation costs (or more broadly spatial frictions) and the spatial organization resulting from a decentralized economy. Surprisingly he described costs both in monetary and in energy terms.

For these reasons, *The Isolated State* is a fantastic starting point for a reflection about sustainable commuting at the local scale. Indeed, there is a great value in revisiting older work that can bring novel perspectives on contemporary problematics (Dusek, 2013) .

"*And still not all the riches which are buried in his work are brought to light. To find them, you must without doubt read The Isolated State carefully and often.*" - Erich Schneider

A Map of the Road Taken

The present thesis inquires about the impacts of a light rail system (Bybanen) in shaping the city of Bergen, Norway[1]. A von Thünian model of commuting is developed to explain the spatial role of the Bybanen in the development and densification of the municipality of Bergen. It is proposed that the Bybanen has a strong potential to overcome historical spatial hysteresis, but due to certain barriers this potential is not fully accomplished.

The work is divided in three chapters. The first part is about Johann von Thünen and his major contributions to economics. It was necessary to give a detailed introduction to the reader of this almost unknown economist in order to understand how distinct or similar his thinking was from other classical economists. Also, an historical background is required to fully appraise his theories that have been often misinterpreted by neglecting the circumstances and the state of technology at that epoch *(Grotewold, 1959).*

The second chapter relates the development of spatial economics in the footsteps of von Thünen. The theories of his main successors are resumed with special attention given to the thread leading to urban economics and other relevant concepts for the present inquiry. This constitutes an extensive literature review.

In the last chapter is developed a model of commuting tailor-made for the city of Bergen. The model is built in a close spirit of von Thünen but also relies on valuable insights of modern thinkers. A Weberian approach of successive layers describes the urban sprawl over different eras. The "Ideal Commuter" is crafted by recent findings in transportation and behavioral economics. A simulation demonstrates the dynamic of the transport system. Finally, recommendations are made based on the findings.

[1] The immediate surroundings of the author. The methodology is deeply rooted in the experience and direct observations of the subject of inquiry as well as by a central geographic perspective.

2. Chapter 1: Johann Heinrich von Thünen

Johann von Thünen was an impressive but underestimated thinker of the 19th century. He has been nicknamed the "great unrecognized" by Alfred Marshall, a "patron-saint of econometrics" by Joseph Schumpeter, and a "founding god for geographers" by Paul Samuelson. Behind this late coming and rare praise lay an obscure but enlighten manuscript, *The Isolated State*, almost unknown to mainstream economists until the 20th century. Even today, economic history curriculum barely mentioned its author's name and contributions although prescient and important foundations he had built. Several reasons explain this lack of recognition.

In his motherland Germany, his ideas were against the tide. First, "Thünen was a liberal in every sense of the word – a liberal in politics and a disciple of Adam Smith in political economy."(Dickinson, 1969) Liberalism was not popular in German States, especially after the revolution of 1848. Second, he was not recognized by the academic establishment. He did not complete his studies and was not affiliated to a university[2]. He was a farmer. In the best case, he was perceived has an agronomist. He has indeed consistently published in the local Mecklenburg Agricultural Journal (Hall, 1966). Third, the Historicist School, which has dominated the 19th century in Germany, rejected the use of general economic theory. Historicism offered relative explanations of the world based on history, traditions, culture and geography. Thünen's novel empirical methodology was based on rationality and the unfolding of markets forces.

Like many other *avant-gardist* thinker, he was not fully understood by his generation. Like a good wine, his ideas took time to be fully appreciated. Samuelson wrote: "At 200 (years old) we hail Thünen more admiringly than was possible at 100 or at the time of his death."(Samuelson, 1983) Most of Thünen's methodological apparatus (marginal analysis, principle of substitution, partial analysis, econometrics, economic modelling, etc.) is nowadays included in introductory economics textbooks. However the credit went mostly to Neoclassical thinkers. While some borrowed elements from *The Isolated State*, in many cases the tools and concepts were independently rediscovered but many decades later.

[2] Although he was conferred a doctor *honoris causa* degree from the University of Rostock

Outside Germany he was virtually unknown. Some dispersed groups took interests in his ideas but not in his most salient contributions. Some partial translations existed in French, Russian, Italian and Czech, but the first English translation appeared only 100 years after his death. In addition, these translations were made with a specific topic in mind and therefore constitute disparate collection of extracts. This situation has created confusion and undermined the unity of Thünen's work.

Few people have read Thünen's original *magnum opus*. If Thünen was outstandingly gifted in mathematics, his writing was described as "messy" and very difficult to read, even in German his mother tongue. (Hall, 1966) In addition, he used a unit system from the early 19th century in Mecklenburg, making his work not readily accessible for modern readers.

For these reasons, Thünen's theories remained almost exclusively studied and discussed in the German speaking world where the location theory thrived. If Alfred Marshall recognized Thünen's influence on his work, for example he borrowed the concept of marginal productivity; he was not specifically interested in location problems. In fact, Anglo-Saxon economists ignored or, like Marshall, diminished the importance of space in their models. Therefore, location theory remained essentially a German hegemony (Blaug, 1979).

In the early 20th century, under the influence of geographers and location theorists, economists rediscovered *The Isolated State* and a plethora of dissertations emerged either praising or severely criticizing Thünen. Critics attempted to dismiss all his work on the grounds of a now famous mathematical mistake in his theory of natural wage. He has been an early adopter of extensive use of mathematics in economics, and also one of the first to commit a serious error in its application.

Probably to compensate for all the criticism, his followers went on to praise his lifework as a fountain of almost infinite wisdom. This exaggerated enthusiasm still transpires from the recent papers in New Economic Geography (Masahisa Fujita, 2012). Therefore it is hard to grasp a neutral appreciation of Thünen's theories.

We have made an attempt to get an unbiased appraisal. However due to a language barrier, we were obliged to rely on translations as well as many secondary English and French commentaries on *The Isolated State*. All of these books or papers were written or edited by enthusiastic followers of von Thünen. In those circumstances, it is easy to be carried off by this wave of enthusiasm.

Nevertheless, being acquainted with Johann von Thünen, his ideas, his theories, and especially his methodologies, is to develop a profound respect and admiration for a tedious lifework achieved only by extreme perseverance that is unheard of nowadays.

This chapter is portraying the epoch and the man that has given birth to location theory. Understanding the *zeitgeist*, the spirit of the age, is imperative to fully appreciate the contours of the model of monocentric rings, its assumptions, its strengths, and limitations. More than any other economic theories, it was subjected to a specific time and place of history.

Figure 1: Map of German States, approximate boundaries in Thünen's time (After 1815). Duchy of Mecklenburg-Schwerin in red. Source: Wikimedia Commons

2.1 Biography and historical context

Johann Heinrich von Thünen (1783-1850) lived through the industrial revolution that transformed Germany from a traditional agrarian society into a commercial and exchange economy. German Enlightenment and Industrialization were almost 50 years behind the intellectual and technical revolutions of France and England. Thünen lived in northern Germany which was somewhat of a remote place before the advent of railways.

Johann Heinrich was descendant of an old feudal family. His father's estate, Kanarienhausen, was located in the Grand Duchy of Oldenburg, near the North Sea Coast in the north-west of today's Germany. At the age of two, young Thünen lost his very learned father, Edo Christian von Thünen.

Like his father, Thünen was particularly gifted in mathematics. After his mother remarried to a timber merchant, the family moved to the town of Hooksiel where Thünen received primary education. He attended secondary school in Jever where he lived with his maternal grand-father. "*He occupied himself with special zeal and success with mathematics... In the papers which he left from that time we find solutions of problems which give testimony of extraordinary talent.*" (Schneider, 1934)

Following familial tradition, agriculture became Thünen's vocation. At the age of 16 he started a three year apprenticeship of practical farming in the Jeverland at the typical German estate of Gerrietshausen. He then followed a two-year program at the Agricultural College at Gross-Flottbeck near Hamburg where, in 1803 at 20 years old, he conceived the idea of the Isolated State[3]. He understood the influence of Hamburg on the surrounding farmlands. That summer, he also attended lectures of Albrecht Thær who was the German reference on English agricultural techniques. He pursued his education by following two semesters at the University of Göttingen but never completed his degree. In the summer 1804, he accomplished an agricultural tour via Saxony to Mecklenburg during which he met Helene Berlin. The couple was engaged in the autumn of 1804, and married in October 1806. By then the Napoleonic Wars (1803-1815) were raging in Europe. He sold his father's estate and moved eastward.

[3] In 1803, Thünen wrote a treatise: *Description of the Agriculture in the Village of Gross-Flottbeck*

From 1806 to 1808, Thünen leased the estate of Rudkow near Anklam[4]. The farm had a mediocre soil. Not only harvests were small but cattle were affected by pest and epidemics. This was a period of hardship for Thünen and a test of his agricultural skills. In addition, he had to deal with the quartering of troops, requisitioning of men, horses, cattle and forages. Although no major battles have been fought in that region, the territory has experienced movement of armies. German states are located in the hearth of the North European plains making it a "geopolitical highway" between the French, Austrian, Prussian and Russian empires. The end of the lease came as a relief and Thünen moved closer to his wife's family in the Grand Duchy of Mecklenburg.

In 1810, a few days after his 27th birthday, he bought from his brother-in-law the large estate of Tellow which he managed until his death. For 40 years, Tellow has been the laboratory where he would conduct his scientific experiments. He thoroughly recorded the estate's accounts. These records provided him an extensive source of data upon which he would rely to empirically prove his theories.

On Tellow

Thünen owned the 1146 acres estate of Tellow, a green land of smooth low hills shaped during the last glaciation. The property is also punctuated of small lakes and alluvial marshes. Thünen cultivated a soil ranked among the bests in the region (Hall, 1966).

Tellow is located in what was then the Grand Duchy of Mecklenburg. The Duchy has been affected by several lethal wars in the previous centuries which have delayed its economic, social and technical development. When Thünen established at Tellow, Mecklenburg was almost a medieval society. Serfdom was not yet officially abolished and agricultural techniques had just recently been upgraded from the three-field system to the "improved system" developed in Holstein in the west.

Mecklenburg was indeed an isolated region in the early 19th century. There are no major navigable rivers in the area. Transport was only possible by carts drawn by horses or oxen. East of the estate, lay a road connecting to the harbor city of Rostock 37 km to the north-west, and the small market town of Teterow 8 km to the south. Railways reached Teterow more than a decade after Thünen's death.

[4] Territories north of the Penne River were under the Swedish Crown until it became part of Prussia in 1815.

The important market in the region was Rostock, an old hanseatic town on the shore of the Baltic Sea. Thünen recognized its influence for the surrounding agricultural lands including his own estate. Rostock could be associated to the central market in Thünen's theory.

Today, Tellow is a museum dedicated to its most famous manager: Johann Heinrich von Thünen.

Figure 2: Map of Germany
Source: GoogleMaps.

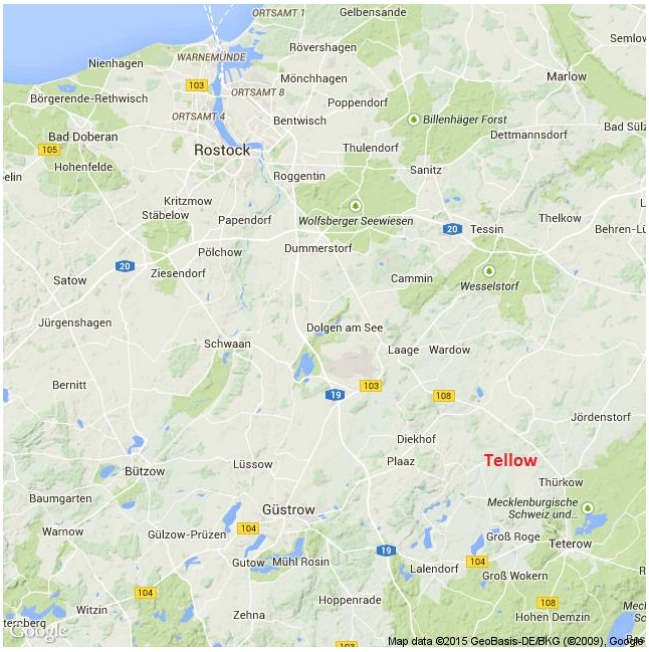


Figure 3: Map of the Region of Rostock and Tellow

Thünen's mentor: Albrecht Thaer

Albrecht Daniel Thær was a famous German physician turned agronomist. He has been summoned to England to become King George III's personal doctor. However his real passion was gardening and agriculture. Amazed by 18th century agricultural improvements in England, he decided to disseminate the knowledge to Germans. He published *Introduction to a Knowledge of English Agriculture (1798)* which was acclaimed in German States and in England. In 1802 he founded the first German agricultural training institute in his hometown of Celle, which Thünen frequented. From 1809 to 1812 Thær published *Principles of Rational Agriculture* in four volumes. He was granted nobleman privileges by Prussia and was honored both while living and posthumously (Patent Office, 1848).

Thünen was greatly inspired by Thær's treatise and seminar on English Agriculture. Thær insisted on intensifying cultivation and was an advocate of the most intensive system called

"crop alternation": an alternation between grain crops with non-grain crops. The latter would enrich the soil and also support more livestock to produce manure to fertilize the land. Thünen disagreed with his mentor on the universal application of the same agricultural system regardless of place and time. In Thünen's view not every type of soil could support an intensive system. Despite this diverging opinion, Thünen was greatly influenced by Thaer's scientific approach to evaluate the equilibrium between yields and soil exhaustion which underlined the importance of mathematics and a theoretical approach in agriculture (Hall, 1966).

The writing of The Isolated State

The Isolated State refers in the literature as the multi-volume lifework of Johann von Thünen. It is a collection of Thünen's writings published in successive parts, some of which posthumously. The first part establishes his famous agricultural location theory. Initially published in 1826, it was only after the second edition in 1842 that it received a significant public attention. The first section of the second part discusses the natural wage theory and the concept of marginal productivity. This part was published a few months before Thünen's final breath with the help of Hermann Schumacher of Rostock, his friend and disciple. Schumacher then assembled and edited Thünen's notes which were published in 1863 as Part II section 2 and Part III. These incomplete inquiries are indications of Thünen's intentions for further elaborations; topics prefiguring his successors such as Alfred Weber by more than half a century.

The present thesis will focus on the location theory included in Part 1. Table 1 shows all original parts in German and gives an overview of their content. Appendix II details the complicated assortment of corresponding translations.

*Table 1: The Isolated State in Relation to Agriculture and Political Economy**

Year	City	Parts/Editions	Content
1826	Hamburg	Part I	Agricultural Intensity, location of agricultural systems and crop zones
1842	Rostock	Part I, Second Edition	Improved and extended edition
1850	Rostock	Part II, Section 1	Wage theory
1850	Death of von Thünen		
1863	Rostock	Part II, Section 2	Taxation, customs duties, settlement policies, the consequences of improved roads and railways
1863	Rostock	Part III	Collection of papers on forestry
1875	Berlin	Complete Work	The only existing edition regrouping all parts

Source: Hall, P. 1996, *Von Thünen's Isolated State*

*German title: *Der isoli[e]rte Staat in Beziehung auf Landwirtschaft und Nationalökonomie*

Originally the title was supposed to be *The **Ideal** State*, referring to the method of idealization, the use of simplifications to inquire and learn about a complex world. Thünen was developing what would become one of the first economic model (Hall, 1966). But following his brother's advice, Ideal was replaced by Isolated, a better depiction of the ideal state has he imagined it: a central market town surrounded by agricultural lands and isolated from other regions of the world. Later in his work, he relaxed the isolation assumption and allowed trade and interaction between towns. It would be a reduction of Thünen's theories of believing it only allowed one town. In addition, he had to defend, explain and justify his novel method of analysis, which isolates one factor at the time. This method of breaking a problem into its component parts became generally accepted only after 1890, when Alfred Marshall introduced the famous *Ceteris Paribus*, "All other things being equal or constant". Thünen was proposing the partial analysis of a phenomenon, starting with a simple model and adding complexity gradually. The simplest model was a town in the middle of uniform plain, *The Isolated State*; a title successfully depicting both the model and the methodology.

The complete title is somewhat much longer; for part I: *The Isolated State in Relation to Agriculture and Political Economy, or Researches on the Influence which the Price of Wheat, the Richness of the Soil and the Market, Have on Agriculture.* Not surprisingly such a colossal project took more than two decades to complete. The first reference to his model

was made in a treatise while attending the Agricultural College in 1803, but he had to wait until he had accumulated sufficient data to support or refute his speculations.

Having recorded meticulously his estate's accounts from 1810 to 1815, it took him 4 years to complete the thorough analysis of the costs and returns. In a correspondence with his brother, Thünen confides that this inquiry precluded most of all other researches (Hall, 1966). He was rewarded by succeeding in his goal of creating an abstract economic model supported by actual facts and data. In 1819 he wrote the first draft of *The Isolated State* but was reluctant to publish for fear of not being understood. He finally revised and eventually published the first volume in 1826. Thünen then shifted his focus to what appears as a different concern.

On Natural Wages

Romanticism's apogee concurs with the beginning of his work on the Natural Wage. Romanticism, a wide artistic and intellectual movement, was born in a period of turmoil and wars, namely the French Revolution and the following Napoleonic Wars. It incarnated a counter-reaction to the Industrial Revolution, scientific rationalization, and the Aristocracy; all constituents of the Age of Enlightenment. Submerged in nostalgia of a past era, Romanticism glorified nature, emotions, imagination, as well as self-expression. It was also a rebellion against the established social order and conventions. Thünen partly succumbed to the Romanticism *Zeitgeist* when he elaborated his theory of Natural Wage.

Classical economists had partially inherited of their view on labor's compensation from Physiocrats, who advocated that wages should be providing barely enough to survive, *le strict nécessaire*. However for Classical economists, market wages could be higher than this *strict nécessaire* because they were determined both by the supply of labor and the acceptance of this subsistence wage (bargaining power). Inspired by mechanical physics, English Classical economists saw the "Natural Wage" as the inevitable long term trend around which continuously oscillates the market wage, a level influenced by a characteristic sociological order of an era (Caravale, 1988).

In the 19th century, many believed (Malthus, Lasalle, Marx) that the "Iron Law of Wage" prevailed; in the long run leading real wages to tend towards the minimum wage on which the workers could physiologically preserve their capacity to work as well as sustain the supply of labor by sufficient reproduction rate.

Von Thünen held a different normative prescription. He introduced the grand principles of justice and fairness to claim that workers deserved higher compensation then the bare subsistence. He was searching for a natural law, a guiding principle for determination of wages levels. His *naturgemäße arbeitslohn* can be translated as: a wage in accordance with nature. The evocation of harmony with nature clearly labels this theory as Romantic. This distinction is lost in its English version of "Natural Wage", but the reference to a moral, normative, and even rational theory remains. True to its roots, the German tried to proof this Romantic endeavor in the realm of rationality using his mathematical apparatus.

The key intuition was to rely on marginal productivity. For von Thünen, both capital and labor should be rewarded according to their just share of productivity. The idea of productivity to explain interest by the productive power of capital was invoked by some predecessors such as Lauderdale, Say, and Malthus. However, Thünen went deeper in the cause and nature of interest by suggesting the interdependence between wage and interest. He considered that labor is both a producer of capital and a substitute of capital. He applied a marginal analysis to determine the specific contribution of each factor which led him to a mathematical expression for the Natural Wage. In a simple Romantic aesthetic, the Natural Wage should be the geometric mean of the value of labor (efficiency of labor in total product) and the subsistence level of the laborer and his family. He was very proud of this simple elegant result: A = $\sqrt{ap}$. Upon his request, the formula was inscribed on his gravestone.

Dickinson stresses the normative stance of this formula: "It is not a descriptive proposition, asserting how wages are actually determined. It is a normative proposition, asserting how wages would be determined in a just and rational society."(Dickinson, 1969)

However there is a unanimous consensus[5] that Thünen's formula is flawed on many accounts. He was extensively criticized, ridiculed and even ostracized for this mathematical expression of Natural Wage. Even one of his greatest vindicator, the late Paul Samuelson, qualified this theory as "weird" and said the formula was a crime against normative and positive economics in addition as constituting a logical mistake of Thünen's own model and a Sentimental Fallacy (Samuelson, 1983).

[5] Except maybe for Bernard W. Dempsey. See (Dempsey, 1960) Reinstatement by (Neishi, 1990)

The culprit is an inadequate maximization both in its specification and execution. Basically he based his maximization on wrong assumptions and solved it improperly. The full controversy is not in the scope of the present work, but here is a very concise version of the demonstration based on Knut Wicksell and Paul Samuelson:

Thünen expressed capital as (w – a), the surplus between a yearly worker's wage (w) and his subsistence (a) for a year.

p: gross product of labor (fixed)	p – w : profit
w: wage	z = (p – w) / w : profit earned on each unit of wage
a: subsistence consumption (fixed)	y = (w – a) : current savings

Maximize $z \times y$: the profits (interests) of current savings

$$\frac{(p - w)(w - a)}{w} = p + a - w - \frac{ap}{w}$$

Since p and a are fixed, the maximum will be achieved when $w + \frac{ap}{w}$ is minimum.

$$w^2 = ap \rightarrow w = \sqrt{ap}$$

His maximization equation implies that workers should not consume more than the subsistence level in order to save and maximize the return of the current surpluses. (He also bizarrely assumes that past savings and profits are not contributing to current savings.) By imposing a restriction on consumption for society in this manner, the proposition contradicts both the *laissez-faire* principles and recent findings about cognitive bias and savings choice in behavioral economics. Moreover, even if one would accept these assumptions, the mathematics revealed faulty (Dickinson, 1969). For a deeper explanation on the deficiencies of the Natural Wage, see (Blaug, 1992).

On Human Capital

However wrong his theory of Natural Wage was, Thünen shone light on the principle of marginal productivity of labor and on humanitarian aspects in wage determination. That is still a remarkable feat in the early 19th century, an era notoriously infamous for its working conditions. Serfdom in Mecklenburg was officially abolished only in 1820 (Genealogy.net, 2010). Since the nobility did not have the responsibility to offer subsistence to peasants

anymore, conditions got only worse for them. However, von Thünen, a model employer, treated his employees according to what would be late 20th century principles. "On his estate of Tellow there was a doctor, and a nurse and a cottage-hospital. All employees and their families were treated free. This service, together with a system of sick-pay and retirement-pensions, was financed by a deduction from the worker's pay." (Dickinson, 1969) Later he even introduced profit sharing and pension schemes. He also emphasized the importance of education in the productivity of labor and reflected in the modern framework of "human capital"(Kiker, 1969). He was a proponent of universal education. Also he stressed that a farmer possesses a human capital, the local knowledge of his field acquired over the years. For this reason, he argued in favor of farmer's financial support offering protection from disasters such as floods and drought in order to avoid bankruptcy and the loss of specific knowledge tied to the land. We could see in Thünen's ideal some prefiguration of the Rhine Capitalism model.

On Fairness

Thünen was obsessed with fairness at a time when most employers mistreated or disregarded their employees. Fairness, which was almost completely obliterated by Neoclassical thinkers, is nowadays a central preoccupation in Behavioral Economics. Practitioners like Thünen are indeed confronted to this reality. The former US director of the Council on Wage and Price Stability, Albert Rees, a Chicago and Princeton renowned labor economist, confessed in 1993 (Akerlof & Shiller, 2009) :

"The Neoclassical theory of wage determination, which I taught for 30 years… has nothing to do with fairness… In none of these roles did I find the theory that I taught so long to be the slightest help. The factors involved in setting wages and salaries in the real world seemed to be very different from those specified in the neoclassical theory. The one factor that seems to be of overwhelming importance in all the situations was fairness."

Von Thünen was a progressive liberal and his wage theory was an attempt to promote social harmony. Thünen's rational abstract approach must be interpreted along the influence of Hegelian philosophical idealism on his teleological propositions (Barnes, 2003).

Lasts words on Thünen's life

The striking aspect of Thünen's biography is how advanced his intellect was, and perhaps how economic thoughts failed to learn from him. Thünen was son of the Enlightenment. He shared the Enlightenment's optimism of rationality along the idea of progress through scientific experimentation. His adult life was also shaped by the aesthetic of Romanticism. His actions were subjected to strong moral and social principles. He believed in "benevolent egoism"; a middle ground between the Scottish moral philosophy and the romantic-ethical schools of economics inspired by Immanuel Kant's "Critique of Pure Reason" (J. Backhaus, 2012). Thünen was therefore both a social philosopher as well as a prescient and applied economist; he was a true classical thinker.

"Thünen belongs in the Pantheon with Léon Walras, John Stuart Mills and Adam Smith. As Schumpeter would say, it is the inner ring of Valhalla they occupy." – Paul A. Samuelson

2.2 Main Contributions to Economics[6]

Different thinkers have read different things in *The Isolated State*. Thünen's prolific mind had indeed touched or envisioned a myriad of economic tools and concepts most of which he did not developed to its full extent. He had summoned them mostly for the purpose of his inquiries. He focused on explaining scientifically some aspects of the world and his tools were not finality in themselves. He failed to foresee the full implication of these concepts for other branch of economics. Therefore the paternity of discovery was attributed to those that wholly nurtured and popularized the notions. However, his *chef d'oeuvre* clearly contains elements of future theories. This section briefly relates von Thünen's contributions to economics as recognized by Schumpeter, Dickinson, Samuelson, Hall, and Fujita. These innovations emerged from diverse roles he played; different facets of his fruitful life.

The gentleman-farmer is acknowledged as the founder of **agricultural economics[7].** He was the first to systematically apply principles of economics to the production of crops and livestock. His purpose was to rationally determine use of agricultural lands, not simply relying on randomness or tradition like most farms of his time. He understood the impact of the emerging market economy for agriculture. He also focused on *agricultural static*, "the study of the relation between manure application and crop yields…" (Hall, 1966) To prove his intuitions, he kept for ten years very detailed and meticulous accounts of his estate. It also constitutes one of the first usages of accounting data in economics.

The estate manager was concerned by his worker's welfare and is recognized as a forerunner of **managerial economics**. Applying rationality to the conduct of his affairs led him also to consider a fair and just treatment and compensation for his workers. Von Thünen was a practical businessman and was praised as a model employer.

[6] Contributions in Agronomy, Agriculture, and Politics will not be detailed in this dissertation.

[7] Thünen also made a contribution in forestry and resource economics in Part III of The Isolated State, he is considered as a forerunner of Faustmann.

The *bel esprit* thinker is however chiefly renowned and remembered for the **theory of economic location**. By unifying the theories of rent, land use and location of economic activity, Thünen has laid solid foundations for his successors both in the fields of economics and geography. Spatial Economics and Economic Geography were born in *The Isolated State*. While his name is mostly associated with agricultural location and land use theories, Fujita asserts Thünen's preoccupation for industrial agglomeration and city formation; prefiguring Alfred Weber and even some aspects of New Economic Geography (Masahisa Fujita, 2010). In the posthumous extracts edited by Schumacher in 1863, Thünen meditates on factors that repel or attract industries in cities. His explanations of industrial agglomeration even include *ersatz* of modern concepts like innovation clusters, interindustry linkages and technological spillovers.

The pioneering researcher designed his own methodology. He instigated an abstract model in order to deduct knowledge about the world. The method of idealization was borrowed from natural science and applied to society, a sin in the eye of the *zeitgeist* Historicist School. He introduced underlying hypothesis to construct a simple model that would behave as if reality respected these conditions. This approach would allow him to study a complex world by isolating factors one by one. Therefore, he conducted several **partial analysis**, a technique familiar to every modern economist.

The mathematician was one of the first to systematically **apply mathematics to economic analysis**. He built an economic model expressed in mathematical terms, and successfully proved its validity with real data consigned in his detailed estate's accounts. Schumpeter has sacred him a "patron-saint of econometrics" for his pioneer work using empirical data to tests his theories. Indeed the early 19th century a handful few economists used mathematics to such extent, the most notorious being Antoine Augustin Cournot and Hermann Heinrich Gossen. Mathematical Economics gained importance only at the end of the century after major contributions by Léon Walras and Vilfredo Pareto.

In the pursuit of his investigations, the economic theorist has also elaborated on several important concepts. He included the differential **advantage of location in the concept of land Rent**. He proved that a differential rent could arise from variation in transportation costs. During his inquiry on the Natural Wage, he introduced the **concept of marginal revenue productivity**. The principle of diminishing returns, classically applied to land, was extended to labor and capital. The wage of laborers was approximatively equal to the

marginal production (the additional production) of the last laborer employed. In addition, his argumentation relied on the **principle of substitution between labor and capital**. Far ahead of his time, Von Thünen deployed a set of concepts and methods generally associated with Neoclassical economics.

Finally, von Thünen was a genuine social philosopher in the tradition of Classical thinkers occupied by strong ethical and moral questions such as Smith, Malthus and Mill. Thünen believed in free markets for building a rational and just society. With all the optimism of the Enlightenment, he embarked on a quest to find an objective and scientific principle guiding the ideal determination of wage. Thünen considered his **theory of Natural Wage** as his greatest achievement. Unfortunately this theory proved false to the delight of his critics. However, he sincerely searched solutions to the challenges of his time, a *bona fide* attempt to improve the world through rationality.

Valhalla's Inner Ring

Johann Heinrich von Thünen remarkably combined many roles, responsibilities and professions. As an economist he transcended epochs and school of thoughts. For all his diverse and prescient but underestimated contributions, Schumpeter elevated him in the Inner Ring of Valhalla. Even more remarkable is that *The Isolated State* continues to echo and illuminate more recent developments.

Paul Samuelson has hailed Thünen for elaborating **one of the first models of general equilibrium**. He also reckoned that *The Isolated State* encompasses elements of theory of the comparative advantage (Ricardo-Torrens), the theory of rent (Malthus-West-Ricardo), the theory of factors and goods pricing (Heckscher-Ohlin and Stolper-Samuelson) and the system of input-output (Marx-Dimitriev-Leontief-Sraffa). Samuelson also acknowledged that Thünen's version of these models included the main constituents of **modern competitive theory**. "*Not only he has understood their positivistic features, but in addition, he has anticipated the … demonstration that charging competitive land rents is what leads to normative social efficiency (albeit possibly great inequalities and inequities)"* (Samuelson, 1983). "Johann Heinrich von Thünen was a genius, a neoclassicist before there was neoclassicism." (Samuelson, 1986)

Spatial economist Masashisa Fujita went further as to claim that Thünen's "*monumental work*" was a theory of general equilibrium in space or **general location theory**. Thünen

"attempted to determine simultaneously all variables of the economy through competitive markets of goods, labour, and land, with a special focus on the land pattern and land rent pattern in the agricultural hinterland. To achieve this grand objective, Thünen himself developed all the basic elements of modern competitive theory."(Masahisa Fujita, 2010) However, without the development of imperfect competition models, he was not able to fully explain agglomeration forces of industries near large towns. Fujita claims that Thünen was concerned about industrial location but was simply lacking vital later-developed tools to connect the dots. Therefore his work constitutes a grand attempt at a general location theory; the present quest of New Economic Geography.

Perhaps von Thünen lacked vital tools and formalism to express his ideas; however his chapter on industrial agglomeration clearly supposed increasing returns both for manufacturing and farming cooperatives. Fujita, Krugman and Samuelson assumed that the "*bulk of economic models between 1820 and 1970, focused on the case of perfect competition and constant returns*" (Krugman, 1995) in line with the Neoclassical trade theory. While important elements of that theory like perfect information are present in Thünen's original model, his thinking was overall not limited to this strict definition of market structure. Therefore the perfect competition assertion is a misinterpretation of classical thinking that was not burdened by unrealistic assumptions (Dusek, 2013).

In retrospective, Thünen's ideas can fully be appreciated in the light of 20th century's developments in economic thought. In 1934, Erich Schneider wrote "His work shines brighter than ever today."(Schneider, 1934). In 2015, it seems Thünen's star might not have reached its zenith yet.

2.3 Theory of monocentric agricultural rings

Von Thünen is mostly remembered for the model of monocentric Ideal State. It is the most completed part of his work. The present thesis will build upon that Thünian theory. This section will summarize the main aspects of that framework.

Paul Samuelson in his excellent tribute article to Thünen (Samuelson, 1983), provided his own concise version of Thünen's rings and conciliated it with Neoclassical theory in an attempt to testify of the model's validity. Therefore, he specified a few Neoclassical hypothesis like "all people… have identical (homotethic) tastes at all income levels". While these additions are in accordance with Thünen's model and assumptions, it uses unfamiliar concepts to the German economist and adds complexity to the argument. The following description will be simpler and closer to its original version.

Depicting The Isolated State

The spirit of the *Isolated State* can be best summoned by conjuring Thünen's own introducing words:

> *"Imagine a very large town, at the center 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 uncultivated wilderness which cuts off all communication between this State and the outside world.*
>
> *There are no other towns on 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.*
>
> *The mines that provide the State with salt and metals are near the central town which, as it is only one, we shall in the future call simply "the Town".*
>
> *The problem we want to solve is this: What pattern of cultivation will take shape in these conditions?; and how will the farming system of the different districts be affected by their distance from the Town? We assume throughout that farming is conducted absolutely rationally."* (Hall, 1966)

Thünen vividly create the Isolated State in the mind of the readers, sets the main assumptions and exposes the subject of inquiry. He proposes that transportation dictates the pattern of farming and agricultural location. Perishables commodities or heavy or expensive products to transport will be grown close to the Town. With a steadily increasing distance from the Town, products with a low transportation costs relative to their value will prevail.

As a consequence, farming will be organized in different zones, forming concentric rings around the Town.

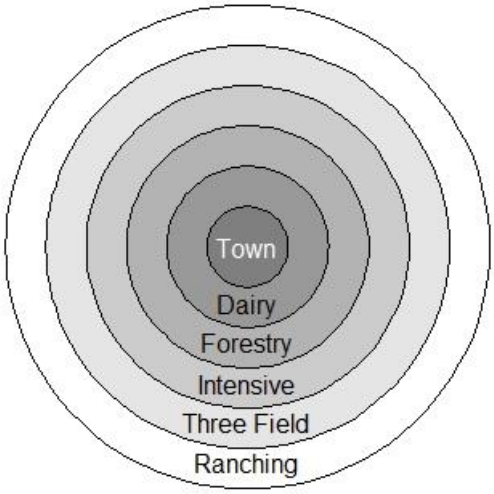


Figure 4: Thünen's Rings

Hypothesis and deductive aspects

The Town is a dimensionless point in space where all trade occurs. Both agricultural and town products are sold there at a unique market price. The location of the town is exogenous in the model. How the Town came into existence is not explained explicitly. It could be considered as the result of historical settlement. Thünen speculated in later parts of his work about agglomerative factors. However for this theory, the location of the town is given and fixed.

The land around the Town is homogenous except for the distance that separates it from the market. Again, later part of the work introduces the possibility of differences in the fertility of the soil but the model starts by assuming uniform flat lands. Topography is absent, so are water bodies such as rivers.

Prices are determined by the size of the Town and the costs of marginal producers. Demand for farm products, both in commodity types and quantities, is determined by the city-dwellers tastes (or preferences) and by the size of the population in the urban area. To meet this demand, commodity prices at the market-Town must be sufficiently high to barely cover the costs of the marginal producer. This producer is the most distant farm that provides the last or marginal unit of a commodity demanded by the town.

Wages are constituted of a basket town-based and farm-based product, in other words, clothes and grains. The ratio of clothes to grains will vary with location. Townsmen's basket will contain a higher share of clothes while remote farmers will obtain a higher share of grains. Clothes are relatively and increasingly more expensive with distance from town. It is also assumed that town products such as clothes do not require agricultural inputs.

Labor possesses uniform skills and is free to move and establish where market forces or the "Invisible Hand" would allocate demand for labor. Thünen mentions individual's preferences between urban or countryside life that will have an impact in the price ratios between clothes and grains. Ultimately, his point is that location of labor is self-determined or endogenous. Samuelson introduces the notion of utility to describe the spatial sorting of labor in Neoclassical terms. Therefore, labor, both urban and rural, would obtain the same real wage in utility terms. "People migrate from low to high utility-wage places, thereby bidding down wages at the former, and achieving stationary equilibrium only when real-utility wage equalization has been attained" (Samuelson, 1983).

Bidding for plots of land operates under (perfect) competition. Agricultural lands located closer to the Town should command a higher price than remote fields. Transportation costs will explain this situational rent. More precisions on Thünian Rent will be given later in in this section.

Landowners are rational rent maximizers. His definition of rationality follows the tradition of English Classical economists where entrepreneurs are profit maximizers operating under perfect information and knowledge. Therefore farmers have complete knowledge about their estate, available agricultural techniques and market conditions.

Thünen admits that his model is not entirely conforming to rational cultivation. In the introduction of part II, Thünen comments the criticism addressed after the release of part I. According to him, critics failed to attack assumptions in contradiction with rational agriculture. The first of such hypothesis is the constant fertility of the soil over time. In his model, fertility of a field will remain the same after cultivation than before. Intensive cultivation of farmlands does alter fertility. The second supposition is uniform skills and effort in farming. Therefore, all over the region would be applied the same thoroughness of tillage, harvesting, threshing, etc. even if the costs would not justify it. These two unrealistic

assumptions were necessary simplifications of the model but in contradiction with the guiding principle.

Thünen's model has other implicit hypothesis not described textually by the author. The conditions of his time are inherent proposition in the model and have been overlooked by modern critics (Grotewold, 1959). Therefore, Thünen considers only one mode of transport (cart propelled by oxen) and the existence of a single freight rate. Firewood was the main fuel, manure was used to fertilize the land, and perishables products could not be refrigerated in transit. Any improvement of these technologies modifies substantially the conclusion of Thünen's theory.

Wisdom of a practical farmer

"…it is indeed remarkable that economic theory has yet failed to expound and systematise what good sense and judgement have long since taught the ordinary farmer." – von Thünen

Adam Smith and David Ricardo had very little knowledge in practical farming. Von Thünen's professional vocation allowed him to grasp the subtleties of agriculture and to propose an appropriate framework to address the complex challenge experienced by landowners.

For each field, depending on their location and market prices of commodities, farmers must decide simultaneously the type of crop and the intensity of its cultivation. Therefore, von Thünen has developed two theories. Chapters 4 to 18 of the *Isolated State* are dedicated to the **intensity theory** where the study concerns only one type of crop but various intensities in cultivation. He shows how distance from town will influence the profitability of different agricultural systems. Then in chapters 19 to 32, he inquires about alternative agricultural products to elaborate a **crop theory**. The combination of these two theories will provide a rational choice of crops with appropriate intensity.

Many thinkers have seen Thünen's theory as essentially an intensity theory (Ponsard, 1958). Therefore they understood the *Isolated State* as describing an agriculture that will be more intense in proximity to the Town and progressively less intense as distance increases. This reduction fails to encompass the complexity of the problem and the subtlety of the analysis. For example, according to Thünen's findings, the second ring is occupied by forests for firewood and building timber. Forestry is the least intensive cultivation. However, due to its transport costs and high yields, wood will prevail on other agricultural products at that

distance. This is a surprising result. An intensity-only model would have put forestry on the outskirt of the region.

Before going into the mechanics of the Thunian intensity theory, we must have a closer look at the relationship between the distance of farms from the market, the revenue for their agricultural products and the land rent.

The Impact of Distance on Transportation Costs

Farmers sell their products at the market price in town and must deduct their transportation costs of their income. Assuming linear freight cost, this implies that farmers closer to town will obtain higher revenue for a bushel of rye than their colleagues in remote regions.

Thünen empirically derives wagon transportations costs from his 5 years accounts. Tellow being 5 miles (Old German measure of distance) from the market of Rostock, he would find a formula expressing the transportation costs at X miles from the Town. He admits a slight simplification in having a linear cost, but defends that it was the best estimation he could come up with.

In addition to monetary freight costs, oxen and horses are eating a portion of a wagon's load on their way in and out of the city. Thünen has quantified this consumption and introduces this reduction of shipment in proportion to the days of travel needed.

Consequently, the situational advantage is in fact twofold since Thunian transportations costs have a monetary component (or in his words market-based costs) and a product component (farm-based costs). Not only a faraway farm will obtain less revenue per bushel, it will also deliver fewer bushels to the town.

To formalize this concept and simplify transportation costs, Samuelson has developed in 1954 the Iceberg Model which is still used in New Economy Geography (Krugman, 1991b). Samuelson's version prices received by farmers are "melting away" thus combining the dual nature of costs into a single monetary unit.

The Impact of Market Size on Land Rent

The size of the market-town dictates the demand for agricultural products. A larger town requires more food. As a result, a wider area of agricultural land will be put into cultivation to meet this demand. Shipping costs increase with distance from town. Therefore, this

expansion is only feasible if there is an increase in prices for goods delivered at central market. Farms located closer to town will benefit from relatively lower transportation costs than the newly established cultivations in more remote areas. Thus, in the proximity of town, lands values will increase creating a situational rent. As the town grows this process repeat itself: the agricultural activities expands to further regions and the closer farms will experience an increase in land rents. Farms from the "second wave" will now command a positive land rent, while the last wave of harnessed lands will not.

Land rent (R) was expressed by Grotewold in function of agricultural yields (Y), market prices (p), production expenses (E), freight rate (f) and the distance of (k) miles from the market (Grotewold, 1959)[8]: $R = Yp - E - Yfk$

Grotewold's equation explains only one aspect of rent, but Thünen's argument was more nuanced.

On the Nature of Rent

In general von Thünen defines land rent in a Classical perspective as "net product minus the interest on the capital invested in the buildings and other valuable equipment" (Hall, 1966). This separation of pure land rent and interest on investments is a departure from Adam Smith's definition of land rent, which is described by von Thünen as Estate Rent. Smithian Estate Rent was the value remaining after the farmer had covered all his costs and covered a usual interest on his capital. Thünen emphasizes the need to isolate the rent of the land itself from the improvements such as buildings and fences. "This distinction is based upon long-run mobility" (Blaug, 1979). In the short run, capital invested in the buildings is immobile and is compatible with Smith's view of fixed assets. But it is not the Estate Rent but the Pure Land Rent that determines if cultivation continues in the long run. Capital will be invested if the estate can offer a return covering or even barely covering the current rate of interest. If the revenues of the estate should decrease, the land rent becomes negative but cultivation would still continue for a period of time until decay destroys the equipment due to a lack of maintenance. Therefore pure land rent is determined by features of the land that are permanent. This view was shared by David Ricardo. However, Thünen's theory is original in proposing that the features of the land can be improved by efforts and skills of the

[8] Land rent per acre, Yield in units of commodity per acre, Expenses per acre, Price in units of commodity, Freight rate in unit of commodity over the distance of one mile. Grotewold also combines all transportation costs into one monetary unit.

farmer. Therefore, Thünen proposes three sources of land rent: situational, intensity, and permanent improvement of the soil.

Situation Rent is based on the given properties of the estate, and has two components related to its situation: location and fertility. Situation Rent arises from superior soil or location compared to the worst lands in cultivation. As explained above, the location of a farm compared to the central market is an important source of land rent derived by lower transportation costs (both in currency and in feed for oxen). The second component, fertility or other properties of the soil, was downplayed in his model. Nevertheless, Thünen like Ricardo, considered fertility differentials as a source of situational rent.

Intensity Rent is obtained by the intensity of the farming system. Intensive systems produce more output per acre, but experience diminishing returns. Each additional worker and capital will add a smaller increase in productivity. The value produced by the last laborer determines the wages of all laborers. Thus, all laborers except the last will produce a surplus above their wage. A more intensive agriculture produces an extra surplus: the intensity rent. In Thünen's view, not all lands are suitable for intensive cultivation. However, this rent is not merely an extension of the situational rent. Thünen has shown it can exist even with uniformity of land (given all lands are under cultivation).

Rent from the permanent improvement of the soil is created by the efforts of the farmer and the expense of capital. Some improvements are permanent such as drainage of bogs, irrigations, enrichment of the soil by adding loam, etc. Thünen warned against deterring such actions by imposing a tax on land rent regardless of the origin of that rent. While situational rent springs from "the fortuitous advantage one farm enjoys over others in the quality of its soil or its location… and owes nothing to the efforts of the farmer… the other kind of land rent is bought at the expense of capital." Thünen argued that taxing situational rent would not affect cultivation, but it would discourage improvements which "is highly detrimental to a nation's welfare".

Thünen argues that estimating rent was difficult because it was not a fixed amount over time. It depended on market conditions such as prices or interest rates. Also, merely looking at the revenues of one particular estate could be misleading, because the skills of the farmers were crucial to fulfill the potential of a given estate.

2.3.2 Intensity Theory or the One-crop Case

Thünen considers at first only one type of crop. The farmer must consider different alternative agricultural systems which vary in intensity. This choice will be driven by the price obtained by the farmer for his products. This price is reduced by transportation costs as distance increases from the market. Intensive systems are more expensive. Thünen distinguishes two types of costs. Town-based costs are associated with expenses in local currency. Farmed-based costs are calculated in grain and include seeds, manure, drought animals, laborer's wage, etc. Farmed-based costs vary with the price of grain, while town-based costs are fixed. For the sake of simplicity, he decided that ¾ of costs were farmed-based and ¼ town-based.

In this setting, as the price of grain falls away from town, the cost also falls but more slowly than the price due to the existence of fixed town-based costs. Therefore, at a certain distance it would become uneconomical to undertake intensive cultivation. The more intensive improved system will obtain bigger surplus of grain in absolute but would face a relative increase in costs that is greater than the surplus product. Because of diminishing returns, the land rent decreases faster with the intensive improved systems versus the extensive three-field system. In addition to the situational rent, lands in the immediate vicinity of the town benefit from this extra intensity rent.

2.3.3 Crop Theory or the Multi-Crops Case

Thünen then considers the case of two or more crops. This situation becomes more complex because of the existence of different pattern of costs and returns for each product and for each intensity of agricultural system. When comparing two products, the concept of "intensive" and "extensive" is blurred since it has no straightforward relation with yields per acre. For example, an extensive cultivation of a product could achieve a higher yield per acre than the intensive cultivation of another. Also, some products are more easily compressible or transportable. Therefore, to determine exactly which product under which system will achieve the highest returns, it is mandatory to analyze and compare all the costs. "When this is done, the general rule will be that the site nearest the market will be appropriated by that product which experiences the greatest cost reduction nearest the market, or in other words, the

greatest cost increase away from the market." (Hall, 1966) After 10 years of data gathering and calculation, Thünen was able to describe the rings.

Short Description of the Rings

The first ring is occupied by perishables that could not survive long journeys by wagon such as fresh fruits, vegetable and milk. Cost for land is extremely high in this ring which creates a necessity for intensive production. Rotation of crops will not follow any particular order. This ring will obtain manure from the town to use as a fertilizer.

The second ring is specialized in forestry to supply for firewood and building timber, because wood has high transport cost. Primeval forests have been cut in the Isolated State; therefore they have been planted by man. Timber for building will come from more mature trees; a longer period of growth means it will have higher production costs than firewood. Even inside the rings there will be different zones. In this case charcoal and firewood will be produced closer to town.

The third, fourth and fifth rings will grow crop from a more or less from an intensive to extensive system: Crop Alternation, Improved, Three-Fields. Crop Alternation, popularized in Germany by Albercht Thaer, is the most intensive system mentioned in the Isolated State. It is the alternation of grain and non-grain crops without fallow. In the Improved System there was rotation of crops in a specific order, a cycle ending with ley grass and then fallow. The Three-Field System was the traditional rotation of two crops with fallow.

In the sixth ring, most of the land will be pasture, and will produce animal products such as wool, meat, fat stock, and possibly butter. Livestock could walk to the market reducing transportation costs. Some industrial crops along with an intensive system could be observed in this ring. This is the case of distilleries that processes rye with a final product of high value but weighting less than the input therefore easier to transport. Alchool production will benefit from lower costs of grain and wage but is also a complement of stock farming since waste could be use as feed.

Beyond the sixth ring is uninhabited wilderness except for a few hunters.

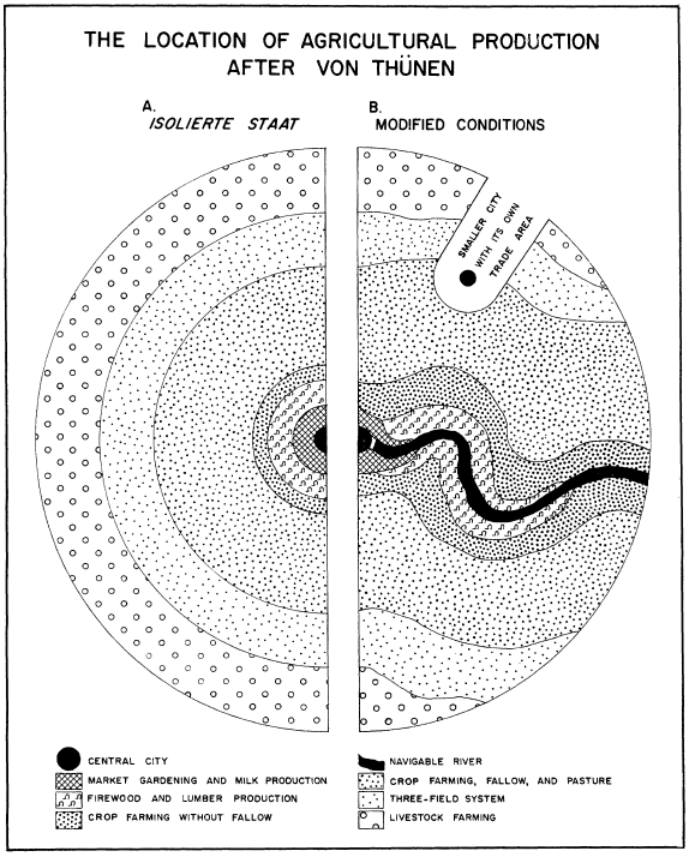


Figure 5: Thünen Rings, Source: Andreas Grotewold, Von Thunen in Restrospect

The concentric model can be modified by transportation infrastructure or topography. Lower transportation costs would expand the circles and boundaries of cultivation. The above figure 5 shows the impact of a navigable river which reduces transportation costs and modifies accordingly the geometry.

In part II, Thünen reflects on highway and railway construction: "Highway construction is justified "because the benefit these bestow on the entire nation outweighs the interest on the invested capital, and because the prosperity of the country as a whole will gain – even though the citizens will have to pay the interest on their building by some tax or other." He also argues that the state should develop the railway network instead of private firms.

2.3.4 Thünen vs Ricardo

Thünen and Ricardo had very different subject of inquiries and methodologies. Ricardo had a more macroscopic view of the economy, and Thünen was more concerned by decisions of individual estate managers. Therefore even if they sometime addressed the same themes they had a very different perspective and preoccupations.

They also had similarities even though they did not know each other in their early writings. Both favoured more rigorous methodologies than the inductive approach of Adam Smith, and they both distanced themselves from the Smithian conceptualization of land rent, which included the interest on the value of building and equipment. For Ricardo, the rent resided in the indestructible powers of the soil. In the second edition of his work, Thünen praised Ricardo for distinguishing the interest invested in the buildings and the yields of the soil.

For Ricardo, land rent emerged from the differences in the soil's fertility. Agriculture activity would establish first on the best lands, and gradually occupying less favourable regions. Since the price of grain would be determined by the labour costs of the less productive lands, the more fertile farms would obtain a land rent that is the difference between their output and this market price. The Ricardian Rent theory ignored transportation costs. It took into account only differentials in land fertility and it allowed only one type of crops, corn. Ricardo's model was restricted to only one commodity while Thünen (and Adam Smith) considered different alternative uses of lands (Sowell, 2006).

Transportation was a crucial aspect of Thünen's work. He considered several crops and different agricultural techniques but started with a simple model with uniform fertility (and topography). However his model could include variations in fertility, whereas Ricardo's model could not include transportation costs without radical transformation (Blaug, 1992). In fact, Thünen needed to assume constant soil fertility for all farms in order to compare various farming system and then determine "under what conditions and to what point is it profitable to improve the soil?" using various agricultural techniques (Hall, 1966).

Perhaps the most telling disparity between the two theories is the intentions of landlords. Ricardo, a supporter of free trade and the abolition of Corn Laws, proclaimed that it was not in the interest of landowners to improve their fields because rents would not rise. However, Roger Backhouse points out that this mistaken result is due to his methodology. "He theorized about aggregates, viewing agriculture as one giant farm. This approach allowed him to reach striking conclusions, but was potentially misleading." (Backhouse, 2004) The theory suggested that the person who owns the land was separated from the person cultivating it (Sandmo, 2011). The farmer would pay a fee for the use of land, creating a rent for the landlord. On the contrary, von Thünen was a very active farmer overzealous about rational agricultural improvements, and envisioned a model with myriad of farms. Thünen

argued that the soil could be permanently improved by the farmer's efforts and skills. Such improvements were both beneficial for the landowner and for the nation.

Thünen was also concerned about the location of labor. Ricardian Trade theory assumed fixed location of production factors, and perfect mobility of commodities between countries. In contrast, Thünen's model stipulates that products movements were subjected to transportation costs and that labor was mobile. In his competitive framework, an increase of labor supply would raise land rent and lower real wages; leading to labor movements. Again Thünen's ideas were shaped by his epoch; Mecklenburg had experienced severe emigration of the workforce.

In addition, Ricardo was not concerned by the location of consumption. Thünen first supposed one market center of consumption, but then considered multiples markets. Furthermore, Ricardo supported Jean Baptiste Say's view that supply creates its own demand (Sraffa, 1952). Demand was a dominating component in Thünen's model. In the German's view, population growth will increase demand for food commanding a higher level of prices which would affect both the size of the area of cultivation and the intensity of agriculture. In addition, he believed in technical improvements of agriculture. Although he did not foresee the extraordinary productivity gains experienced in agriculture in the last 200 years, Thünen was confident about population growth. In general, von Thünen was more optimist than Ricardo and Malthus, both about population growth and technical progress.

Another key difference was the perspective on the theory of value. Ricardo supported the labour theory of value, that the price of goods will be equivalent to the labor required to produce them. He quantified the contribution as 93% for labor and 7% for capital (Backhouse, 2004). While most of the English Classical economists emphasized the role of supply, the tradition in Germany "attached great importance to demand" (Backhouse, 2004). Therefore they proposed a subjective theory of value "in which value of a good depended on what other goods people were prepared to forgo in order to obtain it – subsequently known as an opportunity-cost theory."(Backhouse, 2004) Demand was important for Thünen, but his theory of value was following in the lines of Adam Smith of production cost (but not the labour theory). As a manager, he was carefully appraising all his production costs with a special focus on transportation. He also tried to quantify the contribution of labor and capital in production.

International trade was a central preoccupation for Ricardo. Has an advocate of free-trade, he was interested in commerce between nations and made a significant breakthrough with the comparative advantage theory. Thünen did not elaborate much about international trade except that rings could expand across borders. Thünen was also originally a free-trader, but he later developed some influenced by the "national interest" of Friedrich List.

The two contemporaries' thinkers would probably have gained from debating together. Bertil Ohlin reckoned that "if later writers had followed in von Thünen's path instead of Ricardo's, there can be little doubt that progress in this field of economic science would have been much more rapid than it has actually been."(Ohlin, 1935) However, from his isolated estate, Thünen could not supersede Ricardo in London. In his lifetime, Ricardo was very active and visible on political debates in Britain most notably in stark disagreement of Corn Laws. He had many important friends (James Mill, Thomas Malthus) and followers (James Stuart Mills, Karl Marx). His fame and colossal contributions obliged both supporters and opponents to position themselves in the Ricardian framework. Ricardo arguments were exposed with clarity (which is definitely not a virtue shared by Thünen). Also his themes, having a national perspective on labor and trade, had a broader appeal than the Thünian scale of inquiry for individual farms. The 19th was politically and socially agitated. While Thünen aimed at the reconciliation of the industrial society, Ricardo theory may have nourished these tensions by sending a message that landowners were not acting in the best interest of society. Dissention attracts more publicity, and Ricardian economics, which supposed class conflict, paved the way for Marx (Backhouse, 2004). Therefore, the shy[9] German had no prospect to be heard in England, the bastion of economics, nor in the historical debate between capitalism and socialism.

2.4 Limits, Critics and Relevance

Von Thünen built his own approach to find practical solutions to dilemmas he was facing as an estate manager. His findings appear to have been mostly valid in early 19th century Mecklenburg. Technological advancement in agriculture and transportation is cited as the main cause of the invalidation of his model. This section provides a critical discussion on

[9] Thünen was very reluctant to publish and popularize his ideas.

some assumptions of the model, summarizes the main limits of the Isolated State in the context of agriculture, and argues about the relevance of "Thünian Analysis" nowadays.

A Thünian critique of von Thünen

Some parameters of the Isolated State are questionable even from a Thünian perspective. Transportation of goods is unidirectional from the farms to the town. Town-goods such as clothes or tools should also be subjected to transportation costs making them more expensive farther away from town. But Thünen stipulates town based costs as fixed for simplification. One way to accept this proposition is that carts delivering farm-goods to town could return with town-based products without many expenses since the wagon would be empty otherwise. Thünen did calculate costs in the perspective of return-trips, but it is if town-goods were not weighting anything or at least weighting much less than farm-goods. Another way to look at this proposition is that town-based costs could be purely financial such as interest payments.

Another problematic aspect of town-goods is that they appear to be the product of labor only. The process of making clothes is linked to the price of linen and wool for instance. This interaction between input and outputs would add complexity to the analysis. Even Samuelson in his neoclassical interpretation ignored the need for raw material from the countryside (Samuelson, 1983).

One more unrealistic assumption is the absence of trade between farmlands. Therefore, farmers are assumed to be self-sufficient in terms of food, fuel (firewood), feeds for stock animals. Apart from their main specialty production destined to town, farmers must reserve a portion of their land to fulfill their needs. While having a small garden for personal consumption is probably a very realistic assumption at that time, complete self-sufficiency is a major contradiction with the benefits of situational specialization of agriculture as proposed by the theory.

In essence, the simplified description of the interaction of town-goods and farm-goods (along the unidirectional transportation link without trade between farms) suggests autonomous production units both in town and in farms. The only input needed for the city is food (and firewood) for the workers. Farms would obtain or create all necessary inputs on their estate. In modern ecological words, farmlands are described as autotrophic systems and cities as heterotrophic. Heterotrophic systems exceed the carrying capacity of their

bioregions (Newman & Jennings, 2008). Indeed the requirement of external nourishment and energy sources is a salient feature of urban regions. Town demanding agricultural products is the starting point of the Isolated State but the model is self-limited by not including multidirectional exchanges of goods.

Von Thünen fully acknowledged some of the explicit simplifications of his model but argued these were necessary suppositions; otherwise it would have been impossible to conclude anything. Subsequent researches have given virtually no attentions in elaborating and extending on these simplifications. Rather the debate was mostly centered around implicit assumptions such as available technology and how the model was valid or not to describe agricultural land use.

Limits and relevance for Agriculture

Von Thünen's results are generally said to be obsolete for modern agriculture. The Isolated State was set in a precise epoch and the assumptions were made under available technologies of that time. Agriculture has since been deeply transformed by motorization, refrigeration, industrial fertilizers, the Green Revolution, globalization of trade, etc. Productivity gains have been tremendous and agriculture in developed nations has intensified more in the lines of Albrecht Thaer than Johann Heinrich von Thünen; even if the latter had predicted the most intensive system (crop alternation) could eventually take over the entire Isolated State. Cooperatives of farmers have introduced cost reduction both in operations and transportation versus the self-reliant individual farmer envisioned by von Thünen. Refrigeration allows perishables commodities to be transported on long distances. Locational advantage is lost to distant farmers favored by better land, cheaper production costs and lower taxes. For all these reasons, modern agriculture (food and fuel supply) cannot be described by simple monocentric models anymore.

Transportation has also largely contributed to invalidate Thünen's rings. New transportation possibilities have completely reshaped the distribution of food. One telling example is the salmon shipped by plane from Northern Norway to reach the sushi markets in Tokyo in less than 36 hours after slaughtering[10]. Nowadays cities are fed by a global/continental supply chain. Also, the distribution network is now composed of logistic hubs normally located in

[10] Aurora Salmon from Lerøy.

urban areas. Therefore, some farm products could be cheaper in the center than in remote farmlands. In addition, transportation costs are no longer strictly proportional to distance. In some mode of transport the larger the distance, the lower are costs per tonne/kilometer. In fact, the 20th century experienced such remarkable (90%) reduction in transportation costs for goods that it would be better to assume them costless (Glaeser & Kohlhase, 2003).

Most of the literature agrees that "basic forces identified by Von Thünen no longer are the primary determinants of agricultural patterns around cities" in the developed world, but may be still valid in less developed parts (Sinclair, 1966). However, some severe critics implied the model never worked at all, for example by mentioning that grain was being shipped over long distances by boats even during Antiquity. Even in Thünen's lifetime, the results of his model seemed to be mainly confined to Mecklenburg. For example, Atkins applied the agricultural model to 19th century London and found no evidence of Thunian rings (Atkins, 1987).

However, some researchers found some evidences of the Isolated State by extending von Thünen rings to the national scale (Griffin, 1973) or continental scale (Jonasson, 1925) (Van Valkenburg & Held, 1952) (Peet, 1969). Even in the current globalized era, some strong regional or continental links still remains due to trade agreements, protectionism or considerations like food security. Therefore, a gross generalization of von Thünen was mapped continentally:

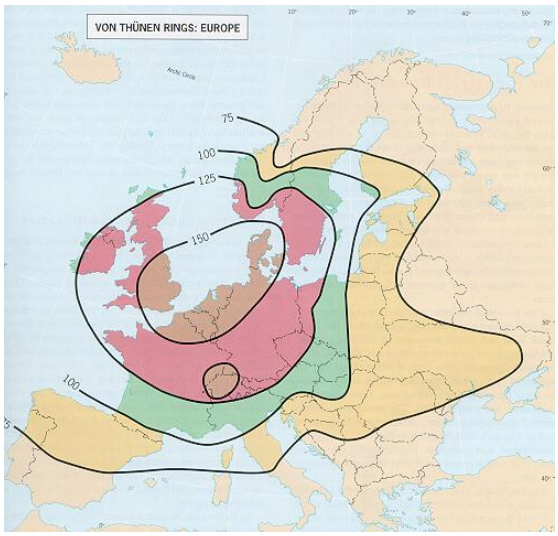


Figure 6: Continental Thunian Rings Around Industrial Centers.
Source: (Boenigk, 2015) adapted from (Van Valkenburg & Held, 1952)

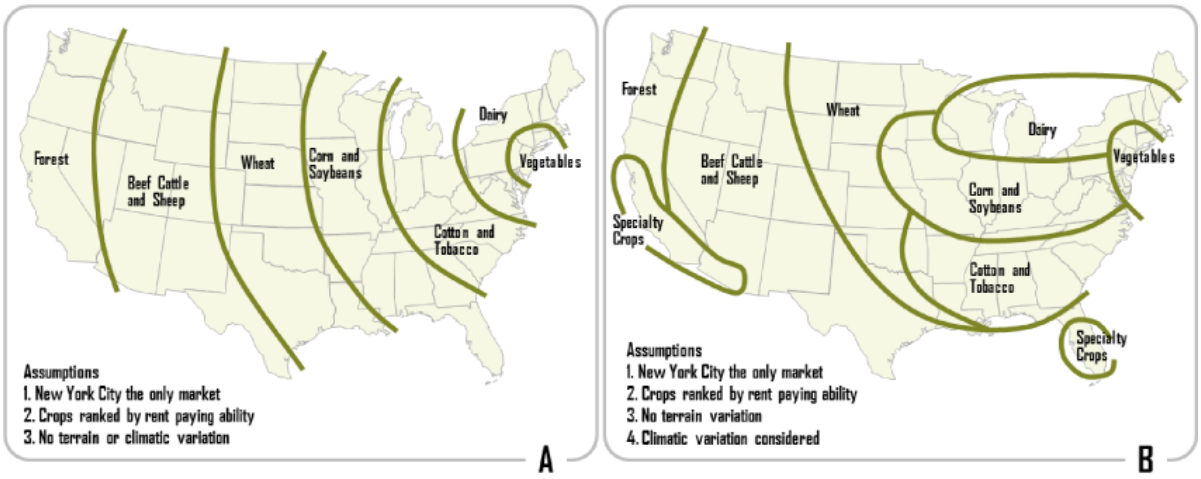


Figure 7: A von Thünen view of United-States. On the right: a realistic zoning including climatic variations. Source: (Rodrigue, Comtois, & Slack, 2013)

There may be other opportunities of modern treatments of von Thünen in the context of agriculture. In reaction to the globalized agro-industrial food production, new alternative trends are emerging such as biological farming, local food foraging, slow food, urban agriculture, etc. There is an increased concern about diversity and traceability of products combined with a preference for local food and low-carbon footprint. A Thünian model applied to these niche products could offer some guidance to small scale producers.

Thunian Rings vs Thunian Analysis

The essence of von Thünen's message was overshadowed by the simple diagram of monocentric rings. Von Thünen was conducting a thought experiment with his Ideal State. His monocentric results were drawn into diagrams by one of his friend and were added in the notes of the 1842's edition but were never referred directly in the main text. As Thünen pointed out, the drawings were not capturing the gradual separation between rings (for Thünen space was continuous and costs must be understood as gradients). However, this simple monocentric image of the rings is how von Thünen's model became remembered and comprehended.

August Lösch, a 20th century authority in location theory, reckoned that monocentric rings was only one special case of several possible shapes (Lösch, 1954). Historical studies that focused less on this exact shape of Thünen rings and ordering of crops but more on the analysis of land use with regards of changes in transportation costs confirmed Thünen's insights (Norton, 1979). More recently spatial optimization as described in the Isolated State

was tested with an Agent Based Model and found that "spatial consideration for the lock-in pattern are still apparently valid."(Sasaki & Box, 2002) Analysis in the true spirit of von Thünen is still relevant today.

Indeed, Michael Chisholm insisted on the method of analysis:

"…the ideas developed and expounded by von Thünen do not constitute a theory of location. They amount to a method of analysis which may be applied to any situation in any time or place, and von Thünen himself was at pains to make clear that his particular findings had no claim to universality. But, he claimed, the method by which these results were obtained could be applied generally." (Chisholm, 1969)

"Thünian Analysis" was broadly defined as application of Von Thünen's methods in locational investigations (Haggett, 1965) (Muller, 1969). Following the German tradition of location theory within economics, Haggett's view of locational analysis was using a model that simplified the "complexities of location and spatial distribution using mathematical forms of representation" (Barnes, 2003). Barnes challenges the designation of "school" of the German location tradition has defined by Claude Ponsard (1983) and Mark Blaug (1979) by contributors (Thünen, Lösch, Weber) pursuing of the same rationalist logic. (…) Rather than generating universal knowledge, each member produced a piece of local knowledge, and not the distillation of some superordinate rationality." (Barnes, 2003)

Von Thünen was very optimist about the benefits and the potential of rationality in the study of the world and in governing of human affairs. He made an attempt to find general guiding principles even "Natural Laws" via rationality and mathematical abstractions. But his method of modelling was "intimately bound to his local situation."(Barnes, 2003) Most commentators have neglected the importance of local knowledge von Thünen's thinking in parallel to the quest to find Natural Laws.

Indeed, personal experience is one of the main particularities of von Thünen's method. Although Thünen does not have much in common with the German Cameralist[11] school, both shared a certain relying of one's own-experience (J. Backhaus, 2012). His subject of inquiry was his own estate. Contrary to other Classical economists such as Ricardo and Smith, he had a "skin in the game". The manager's perspective brings to light considerations

[11] Cameralism: German science of administration in the 18th and 19th century.

left aside by the neoclassical school (for example fairness in wage theory (Akerlof & Shiller, 2009)). It also reduces the universal applications of the findings. A common critique of Geographical theories is that they are too narrow and too specific to existing conditions. However, it is not in contradiction with von Thünen's objectives.

"Thünian Analysis" exactly offer decision-makers a tailor-made method to the subject of their (spatial) inquiry. First, an "ideal" model is built on assumptions designed to isolate one factor at the time in order to address specific concerns of the manager. In a second step, numerical analysis "calibrates" the model to the actual circumstances. Finally, some assumptions are relaxed to see how it would affect the results. This positive method can be applied to a wide range of inquiries. The label "Thünian" suggests a special normative preoccupation about location and transportation costs.

Von Thünen differs from the German Historical School not by ignoring the historical and geographical limitations of theories, but by believing in the power of (rational) knowledge to emancipate from traditions. His normative conclusions were largely criticized, but he was a man of his time, and those were the beliefs he choose to defend there and then.

2.4.2 Relevance Today

Basics aspects of von Thünen's method and tools are now common in economics. However his direct legacy is to be found in location theory, regional science, urban economics, economic geography and new economic geography.

Alfred Weber (1868-1958) built on von Thünen's theory to describe location of industrial production. This led to the evolution of Thünian theories in two directions. One in international trade theory after August Lösch (1906-1945) elaborated a regional and interregional theory. This is branch can also associated with Bertil Ohlin and more recently with Paul Krugman and the new economic geography. The other branch was focused on urban regions and development. First, the sociologist Ernest Burgess (1886-1966) developed a concentric model of cities. Then the urban economist William Alonso (1933-1999) formalized this model with bid-rent curves.

Cities were a particular fertile ground for von Thünen. Indeed there is a large body of literature about monocentric cities. Contrary to the globalized industrial production, the labor market is spatially fixed. Therefore, just like in the Isolated State, commuters will

converge to their workplace in the Central Business District (CBD). This dynamic can be addressed by von Thünen's model.

Edward Glaeser (1967-…) argues that this model is only partially useful because it describes cities of the 19th century. Since modern cities are shaped by past configurations, the model has still some relevance today in describing cities but not future developments.

In recent years a larger focus has been deployed around polycentric or multi-core cities. Cities are more seen as belonging to networks both regionally and internationally. One important area of research has been around knowledge spillovers and industrial clusters. The information revolution has modified the world in many aspects, some thinkers going as far as predicting the "death of distance" (Cairncross, 2001). Therefore the relevance of von Thünen in the 21st century is a legitimate question.

Masahisa Fujita recognizes in von Thünen many novel ideas even today (Masahisa Fujita, 2012). He cites his pioneering but incomplete theory about industrial agglomeration that "coincides with one of the most important theoretical findings in the New Economic Geography: (…) the development of transport technology … will strengthen the agglomeration of economic activities (…) in the core region or in large cities." (Masahisa Fujita, 2012) Fujita argues von Thünen could not unify his theories without the monopolistic competition model developed by Chamberlain (1933) and formalized by Dixit and Stiglitz in 1977.

Von Thünen is definitely a grand source of inspiration. His relevance in today's world depends on the adaption of his theories to today's inquiries and the combination of them with some modern contributions to economic theory. For this reason, each reading of *The Isolated State* shines a new light on our world.

3. Chapter 2: The Legacy of von Thünen

Johann von Thünen has conducted pioneer researches on several topics and is an acclaimed contributor to several disciplines (agriculture, agronomy, geography, economics, management, and politics). In the realm of economics he has inspired a whole domain of analysis.

This chapter tracks the influence of von Thünen in the history of economic thought in the last 200 years. It constitutes a literature review of spatial economics with a closer attention given to urban systems than to location theory or international trade. It also follows specifically those who have walked in the footsteps of von Thünen. Therefore it does not cover prominent "spatial" thinkers such as Alfred Marshall, Bertil Ohlin, Harold Hotelling, Nicholas Kaldor, Edgar M. Hoover, Kenneth Arrow & Gérard Debreu, etc. Also this review sparsely and selectively includes notions from the prolific literature in urban and transportation economics.

This literature review relates the fundamental developments chronologically. The first part spans from Weber to Lösch, a long interlude when space played a marginal role in economics, but when significant contributions were made to location theory. The second part is dedicated to urban structure from monocentric to polycentric models. The last part summarizes recent findings in New Economic Geography about the impact of commuting costs within modern cities.

3.1 From Weber to Lösch

After *The Isolated State*, spatial economics remained almost dormant for nearly 100 years. In the German speaking world it remained active but very few significant developments were made. It was Alfred Weber (1909) who continued the work where von Thünen had left it. Weber is credited the establishment of his own school or paradigm of industrial location. Building on Thünen, Weber, and Schumpeter, Andreas Predöhl (1925) developed a more dynamic model to explain changes in a firm's location. Predöhl influenced both Tord Palander (1935) and August Lösch (1940) in the quest to towards a general equilibrium model. Palander followed in the Weberian geometric tradition. Lösch instated his own regional paradigm: seminal contributions to regional science and urban economics.

Alfred Weber (1868-1958)

Steam powered machines and trains were part of the landscape in late 19th century Germany. Industrialization has induced urbanization and radically changed society since von Thünen. Yet, localization was not a preoccupation of economists even if massive national and international migrations were a consequence of an economic, social and technological revolution. Alfred Weber, the younger brother of the famous sociologist Max Weber, would reinstate the study of localization[12].

Weber built an industrial spatial theory founded on top of Thünen's agricultural theory. As the economy is developing from an agrarian into an industrial society, new layers will be established over the agricultural base. This first layer constitutes consumption areas for the second industrial layer that produces goods for the first. From this new consumption layer, another industrial layer will appear, and so on. "*Division of labors drives the creation of multiple sub-layers superposed, in interrelations and of decreasing dimensions.*"(Ponsard, 1958) The multi-layer industrial location theory explains dynamically economic evolution.

Weber's theory explains spatial configurations solely by industrial production. Consumption and distribution, while important, are subjected to the industrial sector. Therefore, Weber's theory did not explain the localization of commercial centers, nor the financial aspects like credit, exchange rates and capital.

Weber's system relied exclusively on distances and weights to express attraction forces. All tariffs are expressed in weights and distances. He used abstract notions such as "ideal weight" to go around the complications like the nature of different goods, transport infrastructures, and various transportation modes.

Industrial industries are attracted by the location of inputs such as natural resources and energy. Each firm would have a "localization figure" found geometrically by drawing lines from resources centers to the consumption center. He would then calculate the "localization weight" reflecting the importance of each production factor and therefore indicating the optimal location(s) for a firm: the point(s) of minimum transportation costs.

[12] Alfred Weber created and popularized a theory which borrowed concepts from Wilhelm Roscher, Albert Schäffle, and possibly Carl. Laundhart.

Optimal location can be distorted either by the labor attraction or the agglomeration forces. Weber calculates a "labor coefficient", a measure of distortion expressing the relation of "labor cost index" on the "localization weight". An industry with a high localization weight will be less subjected to spatial variations due to the influence of labor costs. The second distortion arises from economy of being located in dense industrial areas. Weber introduces a "manufacture coefficient" to measure the agglomerative force. Together, the three fundamental localization poles, minimum transport costs, labor attraction and agglomeration forces will determine the location of the production sites.

In sum, Weber created a spatial model of industrial production where the relative attraction/repulsion of different factors and forces would be described by abstract measures. Location of firms is determined according to the minimization of transportation costs. This model juxtaposed over Thünen's agricultural layer on which was added several interrelated industrial layers as specialization was driving the industrialization process. Weberian's school had a long lasting influence on spatial economics. The distinction between an agricultural and an industrial model remained until Lösch's general equilibrium and is still kept today in some cases of specific analysis.

Andreas Predöhl (1893-1974)

Predöhl made a first attempt to combine Walrasian microeconomic marginalism with the location theory inherited from Weber and Thünen. He underlined the inconsistent gap between general economic theory and partial theories (agricultural and industrial) of localization. Borrowing from marginalists the concept of substitution of production factors, he would apply it to localization factors. Therefore, Predöhl would attribute a change in location to a substitution of various production factors embedded in space (according to their relative prices) (Ponsard, 1958).

For Predöhl, production and localization was the same problem and therefore could be solved by the same tool. Consumption location was subordinated to production since only a minimal part of consumers (rentiers) was independently fixed from production.

His theory was limited to only one firm in a very small period of time. Firm's relocation was the substitution operated under relative prices in factors located in different points given in space. In Predöhl's model spatial substitution was a translation. Two hypotheses were

needed: a constant technology and a continuous space to allow substitution to operate by an infinitesimal transition.

Localization was solved by a system of indifferent points of interchangeable factors two by two. The indifference point, a minimal cost point, expressed the relative rate of substitution of (pair) factors. In other words, changing location is a substitution of units of land for units of labor or capital. Different combinations of factors can achieve the same result but one of them is more cost efficient.

His theory was very abstract and quite limited in scope, but his contribution framed the problem of spatial general equilibrium.

Tord Palander (1902-1972)

The first major non-German contribution to spatial economics was made by the Swedish Tord Palander in his 1935 doctoral thesis. In this period, both orthodox economists and spatial economics specialists were preoccupied by establishing general equilibrium theories (Ponsard, 1958). Palander identified several problems posed by localization and tried to create such a general model. His method consists of isolating and analyzing one by one different factor. He demonstrated that many possible alternative outcomes could be achieved in reaction to spatial differentiation. His main themes were market localization, market size, transport costs, and market structure or competitive aspects of localization.

The problems of localization

Palander started by examining simple but special aspects of localization. Capitalist institutions such as the existence of markets to trade goods and division of labor introduce the possibility that production occurs at a different site than consumption. Certain production types were linked to consumption sites, and others were independent. Also production was either spatially linked to production factors or independent. Tourism is an example of production that is both tied in space to production factors (renaissance architecture) and consumption site. In this case, consumers must travel to the production site but in general technical progress has mostly made production independent from localization of natural factors. However not all factors are equally mobile. If the mobility of factors could be easy for capital, natural resources, and machinery it is much slower for buildings construction and labor. For Palander, labor is only temporarily mobile (daily, weekly,

seasonally) and labor location is fixed since the choice of residency rely on non-economic motives.

Palander also argued that spatial differentiations could not be compatible with the existing price theory as proposed in orthodox economics following models from Walras, Cassel and Pareto that were applicable to a unique market. Free market hypothesis could not hold in presence of several markets with local variations in prices. If there were permanent local differences, simple relations between costs and prices and marginal relations between factors' prices and product values could not hold. Also, the existing price theory analyzed the equilibrium in a static state that could not explain dynamic variations of localization.

Imperfect mobility of labor was sufficient to suggest the need of a new dynamical approach to explain spatial configuration of economic activity. The repartition of economic activity is subjected to configuration in previous periods and the speed at which the mobility operates. Including time was necessary to portray the adaptation period of diverse localization factors.

Entrepreneur's strategic perspective

To picture the evolution over time of economic activity, Palander focused on the entrepreneurs' reactions according to his own representation of market conditions. Reactions included starting a new business or subsidy, relocate existing business, buy a competitor or merge, close a branch, new sales techniques, etc. According to Palander, previous theories neglected differences occurring inside firms. Different functions (production, sales, or finance) within the same firm could be located at different places and where subjected to different imperatives. From the firm's perspective he analyzed localization choices for stores (market centers) and production sites, and the resulting reactions and strategies in a duopolic market structure.

Market Choice of Location

In Thünen's and Weber's schemas, markets locations where trades are conducted are fixed and given in space. Palander wanted to describe the choice of market centers and their impacts on price levels and competition strategies. Expanding on Hotelling and Laundhardt formulations, Palander imagine a region where consumers choose a product at the best delivered price from two competitors separated by a given distance. (For Laundhart sellers are located at the extremity, while Hotelling allows each competitor his own back-country).

In a first step, Palander looked at market size as a dependent variable. He examined the *isotante*, boundary between the two market centers with varying prices and transportations costs. Points on this boundary expresses equal delivered prices from both centers. The shape of the isotante changes according to prices, market centers, transportation costs, and transport infrastructures. If both retail prices at the market centers are equal, Palander's mathematical formulas showed that a decrease in transportation costs will increase the cheapest product's market size, while an increase in transportation costs will increase the most expensive market size.

In a second step, Palander looked at the relation between price formation and market size. Following Hotelling, he stipulates equal transportation costs and the absence of production costs to identify profits for each firm. Different combinations of prices can result in the same profit, and each firm will try to increase its profit depending of the competitor's chosen price. Geometrically he identifies the firm's *adjustments line* where profits are maximized for a given competitor's price and where stable price equilibrium is achieved. A competitor can choose two strategies: either it adjusts its price to the adjustment line, or it tries to conquer its competitor's market by fixing its own price under its competitor's price minus the transportation cost between the two locations. Therefore, the equilibrium depends on the market center's locations.

Production Center Choice of Location

Many factors influence the choice of location for the production of a good: raw materials locations, energy accessibility, consumer's locations, competition structure, etc. Palander focuses on transportation costs that also influence all other factors.

Transportation costs are subjected to a very wide variety of price structures. Some contracts can have fixed prices (postal stamps) or variable prices depending on demand and offer (traffic capacities, return fret, seasonal changes, etc.). Some are distance, direction and weight dependent, and some are not. The transport vehicle (ship, train, truck) or the nature of the product (finished product, bulk raw material) will have an impact on the transportation costs. To include all those possibilities in a general model, Palander used a technique of *isolines*, level curves that connects all equal points associated with same characteristics. For example, ***isochrones*** represent equal shipping time.

Palander also distinguished *transportation surfaces,* an area linking all points linked by same transport vehicle; *transportation lines,* linking a same set of points*;* and *transportation points,* identifying a characteristic location (train station, port, logistic hub, etc.) A homogenous transport surface could be a sea or a region with dense transport infrastructure like Thünen's Isolated State.

Using this isolines methodology he could add complexity to the analysis. For example, shipping that would use three modes of transports (cargo ship, rail, truck) with different shape of transportation infrastructure (surface, points, lines). It would only distorts and change the shape of isolines.

In conclusion, Palander understood some important limitations of standard economics that could not be applied to location theory. He objected that perfect competition (implying a unique market with same price) could not account for local differences. He made a geometrical analysis of localization factors from the point of view of the firm and its possible strategies (aggressive, defensive, and sharing) in a duopoly market structure. He also insisted on the importance of a dynamic general equilibrium model. However, Palander's work was constraint to partial and static analysis. Indeed his methodology was to isolate decision factors one by one. Nevertheless, his input paved the way for August Lösch and his general equilibrium dynamic model under imperfect competition.

August Lösch (1906-1945)

In his 1940 magnum opus, August Lösch revolutionized spatial economic theory by contributing to localization, regional and exchange theories. His ambition was to create a general theory of localization that not only integrated his own theories but all those of his predecessors (Predöhl, Palander, Ohlin, Hoover etc.). His equation system described spatial relations in a general economic equilibrium under imperfect competition. His main insight was to propose not a unique integrated model but several coordinated models adapted the scale of the spatial problem (Ponsard, 1958). By introducing a regional model where markets were linked by complex networks, he was able to establish a bridge between location theory of specific markets and international trade.

Lösch recognized the importance of establishing a dynamic model. While a pure spatial approach that accounts for peculiarity of economic distribution in space could rely on a static model, explaining the evolution and the economic development required a dynamic

analysis. While time is imposed, space is chosen for economic activity. Lösch preoccupation was to inquire about spatial choices.

Lösch distinguished between real localization and rational localization. Real localization could be explained by historic events while his rational localization was an attempt to determine the ideal location. He observed how entrepreneurs chose their location and their specialization.

There was also a central dichotomy in Lösch's location theory between industrial localization more influenced by region of consumption and agricultural localization influenced by regions of supplies. In his agricultural model, von Thünen's concentric configuration of production was simply a particular case. Different configurations were possible depending on the assumptions retained, for example if you force the import of one of the agricultural product from outside.

For location theory, he formulated a general spatial equilibrium based on a Walrasian system of equations sufficiently large to encompass spatial interrelations of an interdependent economic system. His equation system could determine simultaneously both the location of production and volumes. Location of production could be juxtaposed and did not require monoculture or monoproduction in one area. Finding this equation system too general, he preferred to focus on a regional theory that was, according to him, the logical step between partial localization and general localization.

For regional theory, he was concerned to define regions only in economic terms not by political boundaries and jurisdictions. His focus was on the link between localization, regions, interregional and international trade. All markets areas are part of regional networks systems themselves connected in interregional networks. His now famous methodology consists to first eliminate any non-economic spatial differences leaving economic forces dictating spatial differences. His schema relies mainly on three factors: distance, large scale production and concurrence. From this pure model, he then integrates distortions: economic (price or product differentiation, transport tariffs), natural (difference in soil fertility or productivity, transport surfaces), human (cultural differences) and political (state intervention, capital city, trade and mobility barrier). He focuses on distortions that can influence the area of markets.

For the exchange theory, he argued that the classical law of comparative advantage was insufficient to explain international trade. He showed how can emerge spatial division of labor and how it can achieve an equilibrium. The equilibrium state is maintained in the short term by *transfers* and *combinations* in the long run. Transfers are the flow of goods and services over short periods since locations are fixed. Combinations are relocations of economic activities over longer periods. These transfers and combinations can either be spontaneous (automatic auto-regulation from price fluctuation) or the result of interventions. His contribution was to emphasis the difference between temporary transfers due to conjuncture and the necessary transfers linked to permanent structural changes in price levels. Long term disequilibrium led to new spatial combinations of production factors. In rupture with the classical hypothesis of international immobility of factors, his model was explaining capital and labor mobility. Finally, he argued three different motives of intervention: suppression of inconvenient in adaptive process, to facilitate the adjustment process, and a creation of a better equilibrium.

In conclusion, Lösch has made significant contribution to economic geography and regional science despite his early death during the Second World War at 39 years old. Lösch followed von Thünen in elaborating an "ideal" simple economic model. His model does not contradict von Thünen concentric circles which was a possible case of configuration in Lösch's agricultural location theory. Thünen's *Isolated State* presupposes only one economic region living in autarky, which was representative of that period in Northern Germany. Lösch therefore expands Thünen's model by allowing regions to trade and be parts of networks. He also develops Thünen's exercise to analyse how trade influences location and specialization at an international level. In the Thünian tradition, he also allowed free mobility of factors, while the classical anglo-saxon school presupposed immobility at the international level. Finally he meditated on the motives behind intervention affecting spatial combinations of production factors. The goal to pursue in a context of public transportation was to create a better outcome. But one has to keep in mind the dynamic process at hand, and that a new "transportation surface" will distort the market area and affect the equilibrium.

A New Geometry

The Isolated State concentric model was largely metamorphosed by location theorists. Weberian location theory dealt with complex geometric forms. Löshchian regional synthesis relied on several models depending on the scale of analysis. In their minds the economy was not monocentric. Localization factors were fundamentally different in the case of industrial production than for agriculture. Overall, the self-sufficient economy described by von Thünen had also disappeared in the case of agriculture.

Transportation costs remained an important factor in the choice of industrial location. However, the complexity and the diversity of shipping costs could not be described easily. Therefore, abstractions such as Weber's *localization weight* or Palander's *isolines techniques* were used to describe the economy in space. The spatial-dynamic response of firms was explained by Predöhl's *substitution principle*, Palander's *ajustments lines,* and characterized by Lösch in the short as *transfers* or the long run as *combinations.* They all agree about the existence of possible distortions preventing the best rational spatial outcome.

A preoccupation about the location of consumption emerged with Palander, but it remained from the entrepreneur's perspective to locate strategically depending on the type of industry. Workers were simply following production sites, and cities attracted firms for example because of administrative centers. Nevertheless developments made by location theorists allowed the emergence of regional and urban economics.

"A man is, of all sorts of luggage, the most difficult to be transported."–Adam Smith

3.2 The Rise of the Monocentric City

The concentric model of von Thünen experienced a revival with the monocentric city. If mostly invalidated by technology and globalisation, the Isolated State can successfully describe one aspect of modern societies: commuting to work. Labor is not as internationally mobile as capital or commodities, but it moves every workday from a designated residence to a fixed workplace. Moreover these workplaces appear to be spatially concentrated in cities and more precisely downtown, the siege of economic activity, where firms have incentives to agglomerate. As Adam Smith mentioned, there are specific challenges and costs in transporting humans which were not abolished by the industrial revolutions in the same manner as in the transport of goods. In this context, von Thünen offers an approach to describe the spatial organization of urban life. This section relates how the Isolated State evolved into the monocentric city.

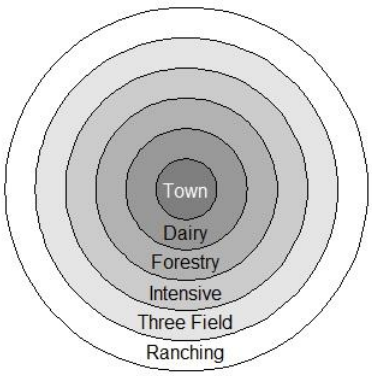


Figure 8: von Thünen (1826)

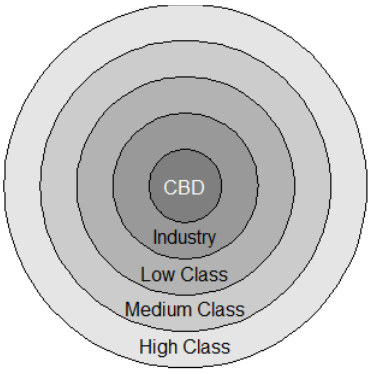


Figure 9: Burgess (1925)

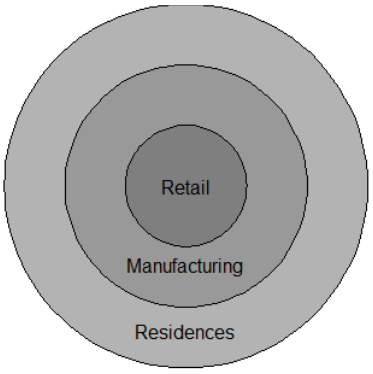


Figure 10: Alonso (1964)

A Natural Habitat for Human Migrations

A century after von Thünen's first publication of the Isolated State, Ernest Watson Burgess (1886-1966) developed a concentric zone model of the city to explain social problems in different districts of Chicago (Park, Burgess, & McKenzie, 1925). Burgess and Robert E. Park elaborated a theory of urban ecology that would become the Chicago School of urban sociology. *The City*, published in 1925, "*proposed that cities were environments like those found in nature, governed by many of the same forces of Darwinian evolution that affected natural ecosystems."* (Brown, 2011) :

"*The city is … the natural habitat of civilized man. (…) The city is rooted in the habits and customs of the people who inhabit it, (…) and acquires an organization and distribution of population which is neither designed nor controlled. (…) Land values, since they reflect movement, afford one of the most sensitive indexes of mobility."*(Park et al., 1925)

Mobility was a central element shaping the spatial organization of urban areas. Burgess observed both the daily commute and the long term residential migrations to explain the growth and evolution of cities. He proposed a concentric zone model organized around a Central Business District (CBD). Economic activity of tertiary employment is located downtown making it a focal point of convergence for the transport infrastructure. Industrial activities are located in the second zone around the CBD to take advantage of consumption markets and labor availability. Close to those industries live the poorest citizens. Then gradually, housing quality increases with longer commuting costs and the upper class are located in expensive rural areas. This model was supported by empirical evidences collected (on Chicago and United-States) by an intensive research program with the participation of his students (all of which obligatory trained in the map-making techniques) (Brown, 2011). Burgess does not mention directly von Thünen, but he was influenced by Alfred Weber, broadly known to sociologists at the time.

Another important aspect of Burgess's theory was that expansion was seen as a process, a succession of organization-desorganization-reorganization. Urban growth was an expansion and reconversion of land uses with inner zones expanding in the outer zones. These changes were not only affecting the physical aspect of the city but also the social organization and even personality types. A view shared by his other co-author, McKenzie: "*In the process of community growth there is a development from the simple to the complex, from the general*

to the specialized; first to increasing centralization and later to a decentralization process."(Park et al., 1925)

This transformation was seen as a threat to the moral order of communities. In particularity daily mobility which allowed relations outside the immediate community was considered a factor of social disorganization, a loss of social control by the group (for example by increasing promiscuity).

Therefore there was a specific worldview behind the model that shaped important assumptions. Because of "urban decay", it was better to live outside the city, or at least in the suburbs. "*The model assumes a relationship between the socio-economic status (mainly income) of households and the distance from the Central Business District (CBD)."*(Rodrigue et al., 2013) Without this proposition, the "Burgess Law" does not hold. It was supported by the general observation that "*large proportion of Americans prefer to live in one-family suburban residences rather than in apartment near the city center*."(Grotewold, 1959) While this might have been true in the first half of the 20th century, it fails to explain recent observations of attraction forces of consumers to establish in the center of cities with high amenities (Glaeser, Kolko, & Saiz, 2001).

Many criticisms arose about this simplistic model that was said to be limited to its historical and geographical context. The model was mostly applicable to industrial cities like in North-America. In pre-industrial cities the center was more important for social status, and there was not a clear spatial division between residences and workplaces. Therefore this monocentric model was less demonstrated in European cities.

However, this early attempt to explain spatial structure of cities contributed to incorporate spatial analysis in several disciplines such as sociology, criminology, public policy and even economics. Also, the attraction of a central place such as a CBD is at the foundation of many subsequent developments, but many years passed before Anglo-Saxon economists became involved.

A Central Place for the Economic Landscape

In Germany there was another source of this movement: the Central Place Theory developed by the geographer Walter Christaller (1933). He studied settlements patterns in Southern Germany and tried to explain the number, the size and the arrangements using geometrical shapes. His assumptions are similar to *The Isolated State* with an isotropic plain,

transportation costs proportional to distance equal in all directions, and a perfect competition framework. The key concept introduced was the sphere of influence of the central place. Settlements were categorized as low or high order services providers each with a different sphere of influence. The provision of certain good or services required a minimum threshold of population, and consumers would travel a maximum distance to access to these services. Christaller depicted an urban system in which hierarchies of central places were guided by three principles ranked in increasing order (and area) of influence. The marketing principle stated that the settlements acted as a central place to provide services to the surrounding areas. The transport/traffic principle was about efficient transport network and was concerned about minimization of road lengths. According to the administrative principle, the central place's influence would cover the entire region or market area. The result is a system of cities ("Central Place Theory," 2012).

The German economist August Lösch (1954) further developed the theory of central place into a more realist "economic landscape" with heterogenous space and possibilities of specialization and economies of scale. He was concerned about the consumer's welfare by the minimization of travel to access services or goods.

The attraction of central places was expressed by a gravitational model by Walter Isard. "*This model assumes that the sources of (mobility) flows depend entirely on the power of attraction of a central place, which is in direct proportion to the product of their respective mass (size) and is inversely proportional to the distance between them."* (Senecal et al., 2013)

The American economist Walter Isard (1949) is recognized as a founder of Regional Science as a discipline. During the Second World War he translated in English publications from important German location theorists. He exposed the "*Anglo-Saxon Bias against spatial analysis"* (Masahisa Fujita, 2010). In 1956 he published *Location and Space Economy*, a major seminal work in the "*development of a general theory of location and space economy, embracing the total spatial array of economic activities*"(Masahisa Fujita, 1999). In the footsteps of Isard, spatial economics became developed in United-States in different directions: economic geography, international trade theory, regional economics and urban economics.

Competing Land Uses

Urban economics is closely associated with the foundation work of William Alonso (1964). In *Location and Land Use*, he exposed a theory linking land values and land use within a city, with a major focus on residential land. His theory is deeply rooted in the monocentric economy of von Thünen but describing commuters instead of farmers. The isolated town is replaced by a central business district (CBD) and agricultural lands by residential areas situated on a featureless plain (no topography, no beautiful views, no social cachet, and schools of same quality).

It fact, it formalizes in economic terms the monocentric city described by Burgess. Like in Burgess (1925), all economics activities are located in the CBD, and surrounding residential areas are organized in circle around the center from where workers commute to the CBD. Alonso is associated with the model of monocentric city although he clearly stated Burgess' influence in his book: "*The ecologists view value as a result of a bidding process by potential users, by which the pattern of location of land uses in the city is determined."*(Alonso, 1965) Alonso's major contribution was the formalization of this bidding process by adapting the Thünian central concept of bid rent curves to an urban context (Masahisa Fujita, 2010).

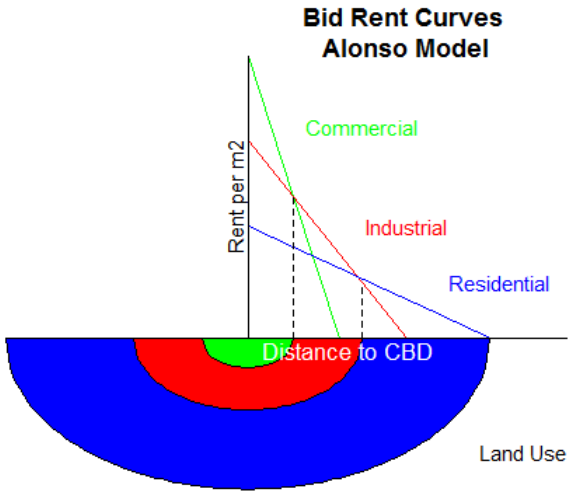


Figure 11- Bid Rent Curves

In this competitive framework, land users are bidding for lands. Land prices vary with distance from the CBD according to the highest willingness at that location. The center is the

most expensive land. Commerce such as department stores possesses the highest willingness to pay for this strategic location. Therefore the inner core would be occupied by retail. However the retail bid-rent curve is very steep as land outside the CBD is less valuable for commercial activities. Industry would be found in the second ring, because it would outbid both commerce and residential use in this location. Then at a certain distance from CBD, the land is more valued by residents than industrials, this is where begins the residential area. Figure 11 shows the formation of concentric zones according to the bid-rent curve of each type of land use.

Around the economic center, residences would be established with a gradual decreasing in density. The inner-city would be denser than the suburbs and the sparsely populated rural areas. Each household (or firms) has its own bid price curve. The curve represents a certain level of utility. It represents "*the set of prices for land the individual could pay at various distances while deriving a constant level of satisfaction* (utility)."(Alonso, 1965) Like in von Thünen's model, land use and land price are differentiated by transportation (commuting) costs.

Burgess' sociological model was built upon observations of Chicago and explained the development of cities based on the transportation capabilities of each zones. Alonso's model is based on the willingness to pay for lands in each zone (considering the combined housing and transportation budget). Preliminary estimations of bid-rent curves were also about Chicago. Both models resulted with the same monocentric shape around the CBD: commerce, industry, and residential (See figures 9 & 10).

Alonso also borrowed from several economists. Following Alfred Marshall and Martin Beckmann, Alonso paid a special attention to land size. His main hypothesis was that each household chooses location to maximize their living space with regards to housing expenditure. He pointed out the complementarity of rent and transportation costs as explained by Robert Murray Haig. Therefore the second hypothesis made by Alonso was the sum of housing expenditure and the cost of commuting could be defined as a function of income. Decisions were purely based on money expenditure; time and bother to commute were deliberately not included in the model.

3.2.2 The Alonso-Mills-Muth Model (AMM)

Richard F Muth (1969) and Edwin S Mills (1967, 1972) extended and modified Alonso's model. "*While Alonso explored these implications in a framework where individuals consume land directly, Muth and Mills analysed a more realistic model where land is an intermediate input in the production of housing, which is the final consumption good."*(Brueckner, 1987)

The Muth-Mills version has an aggregate land rent curve. Household must pay this market land rent and they will choose a location (r*) where their utility is maximized (u*). Graphically, the individual household bid-rent curve is tangent to the aggregate market rent curve. Locational choice of households is a tradeoff between marginal commuting (MC) and housing (MH) costs. The *Muth's condition* states that at the equilibrium, the marginal commuting costs (by traveling one more unit of distance) are equal to the marginal savings in housing price (by living one unit further away): MC(r*) = - MH(r*,u*). Otherwise the household would move either closer (if MC > -MH) or farther (if MC < -MH) from the CBD. A decrease in commuting costs would induce a choice of a farther housing location. The household maximizes its utility (u*) at the optimal distance (r*) with an optimal living space or lot size. Land is assumed to be a normal good: a larger income results in larger demand of land area. Due to the income effect, wealthy households have a less steep bid rent curve which would result in occupation of the more remote lands. Their optimal lot size would be bigger. This result was consistent with the observation that richer families tend to locate in suburbs. Indeed, one of the main achievements of the model is to predict a concentration of poor citizens in the city (although the main cause does not seem to be an income effect but, as Burgess suggested, the access to public transportation in the center) (Glaeser, Kahn, & Rappaport, 2008). The monocentric city is nowadays referred as the Alonso-Mills-Muth model (AMM) and has become a pillar in urban economics.

Monocentric Transportation Systems

The Alsono-Mills-Muth (AMM) model focuses on land purchase and ignores urban transportation systems, different modes of transportation and the effects of congestion. One natural path for the extension of the model was to include transportation infrastructure within the monocentric framework. Substitution between land and capital led to intuitive conclusions: land-intensive transport infrastructure like highways would be built more at the outskirt of the urban area, while underground subways will outbid in the center (Capozza,

1973). Researchers also looked at the impact of alternative mode of transportation (available at all locations) on the structure of cities including the possibility of congestion: "*Transport capacity does not appear to affect city size or density, but has profound effects on commuting costs and relative land rents*."(Haring, Slobko, & Chapman, 1976) Another bimodal model was based on a radial system consisting either of expressway or mass transit corridors (Moses & Anas, 1979). They found that shape of cities depended on relative the costs of competing transport modes including travel time. In these models, because of congestion, "*utility always declines as city size increases*" (Moses & Anas, 1979). It is a view lately challenged by the New Economic Geography.

After the oil shocks, too long commutes or "Wasteful Commuting" was analyzed to see if the energy use could improve. Hamilton (1982) found that excess commuting was 8 times bigger than predicted by the monocentric model, and therefore concluded the model was flawed (Hamilton, 1989). Without assuming monocentricity and with a different dataset, White (1987) found evidences of excess commuting but in a much smaller magnitude (less than three times) (White, 1987). Hamilton's model is said to overestimate excess commuting because, in real life, not all commuters work in the CBD. While Hamilton considered only distance, White focused on time. But both minimized aggregate commuting costs (of one zone to the CBD). Small (1992) confirmed the rejection of the monocentric model in commuting to work and found it made no difference if commuting was assessed by distance or time. In addition, they argue that empirical journey-to-work data rejects the fundamental assumption about the minimization of aggregate commuting costs (Small & Song, 1992). They estimated that two-thirds of the actual commute was not between aggregated zones but within zones.

While the monocentric model was a starting point in urban transportation systems, models have evolved around more complex network analysis, also helped with more precise data on commuting patterns for example by using cellphones positions. Nevertheless, the idea of a focal point (or several central nodes) is still useful even if the monocentricity is widely questioned.

The AMM Model in Reality

A loud critique about the AMM model came from urban morphology. Cities come in diverse shapes with complex patterns which are not captured by the monocentric model. Edward Glaeser reckons the monocentric model explains cities of the past. CBD existed in the 19th century because of the importance of ports and railway stations. *"The automobile has allowed cities to sprawl and eliminated any tendency towards a single city centre."*(Glaeser & Kohlhase, 2003) Polycentric models were an improvement towards realism; but capturing the complexity of urban structures remains a challenge.

Despite many criticisms, this simple model can still offer insights in the complex dynamic of cities. Indeed some lessons are still valid under a polycentric assumption Muth (1969). Also important modification like allowing for multiple housing instead of single housing or including income inequality among households did not invalidate important predictions of the model (Brueckner, 1987). Therefore the AMM is still relevant for some type of inquiries where the economy is monocentric.

3.2.3 When is the Economy Monocentric?

The AMM monocentric city model requires the prior existence of a center (CBD). This is a valid assumption when analyzing a specific existing city having an observed CBD, but perhaps not when inquiring about the location of economic activity in general. The economy is in fact rarely monocentric; nonetheless there are evidences of regional centers of influence. If the model struggles to describe the exact spatial geometry, it completely fails to explain emergence of these centers of influence.

The main limit of the AMM model is the explanation about the existence and location of the city in the first place. The usual explanation involves spatial heterogeneity: towns would locate around precious natural resources or because of favorable topography. Once a town is built it creates further attraction due to the presence of infrastructure or a market. Immobile factors (for example the existence of a port, railway, or mineral deposit) create a comparative advantage to location both in the initial choice of location, and in the expansion process. While it describes the establishment of towns around natural resources such as mining towns, it does not satisfyingly explain the creation for most agglomerations. For this reason, the primal existence of a city has become a fertile research area; generating a large body of literature on the location of economic activities in space, city formation, urban structure and

interregional trade. The competitive framework of the AMM model has been identified as a source of limitation.

In a competitive framework it is generally assumed that firms will experience constant returns to scale; that output would increase by the same proportional change in inputs. In this setting, firms would disperse their production to bring it closer to customers, and therefore reduce their transportation costs. Each location would be self-sufficient. Trade can only be explained by uneven spatial distribution of immobile factors of productions. Therefore if space is homogenous, the only feasible equilibrium in a competitive framework, is an economy of settlements operating in autarky like in the Isolated State (Starrett, 1978). This *spatial impossibility theorem* (Starrett, 1978) has demonstrated that general location models must assume either spatial heterogeneity, either externality in production and consumption, or either imperfect competition (Masahisa Fujita, 2010).

Non-market interactions have been a popular explanation for agglomerations. Indeed, many models have been built on externalities such as social interactions or knowledge spillovers. The need for face to face communication both in business and in social life is an important agglomerative force to the CBD, while the desire of space and consumption of lands acts as an opposing degglomerative force to the suburbs (Beckmann, 1976). Individuals do not take into account the locational externality they generate; they only consider their own travel costs. Otherwise they would concentrate even more near the center and consequently reducing the costs of interactions for others (Borukhov & Hochman, 1977). Cities facilitates knowledge spillovers between firms both within and between industries (Glaeser, Kallal, Scheinkman, & Schleifer, 1992). In cities firms experience increasing returns to scale by being in the proximity of other producers.

Other recent developments focused on monopolistic competition (Mashahisa Fujita, 1988). Under a Chamberlinian monopolistic competition model, spatial agglomeration of economic activities can arise by pure market interaction (Mashahisa Fujita, 1988). Firms supply differentiated goods and choose location according to the spatial distribution of consumers. Consumers like variety and they will also locate according the location of firms and availability of differentiated products. The dual attraction of firms and consumers can explain the existence of a CBD. Cumulative causation happens when a larger market attracts more firms (which increases the nominal wages) and in turn, more firms offers a greater variety of differentiated products (this increased offer translates in a rise of real wage).

Therefore, this cost-of-living effect induces a flow of workers attracted/dispersed by the combined nominal and real effect wage. This finding was a stepping stone in understanding agglomeration mechanism and in urban systems theory.

Core and Peripheral Specialization Zones

New Economic Geography (NEG) is described by Fujita has the unification of two pioneering ideas of von Thünen: monocentric spatial economy and industrial agglomeration (Masahisa Fujita, 2012). For Krugman, New Economic Geography is a new "genre" of economic analysis made possible by technical and modeling tricks which he refers by the slogan: "*Dixit-Stiglitz, icebergs, evolution, and the computer*"(Krugman, 1998a). In other words, he refers to the Dixit-Stiglitz monopolistic competition model, the Samuelson iceberg transport cost function, game theory with multiple equilibriums and the possibilities of computing power. These tricks and strategies could develop general equilibrium models describing the spatial structure of the economy. New Economic Geography successfully reinstated geographical analysis in mainstream economics (Krugman, 1998b).

New Economic Geography (NEG) meditated on agglomerative (centripetal) or degglomerative (centrifugal) forces of economic activities at the urban, regional and international levels. Incorporating Chamberlinian monopolistic competition into The Isolated State model suggested the existence of several towns (Masahisa Fujita & Krugman, 1995). The Core-Periphery theory is combining the idea of central place with increasing return from the Dixit-Stiglitz monopolistic competition framework (Krugman, 1991b). The economy is organized around a hierarchy of industrial interlinked cores having a zone of influence in their periphery. In an urban setting, the core is the central business district (CBD) that would be accompanied by Secondary Business District(s) (SBD) under its influence in the periphery.

A key component of the interdependence between CBD and SBD is vertical linkages. The final product or services requires intermediate suppliers. These suppliers can be part of the same firm but spatially distanced. For example, a "front office" could reside near the customers in the CBD while the "back office" could be located in the SBD where the cost of land is lower. A concentration of final producers will attract more intermediate suppliers which in turn will lower the costs for final producers through augmented competition. These intermediate suppliers can be established in the SBD as long as they have access to the CBD. This access is subjected to the existing spatial friction: transportation costs, transaction costs,

tariff and non-tariff barriers, as well as time costs. In addition to transport costs of merchandise, communication costs are scrutinized. The "abyssal fall in communication costs has led firms or developers to form enterprise zone or edge cities." (Gaigné, Thisse, Paper, & Lereco, 2013) Lower spatial friction results in the specialization of economic activity of different zones of the city (Thisse, 2009). Therefore, high commuting costs or lower mobility increases agglomeration.

The agglomeration mechanism is self-reinforcing in nature (Thisse, 2009). After a specialization zone has been established there is a lock-in effect that arises. It is consistent with the observation about the impact of history on the shape of cities. "…*The precise nature of urban configurations in a particular economy will be dependent on the history of that economy."* (Masahisa Fujita & Thisse, 2014) Most models in economic geography exhibit this spatial hysteresis, which in the case of cities is stronger than predicted by von Thünen. NEG borrowed this self-reinforcing idea from the Circular Cumulative Causation theory of Gunnar Myrdal (1956).

One source of a lock-in effect is the increasing returns from agglomeration, externalities that benefits the firm from evolving in a bigger market. In Gravity models, the core possesses attraction capacities, a market potential, similar to gravitational forces. Once a zone has been established, there is a circular process that encourages more firms to aggregate. Also once substantial resources are committed to an area, for example an infrastructure, there is a certain resistance to a change in specialization or land use. In cities, adjustment costs can be high if it involves tearing down buildings and expropriations. Moreover, lock-in effects can subsist even if the cause of the creation disappears[13] (Thisse, 2009). Thisse supposed existing spatial specialization can remain even after spatial friction is reintroduced. Under this vision, locked-in of spatial specialization patterns are predominantly explained by historical accident.

An opposing force to the initial conditions of history is the expectation about the future. Expectations about future conditions also affect business decisions. These expectations can involve in self-fulfilling prophecies and influence the spatial development. In fact, there are multiple feasible spatial equilibriums. Generally history will be the dominating effect but

[13] Cities completely demolished by bombings in World War II were rebuilt in the same location.

there are conditions under which expectations will prevail (Krugman, 1991a). In summary, it depends the rate at which an economy adjusts; if the economy adjusts quickly it is likely the expectations will weigh more in the balance. However if adjustments are too slow history will always prevail (in the presence of adjustments costs).

3.3 In Praise of Service-Cities

"*…we find the nature of the industry determines its location."* – Johann von Thünen

The study of spatial distribution of economic activities has focused primarily on the transport costs of commodities and the locational choices of firms. From Weber to Krugman, both in location theory and in international trade, manufacturing occupied the center stage. The Core-Periphery model explains the concentration of manufacturing in certain specialized regions by the dramatic decline in transportation costs of commodities. In this globalized world, the economy is less monocentric but more polycentric, and cities are part of regional and international networks. New possibilities in communication technologies have fostered the emergence of peripheral edge cities (SBD) for manufacturing (back-office) activities around central zones (CBD). Therefore manufacturing activities has eroded in cities. On the other hand, the service sector flourished.

For Palander, services were linked to the consumption center. Conversely, unlike mobile manufactured goods, consumers can only access to the diversity of services provided within their residential area. Services and commercial activities always occupied the core space in the CBD of the monocentric city model. In essence, the third sector has expanded as the economy evolved, but this transformation was even more important for urban economies. The retreat of industrial activities induced the service sector to provide an increasing share of employment for urban dwellers. Moreover the role of the city has shifted from a center of production to a center of consumption, which is epitomized by "reverse commuting"; people living in cities and working in suburbs.

Traditionally the cities were seen as having advantages in production and disadvantages in consumption. Agglomerations were associated with crime, pollution, and congestion. Workers were only attracted by higher urban wages but in fact preferred to dwell in pastoral (suburban) landscape. However, urban density also facilitates consumption. Large cities offer a wide diversity of services, events and products. Consumers benefit from increasing

scale economy both in market and non-market interactions and will therefore be attracted by density. The success of cities increasingly relies on their role as consumption centers (Glaeser et al., 2001). Strong demand for urban living is supported by empirical of evidences about a faster growth in urban rents than in urban wages. However, not all cities are equally prized for their quality of life.

Prosper cities will be those able to provide attractive amenities to the "creative class", highly skilled workers which command high incomes. Glaeser distinguished four types of amenities: 1) variety of services and consumers' goods 2) aesthetics and physical settings (architecture or weather) 3) public services (good schools, low criminality) and 4) speed.

Glaeser emphasized the importance of attracting human capital. An Educated population is related to growth and higher productivity. Marshall understood the role of cities as allowing the transfer of knowledge and skills by pooling the labor market. Glaeser went further by proposing that cities and industrial clusters are generators of ideas. He therefore advocates the improvement of transport for people, goods as well as ideas. Entrepreneurship can flourish in cities. Indeed, innovation is seen as the main driver of post-industrial cities (Florida, 2002). Via face-to-face interactions, urban density fosters human achievements. According to Glaeser, cities are in fact our greatest invention (Glaeser, 2011).

The positive view about cities and their role as consumption centers is attributed to modern urban or NEG economists; however von Thünen already saw cities as service providers[14]. He was especially concerned about the lack of density in the countryside which hindered the reception of urban services from doctors, specialized craftsmen, and schooling. And again the crucial aspect in accessing services was transportation costs. The triumph of cities depends on mobility.

[14] In the unfinnished Part II, Section 2 of the Isolated State: "The Role of Population Density."

3.3.1 Inter- Vs Intra- City Transportation

Apart from the work of urban economists, transportation has been mostly been examined between cities or production sites. However transportation reveals different characteristics depending on the (Löshcian) scale of observation: urban, region, international. The spatial organization of the economy results from the interaction in all these levels.

The space economy must be described both **inter-city** and **within-city** by analyzing transport costs of **commodities** as well as **persons**. In the case of manufactured goods, a reduction of inter-city transport costs induces agglomeration of production in specialized zones and therefore creates regional divergence (Krugman, 1991b). When this reduction of transport costs is examined within-city, there is a degglomeration of production and a decentralization of manufacturing jobs to SBD (Gaigné et al., 2013). The opposite is true in the service sector: a decrease in within-city commuting costs encourages agglomeration to the CBD (Gaigné et al., 2013).

Hence infrastructures for commuting and for the transportation of commodities are differently shaping urban regions. Spatial frictions greatly influence the agglomeration or degglomeration forces and ultimately the specialization zones in a city. As a consequence, cities differ in size and in structure. This has a strong incidence on its regional and international connections with other cities as well as its relative position in the network. With the growing importance of the service sector, "*the evolution of commuting costs within cities, instead of transport costs between cities, becomes the key-factor explaining how the space-economy is organized."*(Gaigné et al., 2013)

Commuting costs impact the agglomeration of services. Urban costs are defined as the sum of housing and commuting costs. High urban costs acts as a dispersion force crowding firms and individuals out of the urban area. On the other hand, high urban costs in the CBD are compensated by relatively lower costs for other goods and services, and possibly higher wages. The attractive force of a large city lies in the variety of the services offered. A diminution in commuting costs will increase the access to a larger variety of specialized services. Specialization is fostered by larger customer base, both from access to a larger area and from a population growth (additional consumers attracted by this variety of services).

However, because of the rise in urban costs, agglomeration stops once a certain threshold of population size is reached. Even von Thünen[15] recognized the dispersion force of urban costs (food, fuel housing) in larger towns (Thünen, 1850). Households make a trade-off between urban costs and gains from variety, and their spatial choices will be reflected in the structure and the density of the city.

3.3.2 The Triumph of Compact Cities?

Dense and compact city is an ideal pursued by many urban-planers and scholars to reduce the ecological impact and mitigate emission of GHG. The conventional wisdom is that compact cities always lead to a better ecological footprint. However, this is not necessarily the case. Compact cities are only better if they result in shorter commutes. Large and dense cities might have longer commute and higher emissions levels than polycentric cities; in this case the creation of dispersed SBCs could allow a reduction in pollution (Gaigné, Riou, & Thisse, 2012).

Unconditional advocates of compact cities are neglecting basic urban dynamics familiar to von Thünen and NEG economists. Gaigné & al. (2012) claimed that the urban morphology, and in general the spatial organization of the economy, are neglected in the environmental debate. An increase in density may induce a relocation of profit maximizing firms and utility maximizing households. Policies aimed at increasing the density in the central city must take into account the counter effect of relocation towards the periphery that is often in another jurisdiction. Therefore the environmental assessment must cover the entire urban region. In addition, the structure of the urban system will also affect the shipping of commodities. There is a trade-off between commuting of workers and transport of commodities; between a few dense cities or several small ones. Small cities have a low average commuting but require more travels for the transport of goods to a larger number of cities. Therefore, the minimization of transport-related GHG requires a broader view of the spatial distribution of households and firms. Furthermore "imposed density" may generate welfare losses. For these reasons, the development of sustainable cities should benefit from closer attention to the various consequences of compactness and the spatial organization of the economy as a whole (Gaigné et al., 2012).

[15] In the unfinnished Part II, Section 2 of the Isolated State: "Order and Distribution of Towns in the Isolated State"

3.4 Commuting: the Next Frontier

"*Wherever economic theory is studied today, his ideas, his working methods, the problems he posed, have proved seminal right up to the present day –even there, where his name seems to have been forgotten, Thünen has worked."* -Erich Schneider

The legacy of von Thünen is far reaching and impressive, but was first ignored then slowly rediscovered. Spatial Economics which emerged directly or indirectly from von Thünen is now acknowledged by mainstream economics. Space was even labelled as "The Final Frontier" by Paul Krugman (Krugman, 1998a), which expresses both the great challenges and opportunities of spatial analysis. In this regard, teachings from The Isolate State and its worldly author are still relevant to contemporaneous challenges.

Nicholas Stern described the emission of GHG as the biggest market failure humanity has ever faced (Stern, 2008). The transport sector is an important and growing emitter of GHG, and smarter commuting within-cities is recognized as a central part of the solution to mitigate climate change. Commuting costs have been shown to generate a crucial impact on urban morphology, and therefore on the carbon footprint of cities.

Surprisingly, there is a chapter on commuting in The Isolated State. To paraphrase Schneider: *Thünen has worked even there!* In the Isolated State there is no pollution externality; manure is appreciated as fertilizer and sold to adjacent farmlands. However, commuting was seen as wasteful: Von Thünen reckoned a daily average of 32 minutes for one-way trip to the field. Therefore about $1/10^{th}$ of the 10 hours workday of his laborers was lost to commuting (in the uniform topography case). Some of this commuting was due to suboptimal allocation of property rights, and Thünen argued against barriers such as hefty tax on land sales and transfers. In today's urban landscape, zoning and building heights regulations can create these distortions (Glaeser & Gyourko, 2002); which in addition to productivity losses result in GHG emissions.

This chapter has conveyed the evolution of von Thünen's theories from location theory to urban economics. It has showed that von Thünen's methods are well suited to address commuting costs, cities' structures and even perhaps climate change. The next chapter will extend The Isolate State beyond the frontier of the 21^{st} century.

4. Chapter 3: A von Thünen model of the Commute

"*In such a* (sub-optimal) *country men and horses waste their energies on constant tiring journeys to and from the field, a labourer (…) will here consume nearly all it wins from the land and will have little extra left to sell to the towns."* –Johann von Thünen

In those words Thünen describes the impact of "too long commuting". Time and energy spent on commuting are subtracted from productive activities. Motorization has eased commuting by substituting human energy; however vitality is affected both by the comfort of mass transit and the attention (stress) of driving. If the conceivable range of commuting has largely increased, transportation technologies have not released humans from time and energy constraints.

Commuting is generally seen as wasteful both for individuals and for the society. Of all daily activities, commuting to work was ranked as having the least positive effect in a study combining time budget and experience characterization (Kahneman, Krueger, Schkade, Schwarz, & Stone, 2004). Commuting also generates massive amounts of air pollution and GHG emissions. Clever urban designs have the potential to reduce commuting and improve sustainability and the society's welfare.

Urbanism is generally thought in terms of "Urban Planning", a paradigm of centralization of the decisions. The polity relies on expert opinions to design land use and transportation. Careful planning and coordination at the regional level are definitely key strategies in improving urban sustainability. Incentives can influence the choice of commuting mode. However the ultimate decision is decentralized. Each individual interacts with its environment according to his priorities and preferences. Planners often impose a design to the final users without being able to understand their needs. A classic example can be seen in inappropriate sidewalks shapes resulting by mud trails being created by a crowd following the shortest route to the bus stop for instance. To insist on the elegance of their design, planners will go as far as adding fences. While seemingly erratic, mass human behaviours are in fact somewhat predictable because individuals decisions are not made in total isolation but significantly influenced by social interactions (Ball, 2006). Of all the possible mud paths that could have emerged on the grass yard, a specific one will emerge because of herding behaviours. Urban systems express predictable regularities.

Like other of his contemporaries von Thünen was on a quest to uncover such "natural laws". Von Thünen proposed a model of decentralized decisions of a multitude of rational managers. He understood the increasing importance of markets forces during the Industrial Revolution, and how it would become a guiding principle of firm's operations.

A von Thünian model of the 21st century cities would therefore include the following elements: 1) decentralization of decision making 2) a guiding principle of observed regularities 3) close attention to spatial frictions 4) Thünian concept of land rent 5) both ring and intensity theories and perhaps 6) make bold predictions about the winds of change in the upcoming Third Industrial Revolution.

A von Thünen approach is well suited to address decentralized aspects of life, such as commuting to work; it can perhaps shed new and complementary light on urbanism and urban economics.

This chapter develops a von Thünian model of the commute with Bergen as the "Ideal Town". The first section poses a diagnostic about the dominant trends influencing urban systems and the research agenda in economics. A behavioural perspective is adopted. The second section describes the history and the structure of Bergen which dictates some assumptions of the model. It focuses on the elements relevant in New Economic Geography. The third section deploys the commuting model in the spirit of von Thünen. The dynamic process relies on a Weberian approach of successive waves of developments. Finally, the last section discusses the impact of adding new light rails lines to the Ideal Town of the model.

4.1 Behavioral Aspects of Commuting

Von Thünen recognizes heterogeneous tastes in spatial sorting: labor would choose to locate according to their preferences between town-goods and farm-goods. At the outskirt of the Isolated State, the basket of wage-earners would be dominated by grain for instance. In neoclassical terms, independently of their location, workers would derive the same utility from the combination of their wage and location.

Standard urban economics treat commuting as any other rational decision which involves a trade-off between housing space and travel distance. A longer commute is compensated either intrinsically by better living environment or financially by a higher wage. Individuals optimize their situation and therefore there are no utility differentials between people free to relocate. This view is being challenged both by transportation and behavioral researches.

A study concluded that longer commute was systematically linked to a reduction in subjective well-being (Stutzer & Frey, 2008), but noticed a certain inertia to resolve this spatial disequilibrium. One proposed explanation is a widespread overestimation of the capacity of adaptation to commute which results in longer commuting time than the individual would prefer. It seems there is a significant underestimation of the disutility of commuting prior making residential location choice. Moreover individuals subsequently procrastinate in tackling this situation (by finding a new job or new housing) either because of a lack of will power, loss aversion, or by the existence of transaction costs.

Consequently, there is a very strong spatial hysteresis that is not accounted in most economic models. Myopic agents are also less responsive to changes in expectations and to agglomeration forces than the rational forward-looking agents of models (Mossay, 2013). However these myopic commuters exhibit predictable habits that can be included in the design of an “Ideal Commuter”. This section looks into central behavioral elements of urban transport systems.

Transport Mode

Several economic inquiries have addressed alternative modes of transport. Many studies have focused on prices, elasticities and cross-elasticies between transport modes (Litman, 2011). Often it was guided by policies seeking to discourage car-riding with fuel taxes, toll roads, parking and licensing fees. Norway has extensively used these instruments but car

ownership and usage increased in the period 1985-2009: there were 50% more cars in the country and the share of drivers increased from 46% to 52% (TOI, 2012). Car use and trip lengths have continued to rise since 2009 (TOI, 2014). Travels are normal goods; an increase in income translates in higher travels distances[16]. While important, out-of-pocket costs become a less dominant preoccupation for individuals as they get richer.

An income effect is generally assumed with the choice of transportation; the car is seen as normal good while public transport is expected to be an inferior good (Liu, 2007). A survey made in Iceland on regular users of public transport found that once the bottom decile of income is removed, there is no clear evidence of an income effect (Hagstofa_Islands, 2015):

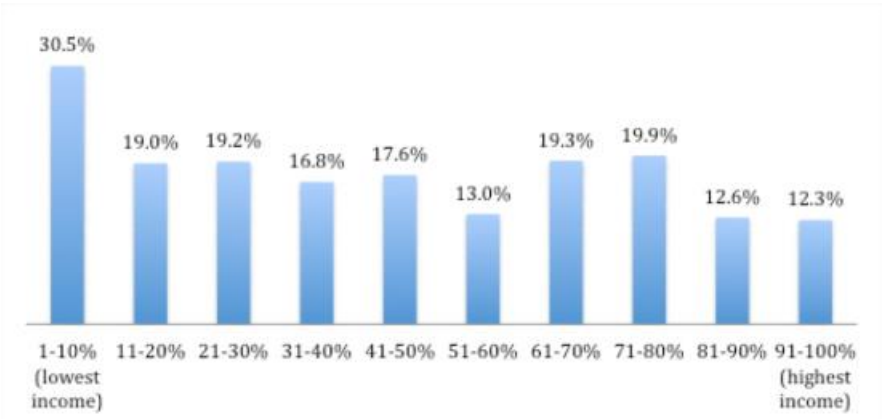


Figure 12- Use of Public Transport by Income Levels; source: Statistics Iceland

There seems to be a constant share of collective transport across all group of income bar the extremes low and high. This result echoes similar findings in other geographic areas (of the developed world[17] (Statistics_Canada, 2007) (Sydney, 2006). The lowest decile of income has less transportation alternatives and therefore will predominantly use public transportation. In the developed world, this group is not composed of full-time workers. For other income levels, other factors are more determinant: education level, house ownership or leasing, walking distance to bus stop, existence of sidewalks, and car ownership (Cervero, 2002). Car ownership is the single most prevalent reason behind the use of car for daily trips (Statistics_Canada, 2007). This point is imperative to emphasize: a car owner will most assuredly use her car for most trips including commuting. It is the principle of least effort in action.

[16] Other explanation in the increased of distance travel include segmentation of the housing market, specialization of the labor market, and better use of travelling time. (van Wee, Rietveld, & Meurs, 2006)

[17] In some countries security becomes the central preoccupation, public transport will be inferior goods.

The built environment has a tremendous influence on the choice of commuting mode (Cervero & Kockelman, 1997): Pedestrian-oriented designs generally reduce trip rates and encourage non-car travel. Households purposely self-select homes and apartments near stations for the very purpose of economizing on commuting. The presence of retail shops within-neighborhood is another important aspect to consider both for the choice in transport mode and the length of trips.

The design of the city influences the commuting mode, but the commuting costs or spatial frictions are directing the structure of the city in the first place.

Transport Costs

One common challenge of spatial economics models is to express transport costs in order to compare several modes of transport with radically different technologies, energy sources, and cost structures.

Monetary costs do not provide the entire picture. In the case of commuting they are not entirely variable to the distance traveled. Mass transit systems are usually accessible for a monthly fee that provides an unlimited access to a zone. Between zones there might a "ladder-step" increase of fees, but this approach completely fails to discriminate inside the collective transport zone; which in some municipalities covers the entire city. Moreover, it fails to distinguish between different modes of mass transit (bus, light rail, train) since they are subjected to the same fee in that zone. In the case of automobiles there are a multitude of fixed costs (financing, licenses, permits, parking) and variable costs (fuel, toll fees) as well as maintenance costs that can be both fixed, variable, and unexpected. All these costs are also subjected to the type and characteristics of the vehicle (size, fuel efficiency, depreciation, etc.).

In everyday life, the commuter experiences more vividly other forms of discomfort such as rain, accident risks, stress, congestion and being late for work. Such features of daily routines will gain scrutiny past a certain level of welfare. Indeed, non-economic considerations of mobility increase with income (Thisse, 2009).

Non Market Interactions and Cities

"*We cannot understand cities and agglomerations without understanding non market interactions." – Edward Glaeser*

Congestion is an archetype of negative externality on urban roads. Commuters rush simultaneously by numbers to the office instead of spreading at various time of the day. The goal of commuting is exactly to be at the office at the same time in order to meet, work and share with others. Face-to-face interactions are the *raison d'être* of cities and the purpose of commuting. Edward Glaeser asserts that non market interactions are a neglected critical segment of the economy that is especially relevant to understand the dynamics of cities (Glaeser, 2000). He also calls to undertake more research in that direction and suggests that urban economists possess the right spatial skills to do so.

Glaeser proposes that time and speed are gaining in importance. Speed is a vital amenity that determines the access to a range of services and employers. "*As time becomes more valuable, individuals will particularly avoid areas where transport time-costs are high."*(Glaeser et al., 2001)

4.1.2 Time

Time is a very precious scarce resource that imposes constraints to every commuter. Indeed many transportation studies report that **travel time is the key consideration in the choice of commuting mode** since it corresponds to people's perception of spatial friction (Frank, Bradley, Kavage, Chapman, & Lawton, 2008). In-vehicule time is the single most important consideration before out-of-vehicule time and monetary costs (Liu, 2007). Travel time calculations are necessary to analyze "modal accessible disparity", and door-to-door approach is favored to make comparisons (Salonen & Toivonen, 2013).

Quantifying the Travel Time Budget (TTB) has been a subject of large debate. Supporters of the Marchetti's constant (Marchetti, 1994) or the constant travel time budget hypothesis *"posits that humans, since Neolithic times, budget approximately one hour per day on travel, independent of location, modes of transport, and other lifestyle considerations."*(Kung, Greco, Sobolevsky, & Ratti, 2014) This bold hypothesis has been largely criticized since there are evidences that commute times vary greatly between and within countries. While many factors influences individual-specific time budget, it seems that there are foreseeable consistencies at the aggregate or sub-population level (Mokhtarian

& Chen, 2004), and that humans derive a certain positive utility of traveling and thus "*possess an intrinsic desire to travel"*(Mokhtarian & Salomon, 2001) A recent research based on mobile phone data and vehicle GPS from several countries over different continents found that "*commute time appears invariant with commute distance*" (Kung et al., 2014). While the debate about a constant TTB is far from being resolved, the key aspect is that commuters are constrained by time limits but also demonstrate certain willingness for a minimal travel time. Indeed there are also positive roles associated with commuting, a time that can be used for work or leisure activities (Mokhtarian & Salomon, 2001). Therefore commuters have a "desired time budget" to allocate.

Perceptions about time are quite relative to the culture, to the landscape, and to the individual. Employed people are often willing to pay more for travel time savings (Litman, 2013). Different from clock time, perceived time tend to increase with discomfort, insecurity and congestion. Drivers often reports that one minute of walking being much more a burden than a minute of driving (Frank et al., 2008). Perceived time is difficult to measure.

Economists have come with average estimates of the monetary Value of Time (VoT). These valuations vary greatly with countries, income levels and mode of transport. In Norway, In-vehicle value of time was estimated in 1995 at 108 NOK/hr (35% the average industrial rate) (TOI, 1997) another estimate was 85 NOK/hr (Halse & Killi, 2015).

While the precise valuation of time is challenging, the literature suggests that time is gaining in importance relatively to monetary considerations[18]. Commuting time, and especially in-vehicule time, is the leading factor behind the choice of commuting mode. In this perspective time could be the main driver shaping urban structures.

Rational Ideal Commuters would allocate exactly their desired time budget to daily mobility. Assuming that the least effort principle is prevailing, Ideal Commuters would seek to minimize their commuting time. In the real world, myopic commuters fail to optimize their time budget because of mistaken perceptions or because they voluntary choose a longer time

[18] A recent survey reveals that city-dwellers off all age group show a mindset associated with millennials (Zipcar, 2015). Experiences and access are becoming more important than properties and ownership (Rifkin, 2000). Lifestyles are increasingly more defined by what you do than what you own. Biking to work defines a subculture of active and environmental friendly people just like owning a car or a house used to be important in identity formation. Millennials have started to adopt a post-materialistic mentality more in the **Being Mode** described by Erich Fromm than in the **Having Mode** characteristic of the industrial society (Fromm, 1976). A driving license is a less common *rite de passage* than it used to be.

for idiosyncratic reasons such as "listening to music". Among other reasons "spatial mismatch" of the built-environment can impose excess of commuting. Nevertheless, in the absence of distortions, time-cost minimization is a guiding principle of urban systems.

4.2 Description of the Town

Bergen : Gateway to the northern fjords

Blessed by a deep natural harbor, Bergen has been a major trading center for more than a millennium. Bjørgvin (the meadow among the mountains) was a Viking settlement and a royal estate, Álreksstaðir[19]. In 1070, two years after the creation of the Diocese of Bergen, King Olaf III consecrated the status of Bergen as a dominant political, religious, and trading city. A fortress was erected on the islet of Holmen located the entrance of the harbor. The fortification (now known as Bergenhus Festning) protected the royal seat (Håkonshallen), the cathedral along the bishop's residence as well as a monastery. In the 13th century, exports of dry cod from northern Norway elevated the city among the largest trade centers of Europe (Næringsråd, 1939). A Hanseatic foreign trading post (kontor) was established in Bryggen[20] (now a World Heritage Site). The German merchants would dominate trade for nearly three centuries, after the Black Death, a pandemic plague killed over 60% of Norway's population. Ever since Bergen has remained an important commercial center even if the political and administrative roles diminished. The city also remarkably flourished culturally and scientifically. Nowadays this rich history is internationally recognized and every summer attracts hordes of tourists and cruise boats.

Shaping Bergen

To protect the historical heritage, the city imposes many architectural and urban restrictions. New constructions are subjected to a height limit that is in accordance with existing cultural-historical buildings to "*give the impression of a continuous carpet covering the landscape and weaving together the spaces between the mountains"* (Iversen, 2008). In addition, according to the tradition tall buildings are reserved for the authorities, the church or special public symbolic value. In essence, the "municipal master plan" prevents further densification

[19] The royal farm was located at the foot of the largest mount: Ulriken, (Alrekr, in Old Norse)

[20] Before the 2nd World War, Bryggen was named Tyskebryggen, historically the German Hanseatic merchants were isolated from town and had restricted contacts with the population.

downtown. Bergen Sentrum is almost frozen in time; this contrasts with a history shaped by fire[21].

Indeed the city was periodically and often severly ravaged by large fires. One of the most destructive brazier was in 1702 where 7/8 of the town burned (Bergenskartet, 2012). Many public squares (menningen) were created as fire barriers to circumvent the propagation of fires. After the last of such devastating fire in 1916 (Amoriza, 2014), many massive buildings and landmarks were built with the classicist style of the 20's which characterizes the architecture of important monuments. While dramatic, all these fires allowed periodic regeneration and modernization of the city; a process that seldom occurs nowadays because of firefighting techniques. Nevertheless, Bergen has inherited of an aesthetic and pleasant walkable Sentrum.

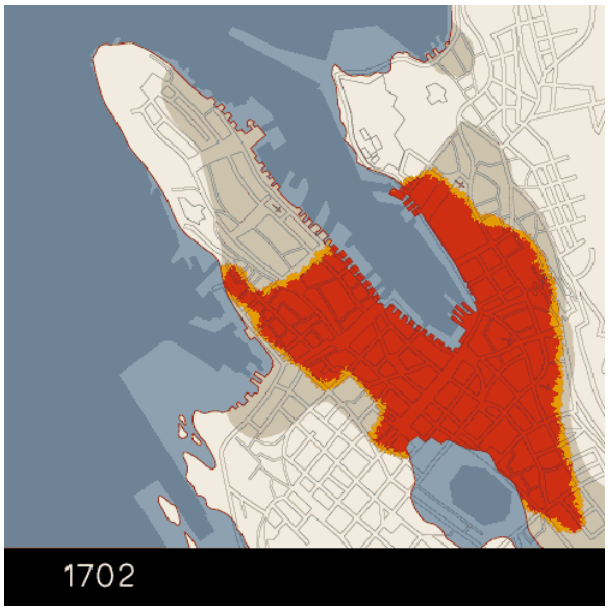


Figure 13 - Map of the 1702 Fire. In red the area destroyed. (Bergenskarteret)

At turn of the 20th century, Bergen evolved from a walking city to a transit city. Many light rails lines were built, including one in front of Bryggen (Hartvedt, 1999). Urban sprawl was facilitated with the Bergen-Voss train line that carried also commuters from Nesttun (before

[21] Fires are so associated with Bergen that it has given the name «Brann» (fire) to its football club.

the tunnel under the Ulriken was completed 1964). In the second half of the 20th century new developments were shaped by automobiles and buses.

Bergen Challenges

The characteristic topography of Western Norway is a major determinant of urban developments. Bergen is clutched between abrupt mountains and the sea. Therefore the agglomeration follows transportation axis along the coastlines or valleys. Suburbs have been extended to nearby islands by bridges but ferries are still used to commute. Flat ground is scarce. In recent years, Bergen experienced a "housing crisis" that is not entirely resolved. Real estate prices have surged in the past 10 years.

Today Bergen is the second largest commune of Norway with its 275 000 inhabitants (2014) which is not large by international measures but nevertheless experiences high levels of air pollution. In some cold winter days the air quality (at Danmarks Plass) is reported to be the worst in Europe (Helgheim, 2014). Cold air acts like a cover over the valley and pollution remains trapped between the mountains surrounding the city. Firewood is still widely used as complementary heating of residences[22]. Emissions from boats stationed in the port are carried by the breeze into the valley[23]. However, road traffic is by far the main source of pollution and GHG emission in Bergen (Haagensen, 2015).

Monocentric Bergen

The historical core of Bergen is similar to the typical monocentric model described by Burgess and Alonso but modified by topography. Bergenhus is a clear commercial and cultural district (CBD) surrounded by industrial sectors with access to sea, and less dense residential areas farther out. This picture was modified in the automobile era, but the center kept the main features. The city is now polycentric with large commercial centers in Åsane and Lagunen. Recently the commune evolved as industrial shorelines in Sandviken and Gyldenpris are becoming more residential, and remote secondary business districts such as Sandsli are emerging as important employment areas. Nevertheless, Bergen Sentrum is uncontestably the commercial, administrative, educational, cultural, and touristic center. Accordingly, most of the transport infrastructure (harbor, train and bus station, highways)

[22] A fog made of particles is often visible in Fana between the Løvstakken and the Ulriken.

[23] Measures such as electrification of boats at the dock have been introduced.

converges towards the Sentrum. Therefore, travelling between secondary centers requires a *passage obligé* to Bergenhus. Topography also imposes this structure.

A monocentric model of Bergen captures a large share of the urban dynamic. However the concentric shape is not appropriate beyond the inner zones. It can be approximated with rectangular corridors along the transportation axis.

Transport System

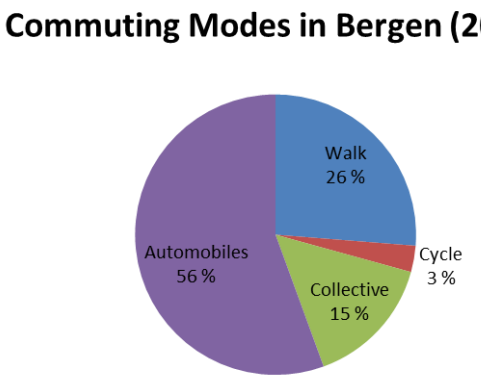


Figure 14 - Commuting mode in Bergen (SSB)

With 15% of daily commutes done via public transport, Bergen is second behind Oslo at 25%. The national average is just under 10%. Bergen experienced from 2005 to 2009 a steep increase in public transportation which coincides with the completion of the first phase of the new light rail (Bybanen). (Haagensen, 2015)

Cycling in Bergen is not a popular commuting option which occupies by far the last rank among large cities in Norway (Haagensen, 2015). The harsh costal weather and topography are probably the main causes. In addition the reliable public transit system may deter the use of bicycle. Bicycles are used more than three times more in Trondheim which is also a university town with similar density but less concentrated public transport routes. As a consequence Bergen has, with Tromsø, the least amount of cycle path (km per inhabitants) in Norway among major cities (Haagensen, 2015). However, walking is very popular making Bergen the third city in active transportation behind Oslo and Trondheim.

Automobiles are the dominant commuting mode in Norway, and in Bergen (56%). In 2013, Bergen had the least amount of personal cars (509) per (1000) inhabitants. Oslo with 516, is almost at the same level. Bergen had also the lowest amount of kilometers traveled by car.

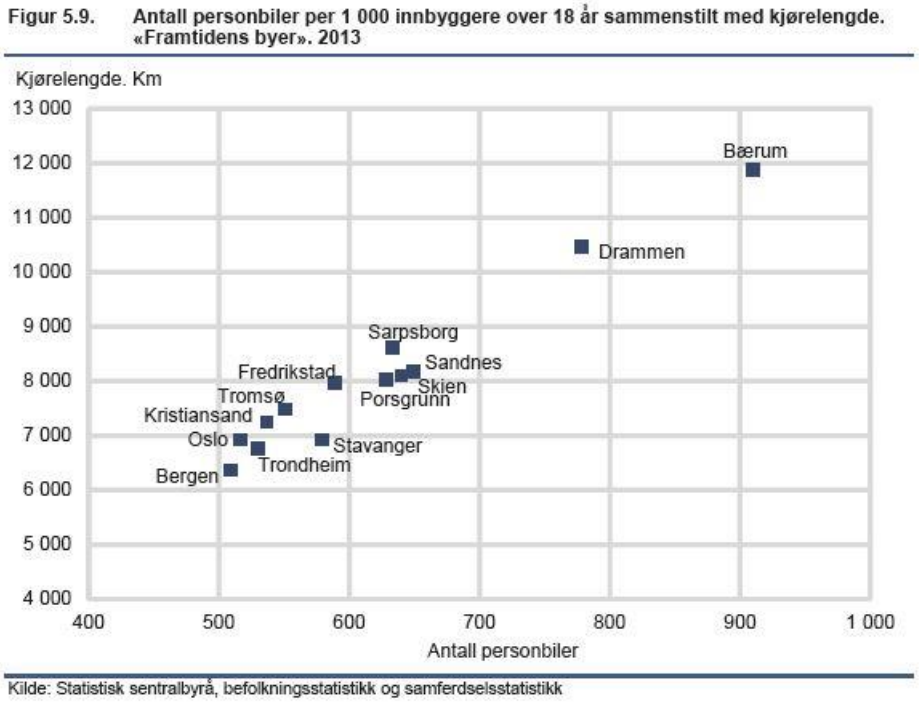


Figure 15- Number of personal cars and usage by 1000 inhabitants (SSB)

Density

Bergen is less dense than other large Norwegian cities such as Oslo, Stavanger, and Trondheim. However every year since 2003/2004, more than 80% of new constructions lie within the town limits (tettsted) making Bergen one of the national leaders in densification (Haagensen, 2015). Densification is a national priority towards development.

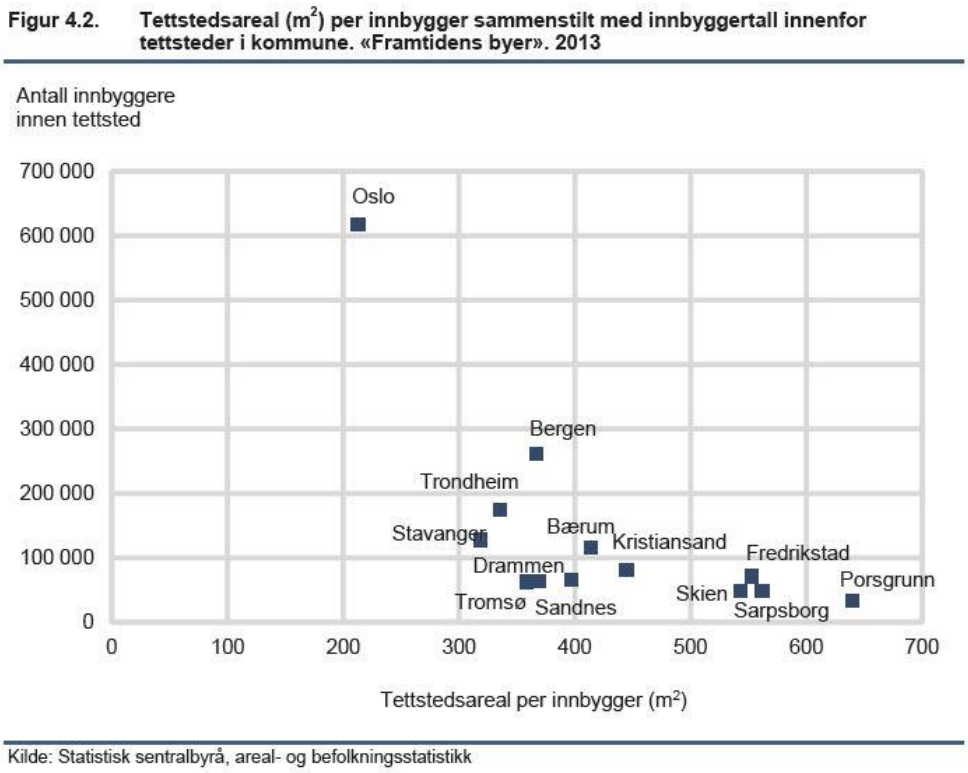


Figure 16 - Population and Density, source: Statistisk sentralbyrå (SSB)

4.3 The Model

Von Thünen developed a spatial model composed of two main theories: an intensity theory to guide the choice of agricultural system, and crop theory to determine which crop to grow. This von Thünian model of the commute is also made of two theories but in inverse order. First, the mode of commuting theory determines which mode of transport to use in order to minimize transport costs (expressed in time). Then, from the flow of passengers is built an intensity theory which defines patterns of housing density.

4.3.1 Assumptions

The Ideal Commuter

The Isolated State pictured a region inhabited by full-time ideal[24] farmers. In our model, commuters are full-time middle-class workers that travel two times per workday to their workplace located in the central business district (CBD). Self-employed or any people working from home are not considered commuters. The same applies for unemployed, retired, part-time workers, and students. While these citizens also have a need for mobility, the focus of the model is about commuters only, and solely on their trip to work. Demand for transport of other activities (recreation, shopping, schooling, etc.) is not considered. The spatial structure of the city has a more direct relation with commuting than other activities (Gaigné et al., 2012). Also, the choice of transport mode can differ between commuting and other activities (for example a car may be needed for a shopping trip to IKEA or a ski trip). Commuting to work is a travel fixed from a point A to the CBD[25], and workers will choose one predominant mode of transport.

Absence of Class and Income Effects

Another convenient aspect of the assumption of full-time workers is that they can afford commuting to work. Part-time workers may struggle to pay for the bus fare. While in some countries full-time workers could still be considered as poor, this model assumes that commuters earn sufficiently to cover the cost of commuting otherwise they would not accept

[24] They were rational decision makers which possessed all the same skills, information and thoroughness.

[25] Attraction to CBD could be even stronger if non-work related travels are included, because public transit access is generally good in rush hours but not necessarily at night and over the weekends, and car usage is incompatible with certain leisure activities.

to work. Poverty and class discrimination have been an important subject of study in urban sociology and urban economics. Poor neighborhoods may suffer greatly from a lack of mobility creating a "spatial mismatch" between affordable housing and location of employment (Kain, 1968). This important field of inquiry is not part of the current model.

In this model, all commuters belong to the middle-class (or are acting as such). This simplification is a reasonable assumption in the developed world where the middle-class represents the major share of commuters. By considering simply that all commuters can afford the costs of mobility, we remove the class distinction and the model becomes a one-class model. This treatment is different from many researches based on several class models but is realistic in countries such as Norway and Canada.

Identical Preferences

In the present model, commuters have identical preferences about housing and mobility. Commuters are city-dwellers[26] living in 50 square meters housing units with possible access to all mode of transportation including car. They are indifferent between active or motorized mode of transport. Their utility is maximized when the commuting time is minimized. Spatial sorting depends on transportation infrastructures which define the time-cost of each mode of transport. In this analysis, are left aside all external other households' considerations such as quality of schools in a neighborhood, security, air pollution, etc.

Sequence of Choices

Commuters choose the mode of transport before the location of housing. In most monocentric models, housing either comes first or dominates the analysis. Urban costs are composed of both housing prices and commuting costs; therefore the choice is understood as simultaneous. But housing costs are generally more substantial and a heavier weight could be attributed in the decision. Indeed, these models focus on land use and land prices, and in fact mostly assume unimodal transportation technology. This model assumes same housing characteristics and observes different modes of commuting. The assumptions are that "experienced" transport costs are more salient in everyday life, and that Ideal Commuters are somewhat location takers since all the best locations are already occupied.

[26] Residents of suburbs and countryside may have radically different preferences and income levels. Suburb lands can be considered a different good than urban land. (Remote) Suburb-dwellers working in suburbs are excluded. But (Close) commuters living in single house district within the city are.

Salience of Time

After energy, time is the most precious resource and increasingly so in a fast-paced environment. Behavioral studies have shown the central importance of commuting time in well-being. There seem to be a flawed *mental accounting*[27] in favor of systematically underestimation of the disutility of commuting, which is followed by inertia to rebalance this disutility. A rational Ideal Commuter in this context would know exactly her capacity of adaptation to commuting. This means comfort and commuting time could be more prevalent than in real life. For simplicity in this model, commuting costs or spatial frictions are entirely described in terms of time. Transportation expenditures regroup both monetary and time costs. Monetary costs are mostly fixed costs, for example a mass transit monthly pass or payments on car ownership. For the middle-class Ideal Commuter, time is the main variable portion of transportation costs. With different transportation technologies and infrastructures, time is not entirely proportional to distance. Commuters will consider *isochrones*[28], equi-temporal points of transport, and choose the commuting mode according the minimum time-cost principle.

History Dominates

There is a strong spatial hysteresis in the built environment of cities. Unlike the wooden farms prone to deterioration in von Thünen's Isolated State, nowadays constructions last centuries. Once built, buildings are seldom torn down in favor of new constructions without a significant change in businesses expectations or political decree. Over time specializations may shift, for example old manufactures can become schools or apartment blocks. In general there are hesitations in demolishing an existing and still useful structure, but reconversion is possible. In addition, many institutional barriers such as property rights, zoning, architectural regulations, and height restrictions are reinforcing the hysteresis. Past decisions are distorting the spatial equilibrium that would be achieved under present conditions without this locked-in pattern. Bergen is clearly a town where history dominates, but this would not be the case for Chinese cities under rapid transformations.

[27] Concept from behavioral economics: where different activities are evaluated in silo by categories instead of having a unified picture.

[28] Concept introduced by Tord Palander.

Path dependence is included in the model by fixing housing units in space. Once a location is chosen and a building is built it stays there. When a commuter relocates or sells her property, someone else moves in. Therefore, only new residential developments are shaping the city. A new development takes the characteristic density of the epoch it was built under the influence of the existing transportation infrastructure. Once all available land is used in an area, no new constructions can rise in this part of town. In reality, new units can be added, for example by creating a bachelor apartment in the basement of a single house family. The model assumes this effect to be negligible. A reasonable explanation is that households tend to be smaller than before, and therefore the renting of available space is somewhat preserving the original density.

4.3.2 The Model

A new commuter arrives to town. She evaluates the time it takes with all modes of transport to commute to her new job at the CBD. Like all Ideal Commuters she has a maximum time budget of 65 minutes. In addition, she cannot live in her office; therefore there is a mandatory minimum 1 minute of commuting. According to the principle of least commuting effort[29] (Zipf, 1949), she maximizes her utility by minimizing her commuting time (T):

$$\textbf{Max } U = \min(T) \quad \textbf{subject to } 1 < T < 65$$

4.3.3 Transport Mode Theory

In the model, in absence of density restrictions, all commuters would locate at the punctiform CBD (exactly one minute from it). A building height limit commands dispersion of the residences. New transportation capacities expand the range of feasible commuting time. And if space was a homogeneous *transport surface*, the Ideal Town would adopt the familiar monocentric shape:

[29] Adaptation of Zipf's Law

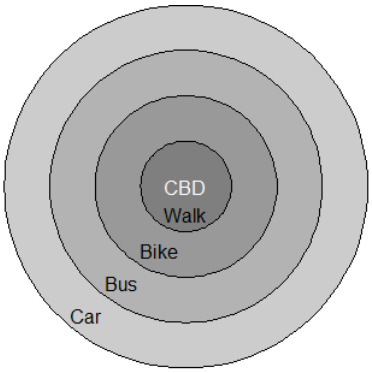


Figure 17 - Ideal Town in Homogeneous Space

The figure above is a simplified version of a commuting model. Each mode of commuting possesses a distinctive speed function. Therefore the range of the rings differs greatly. In addition, transport infrastructure modifies the shape of the "rings". For example a new light rail would be represented by a *transport line*, or each station could be seen as a *transport point* along this transport line.

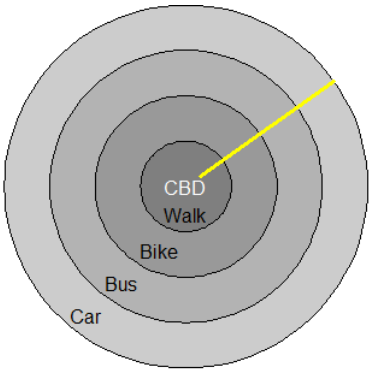


Figure 18 - The Ideal Town with a Light Rail Line

The shape of commuting zones will be determined by transport costs functions expressed in time. The walking zone would still be more or less circular as it is possible to walk from anywhere within a feasible range. Cars can also be driven from anywhere but their speed is influenced by the presence of highways. Therefore the automobile zone would not be completely circular. Collective transport is usually composed of primary and secondary lines. Primary lines have a higher frequency of service with perhaps express buses. This corridor is definitely faster.

Transport Time-Costs

All time-costs (T) are expressed in fraction of an hour. The distance (D) from CBD is in kilometers. For each transport mode the speed estimated according to the Bergen transport system during rush hours.

Walking speed is approximatively 5 kilometers per hour. Walking in the city is mostly fluid and large obstacles that force detours are ignored. Cycling is considered twice faster than walking in average and a time-cost is added for the preparation and locking of the bicycle.

$$Walk = D/5 \qquad Cycle = D/10 + 0.1$$

Buses on secondary lines have a moderate average speed (30 km/h) in residential districts and a frequency at each 15 minutes. Buses on express primary lines are slightly faster but are certainly more frequent, around 6 minutes. Light rail is considered equivalent[30] to express bus lines. In addition for the average waiting time (frequency) a walking distance (S) to the busstop or station is added.

$$Bus = D/30 + 0.25 + S/5 \qquad Light\ Rail = D/35 + 0.1 + S/5$$

Automobiles are the fastest vehicles but are slowed by many factors such as congestion, searching for parking, removing the snow, stoping at the gas station, etc.. All these time-costs are comprised into one fixed amount.

$$Car = D/60 + 0.5$$

These simplified functions are realist in proximity of the CBD. However in longer range (30km+) theses linear function are inadequate especially for automobiles which can drive faster in non congested zones. In this far range lay the suburbs which are outside the limits of the Ideal Town and the present inquiry.

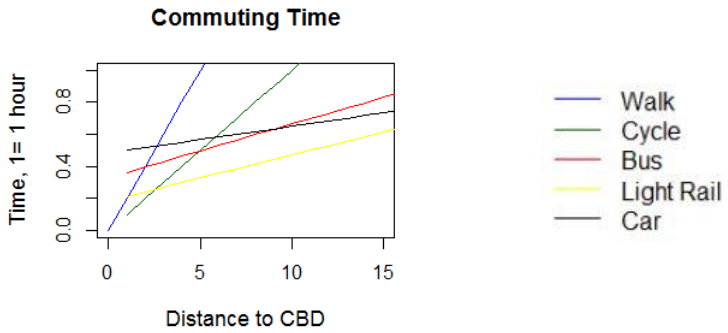
Congestion time losses are dependent of the numbers of vehicles but is considered fixed in the model. Therefore a dramatic change in traffic would modify the results. (Congestion experiences superlinear increase with population (Louf & Barthelemy, 2014)). However it is

[30] The average speed of Bybanen is around 30 km/h which is lower than express buses, but the potential of 35 km/h is within its capacities especially for the newer sections of the lines.

assumed population growth would not be sufficient to trigger substantial societal or structural shifts in comuting habits in the Ideal Town.

Simulation

The new commuter is (randomly) attributed a walking distance to the bus stop. In the case where it takes about 7 minutes to walk to the (regular) bus stop, she considers the commuting time at different distances from CBD:



These time-costs function determines the transport mode the commuter would choose at different distances from the CBD. Within 1 kilometer walking is the most reasonable option. At 1 km, the commuter would be indifferent between walking or cycling. From 1 km to 4km cycling would be faster than the secondary bus lines. Secondary bus lines prevail on cars until 8 km where the two modes are isochronal. Beyond 8 kilometers the car is the most efficient mode of transport. The maximum range (65 minutes) is reached at 35 kilometers.

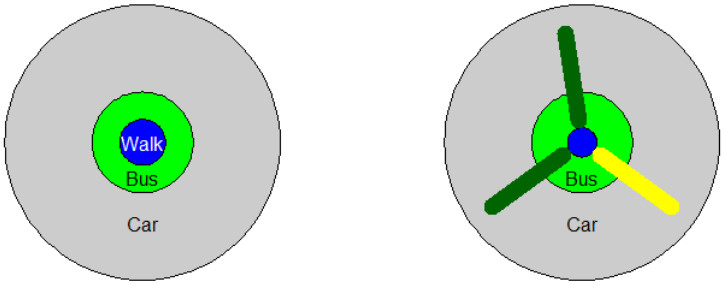
In the presence of a nearby express lines or light rail station, cycling is chosen only between 1 and 1,7 km. Above 2 kilometers the express buses and light rail are very attractive. Cars become dominant only after 50 kilometers which is beyond the allowed time budget and the limits of the Ideal Town. In a city where everybody lives within 7 minutes of an express bus or light rail line, there would be only pedestrians and express commuters. Cycling gains in popularity as increases the distance to the nearest bus stop, but in general it remains a marginal transport mode. Automobiles are not used in such a “linear city”. However, in the Ideal Town there are zones not well covered by collective transport, and the car becomes the favorite mode then. Due to its broad range, the car obtains a large share of the total commuting.

Distance (km)	Walk	Cycle	Bus	Car	Light Rail
0,0	0,00	0,10	0,36	0,50	0,21
0,5	0,10	0,15	0,38	0,51	0,23
1,0	0,20	0,20	0,40	0,52	0,24
1,5	0,30	0,25	0,41	0,53	0,26
2,0	0,40	0,30	0,43	0,53	0,27
2,5	0,50	0,35	0,45	0,54	0,29
3,0	0,60	0,40	0,46	0,55	0,30
3,5	0,70	0,45	0,48	0,56	0,31
4,0	0,80	0,50	0,50	0,57	0,33
4,5	0,90	0,55	0,51	0,58	0,34
5,0	1,00	0,60	0,53	0,58	0,36
5,5	1,10	0,65	0,55	0,59	0,37
6,0	1,20	0,70	0,56	0,60	0,39
6,5	1,30	0,75	0,58	0,61	0,40
7,0	1,40	0,80	0,60	0,62	0,41
7,5	1,50	0,85	0,61	0,63	0,43
8,0	1,60	0,90	0,63	0,63	0,44
8,5	1,70	0,95	0,65	0,64	0,46
9,0	1,80	1,00	0,66	0,65	0,47
9,5	1,90	1,05	0,68	0,66	0,49
10,0	2,00	1,10	0,70	0,67	0,50

Figure 19 - Commuting time in fraction of hour

The model is very sensible in regards of the distance to the bus stop. Above 2 kilometers or 24 minutes to an express bus stop, the car dominates most of the urban area outside the pedestrian center of the city. At 1 kilometer or 12 minutes to the stop, express buses will be prevalent until about 18 kilometers, and there would also be secondary bus lines. Access to collective transport within 5-10 minutes becomes a major factor of adoption. The collective transport frequency is also important but is fixed in the model according to observed average times (Skyss Timetables).

Another Geometry



In Bergen and in the Ideal Town, cycling is a very marginal commuting mode and therefore can be removed from the model. The diagrams above result from new simulation with the closest bus stop at 10 minutes. The automobile clearly dominates most of the areas. The walking zone now encompasses cycling, thus covering 30 minutes (on the left). However, in the presence of express lines (dark green) or light rail (yellow), the pedestrian zone is reduced to about 19 minutes or 1.6 kilometres of radius. Now that we have obtained an estimation of commuting patterns around the Ideal Town, we will look at the location and density of residential developments.

4.3.4 Intensity Theory or Residential Density

A new commuter arrives in town. She will locate as close as possible from the CBD and will take the first available land. The first movers will be located in the pedestrian zone, but passed a certain density, new zones must be populated. The dynamic growth of the Ideal Town will take a Weberian approach of successive layers of developments over different epochs: pedestrian, transit, and automobile eras.

Boroughs of Bergen in 2014

Figure 20- Map of the 8 Boroughs (bydel) of Bergen; source: Wikicommons

Borough (bydel)	***% of population***	***Density***
Arna	*5%*	*130/km^2*
Åsane	*14.8%*	*580/km^2*
Bergenhus	*14.9%*	*1,600/km^2*
Årstad	*14.7%*	*2,800/km^2*
Laksevåg	*14.6%*	*1,300/km^2*
Fyllingsdalen	*10.7%*	*1,600/km^2*
Ytrebygda	*9.9%*	*700/km^2*
Fana	*15%*	*270/km^2*

Figure 21 - Bergen boroughs' density (2014); source: SSB

The First Ring

The first ring is located in walking distance of the CBD. It is the historical district. Until the 19th century, compact **walking cities** allowed citizen to walk to any location in a reasonable time and they were about 5 kilometres across (Newman & Jennings, 2008). In Bergen this region would more or less be the borough of Bergenhus (Sandviken to Danmarks Plass). It takes about 25 minutes to walk from Danmarks Plass to Byparken. However the development of the edges of Bergenhus, for example in Sandviken, was done in the 20th century. Therefore, the density in Bergenhus[31] is a gradient from moderately high to medium. It is not very high even by Norwegian standards (see figure 16). Nevertheless, the Sentrum has the highest density in Bergen. Density can only be increased by reconversion of already occupied area; for example the current residential/commercial developments in Solheimsviken in the borough of Årstad (which used to be an industrial zone).

The Second Ring

In the second half of the 19th century, **transit cities** were following a (linear) development of medium density along transportation infrastructures such as railways and trams and could be 20 to 30 kilometres across (Newman & Jennings, 2008). In Bergen this zone was approximatively 10 kilometres; the distance by train from Nesttun to Sentrum. (Åsane Sentrum is also 10 kilometres North of Bergen but was not easily accessible before the automobiles.) The development followed the railway in the boroughs of Årstad and Fana, and therefore this southern axe became a major residential area. Both Fana and Årstad count nearly as much as citizens as Bergenhus (40 000). By Bergen's standards, Årstad is dense. The second ring is best described as a southern linear axis, along a 2 kilometres-wide valley with mountains on each side.

The Motorized Rings

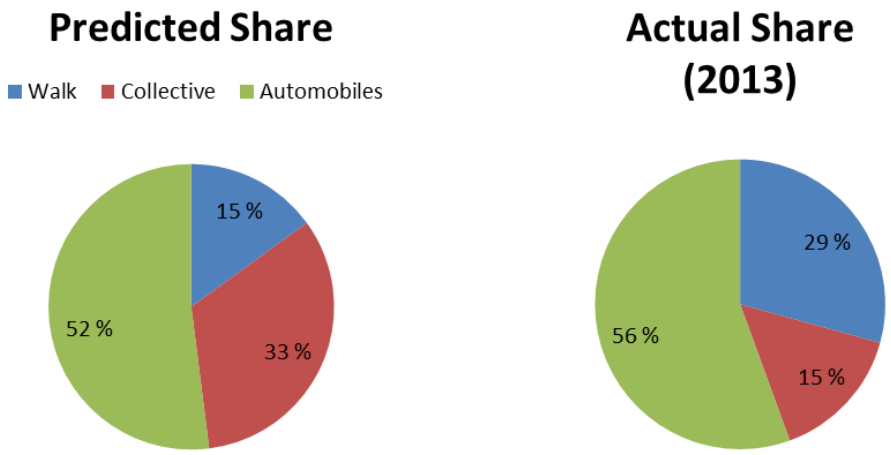
Automobiles cities are the hallmark of the second half of the 20th century. Distances can be more than 50 kilometres in such cities which are characterized by low density and by the shrinking of public realm (Newman & Jennings, 2008). Milde, Knarvik, and Sotra are more than 20 kilometres from Bergen Sentrum. Daily commuting from these areas was rendered possible with the construction of roads, bridges and tunnels. The topography of Western

[31] Bergenhus include less densely populated suburbs like Lønborg making its total density 1,600/km^2 lower than the borough of Årstad at 2.800/km^2. Iniside Bergenhus other districts like Sandviken achieve 3.680/km^2.

Norway with the mountains and the islands constrains the sprawl. The presence of many bottlenecks has facilitated the emergence of a strong bus system along the main corridors. Nevertheless, automobile is the dominant mode of transport in this sparsely populated zone. Between 45 to 50% of Bergen's residents live in this ring.

Predictions vs Reality

The Weberian approach correctly describes the repartition of the population today. In 1855, Bergen had 37,015 inhabitants, which is about the population of the Sentrum in 2014, this is the pedestrian zone in the model. In 1920, at the height of the public transit era, Bergen had 129,118 citizens which included the recently merged borough of Årstad. The model predicts about 90.000 commuters in the collective transport ring. During the automobile era, other boroughs were merged and Bergen went from 162,381 in 1950 to 229,066 in 2000 to reach about 275,000 today. (SSB, 2015)



Based only on residential locations, the density theory predicts the following commuting patterns: 15% walking, 33% mass transit, 52% automobiles. It largely underestimates the 26% of pedestrians (29% of active commuting including cycling). Therefore, either people walk longer than assumed or either they don't commute to the CBD. Since we know not all employments are located at the CBD, it seems that between 1/4 and 1/3 of commuters choose to live in walking distance from their workplace. This seems to endorse the assumption about the predominance of commuting mode over residential location. But why so few actually choose collective transport? The answer lies in the unification of the density and transport mode theories.

4.3.5 Unification of the two theories

The density theory with a Weberian approach considers that all the citizens of the second ring will choose collective transport. The transport mode theory stipulates that only commuters within a reasonable time range to reach a bus stop with frequent departures will do so. As we have seen the model is very sensitive to time it takes to reach a bus stop with frequent departures. Therefore only a fraction of the commuters living in the second ring will adopt collective transport. This fraction will be largely influenced by the spatial distribution of residences.

New residents establish themselves on available lands, as close as possible from the CBD. New transport technologies are expanding the feasible range of commuting. New developments take the characteristic density of the epoch it was built, which is tributary to the spatial equilibrium at that time. As a result the inner circles and especially the second ring risk of not being sufficiently dense for the future size of the city. More importantly the areas **along** the collective transport infrastructures will be generally built first. If this is true, the density along the transportation axis will be too low. This could explain why only a fraction of the second ring uses collective transport.

Focus on the 2nd Ring

The first ring has a limited potential of densification. There are not many vacant lands or wasted areas in the first ring. The third motorized ring is geographically dispersed. The creation of express bus stations with adjunct parking lots is one potential option to reduce the use of automobiles. However even express routes are unlikely to be faster if calculated door-to-door: the commuter must drive first to the station, and then wait for a bus with an inflexible schedule compared to the car. Perhaps in the presence of road congestion, reserved lines for express buses could make this option attractive from a time point of view. Spatially these reserved lines are likely to be located on the highways in the second ring.

The second ring has a very strategic location in the urban system. The fluidity of the transport system depends on the spatial organization of that zone and the bottlenecks it create. In addition, the second ring has the most potential for residential densification and for the increase in commuting by collective transport. The model strongly suggests that inhabitants of the second ring in Bergen rely too heavily on automobiles. What can be done about it?

4.3.6 Shaping the City

Express bus lines and light rail have been treated has equivalent so far. In terms of speed, this is a valid estimation in the medium range. In the long range, because it must stop at every station, the light rail could be slower than a true express bus from the same location. This is in fact one of the actual critic of the Bybanen, the light rail in Bergen. Even if the speed is increased in the remote sections, the light rail will remain slower. Therefore, light rail is not a good option in the third motorized ring. Express buses and even trains with longer distance between stations are better suited for longer commutes from the suburbs. They are also central to the creation of secondary business districts which are part of the answer to reduce energy consumption and GHG emissions. Each mode of transport has its strength and weaknesses; the light rail performs well in the second ring.

Flexibility is the main difference between buses and light rail. A bus system is flexible and adapts incrementally to the demand of commuting. Routes and schedules can be instantly adjusted. Learning is iterative with trials and errors of new routes at minimal cost. Light rail is the entire opposite; long, careful and costly planning must be done prior to its construction and after the route is fixed. This inflexibility can be turned into an advantage: while bus systems are gradually adapted to the city, the city adapts itself to light rails.

Proposition 1: Bybanen creates density

The existence of a Bybanen station is an extremely credible commitment in the long run. In game theory, the existence of a credible treat or alternative option is one important element shaping the decisions of agents. The treat of cancelling the route or severely reducing the frequency exists for a bus line but not for a light rail. The light rail will always behave like the express route in the model. The light rail creates a permanent corridor of lower transportation frictions to the CBD.

This is a permanent improvement of the soil in von Thünen's words. Therefore, it increases the value of land rent along the light rail route. It also increases the locational rent since it is perceived from a time perspective as closer to the CBD. These increases in land rent command more dense and high constructions to recover from the cost of buying the land. Conveniently there will be a higher demand of housing at that location. Commuters will suddenly see this strategic location as highly attractive. Therefore it also creates an intensity or density rent. Choosing a dense mode of construction is feasible and profitable while it was

not before the light rail. **All three aspects of von Thünian rents are greatly influenced by the proximity of a Bybanen station.** In addition, we could expect a circular cumulative causation à la Myrdal that would reinforce the agglomerative effect and the locational rent, for example with the establishment of services and retailers like grocery stores. After the Bybanen reached Nesstun, new high appartments blocks were built and new retailers including a large grocery store settled there.

Proposition 2: Bybanen is a potent shaper of the city

In essence, the light rail can extend the core into the second ring. Areas in walking distance of a Bybanen station can adopt characteristics of the first ring, for instance higher density as we have seen. However, this transformation can only occur under specific circumstances.

Strong population growth is required. In the model, households are immobile and only new citizens will occupy new residences. In real life, existing housing units seldom remain vacant if the owners move near the Bybanen. So in general, new spaces will be occupied only if there is a growth in the number of households.

Available lands along the light rail route are a critical constraint. As it was mentioned earlier this area is probably already occupied with low density residential area. Households are immobile in the model, but are in reality quasi-immobile. Only in the very long run that existent buildings will be demolished. According to von Thünen this transformation will eventually occur, but remains nevertheless a slow adjustment to market conditions. Therefore, spontaneous order can arise more easily if they are lands readily available.

The municipality must have a coherent zoning with the new infrastructure. In the model, zoning is understood as implicitly coherent with spatial structure. In reality, any Löschian distortions such as restrictive regulations and zoning may be a hindrance to the spatial equilibrium and market outcome.

In addition to the space and the freedom to realize its potential, the Bybanen must influence expectations about the future. Paul Krugman has shown the difficulty of expectations to outweigh historical configurations. During the planning process, the project must reach a certain public acceptation before it is authorized. In essence, this constitutes a discussion about the future structure of the city which fosters the awareness about the project. Once it

has received the stamp of approval and the political commitment, the Bybanen should in theory benefit from a strong momentum.

Even with all the conditions reunited like in the model, the Bybanen will struggle to achieve its full potential in reshaping within second ring of the city. Spatial hysteresis is extremely strong, but the light rail is probably the best game changer in a decentralized[32] spatial economy.

Proposition 3-A: Bybanen can foster Secondary Business Districts (SBD)

The role of the Bybanen is to increase mobility and it does so bi-directionally. Adding a new center of employment in the model radically changed the shape of the city. The CBD is linked to an SBD by the light rail. In between there is a long linear second ring where collective transport dominates. As the commuting time becomes too long to reach the CBD, the SBD becomes an alternative employment center. Therefore, a "slow" Bybanen over the long range fosters the emergence of SBDs. Following the least commuting principle, a share of commuters from the second ring will instead travel to this newly accessible SBD. The city becomes polycentric.

Surprisingly the Bybanen also plays a role in the third motorized ring. An existing SBD will greatly benefit from a connection with such a dedicated infrastructure. Expectations about the commercial and residential potential of the SBD are magnified. Density is likely to be created in proximity of the SBD. The third ring is suddenly partially densified. There are possibly more available lands in this region of the city to allow some of the densification process to happen. Most importantly it reduces the commuting time and distance from the motorized ring. With more employments in the SBD, some car commuters will be redirected to the SBD.

Proposition 3-B: Bybanen creates Tertiary Business Districts (TBD)

The core-periphery NEG theory describes polycentric cities and regions with a CBD surrounded by one or several smaller SBD. The NEG theorists have not divided the different sizes and influences the SBDs can take in more Christaller-like hierarchical levels (Gaigné et al., 2013). A tertiary business district (TBD) would be much less important as a pole of

[32] A planner in centralized economy can expropriate the entire second ring to quickly build new dense residential areas.

employment and almost invisible in the structure of the city compared to a SBD. Clear commuting rings are organized around a SBD. TBDs are dispersed over the entire city, with many of them between the CBD and SBD. Aggregated together all the TBDs represent a significant share of employments. This could explain for example, why pedestrians occupy such a large share in the actual commuting in Bergen. Each station of the Bybanen can create a small commercial area reducing both some commuting and total travels. These shops obtain the market share of residents in proximity as described by Hotelling.[33] TBDs are an important component of the urban system, and light rails encourage their development along their axis.

Proposition 4: Bybanen can mitigate GHG

The growth of SBDs and TBDs has the potential to reduce the distances of commuting and other category of travels (shopping) within the city. Firms would be attracted to SBDs if there is an easy access both in transportation and communication with the CBD (Gaigné et al., 2013). Light rail complements highways in this regards. Both potential consumers and employees have an easier access to the SBDs connected to light rail. Occasional face-to-face communications such as a business meeting is also facilitated by the presence of a direct link to the CBD. This modification in transportation frictions lead to spatial substitutions à la Predöhl. Even if the model does not allow firms to relocate, new firms will establish themselves around the SBDs. In this zone, the third ring, which is dominated by automobiles suddenly a larger share of commuting will be done either by walking or by using collective transport. Also, commuting by cars is likely to be shortened compared to trips to CBD.

If we accept that the Bybanen alleviates some of the commuting time and distances both for its users and for other mode of transportation, the result could be a decrease in the overall energy use of the city and therefore in GHG emissions. This result is valid unless the SBDs trigger an increased reliance on the automobiles (Gaigné et al., 2012) (Louf & Barthelemy, 2014). The Bybanen is a powerful symbol of green commuting, it has the potential to transform the city both physically and psychologically, and therefore modify the expectations and attitudes towards mobility. Consequently, the Bybanen has the potential to significantly abate actual and future GHG emissions.

[33] Hotelling describes competition in the small spatial scale, while Krugman monopolistic competition focuses on global scale.

4.4 Evidences in Bergen

Bergen has experienced a steady growth in the last decades (about 1,3% per year) even leading to a shortage of residential units or "housing crisis". Statistics Norway expects this growth to continue and Bergen would reach 300,000 citizens by 2025 (SSB, 2015). Demand for housing close to the Sentrum is high but the area is built at almost full capacity according to the current regulations. One strategy adopted by the municipality was to plan for densification along the Bybanen route (Iversen, 2008), among other things with residential zoning (Bergen_Kommune, 2014). Densification is a national and municipal priority (Government.no, 2011).

Bergen is reported to densify (Haagensen, 2015). Observations indicate many new constructions sites are located along the Bybanen route, especially near stations of the first phase completed in 2010 which spans from Byparken to Nesttun. New residential developments are particularly noticeable around Slettebakken and Nesttun. In addition, other station such as Danmarks Plass, Brann Stadion and Fantoft have experienced construction of commercial or educational buildings. Construction has started mostly after the arrival of the Bybanen. The second phase of the project from Nesttun to Lagunen has been completed more recently (2013); so far not many dense residential developments have been done in that section. Some major new developments are visible from Lagunen but are hardly in short walking distance of the Bybanen. The dynamic of the first section suggests it can take some time before new project are launched. However, the more plausible explanation is the lack of available lands. Slettebakken and Nesttun had readily available space for development, in Fantoft a parking lot is being replaced by a commercial building. Along the second section of the Bybanen, there is hardly any vacant land. The population density in that area is low and has characteristics of the suburbs of the motorized ring. Individual detached houses are neighboring the Bybanen route. While the properties values have increased (Fredriksen, 2013), it does not seem that reconversion into apartment blocks is planned. This area is likely to remain not sufficiently dense.

Lagunen which is the terminal station (until phase 3 is realized) was already a commercial pole. The shopping mall has become much more accessible from the city center with the annexation of the Bybanen. Lagunen is both a commercial and transportation hub. It subscribes to the broad definition of a SBD but many (back-office) employers are located between Lagunen and Flesland which will be connected with the third phase of the Bybanen.

Therefore the SBD is more diffuse than punctiforme. A similar description can be applied to the SBD of Åsane, an important commercial and residential borough to the north of Bergen. A future line of the Bybanen is planned to reach Åsane. These two SBDs are likely to gain relative importance in the Bergen urban system, and the Bybanen will accentuate this phenomenon. It is not completely clear if this will result in lower commuting by automobiles or accentuates it because of urban sprawl. However, Bergen has seen both a decrease in car ownership and an increase in the share of public transportation after the completion of the first phase of the Bybanen (Haagensen, 2015). The increase in collective transport in the second ring is lower than the model has predicted. How this transformation will occur in the third motorized ring remains to been seen, but we can expect an ambiguous response.

TBDs have flourished at most stations along the first section of the Bybanen. The best example is Nesttun which had already an active commercial area but that was largely vitalized and reinforced with the arrival of the Bybanen. In the model, Nesttun is located in the 2nd ring (it was also accessible by regular trains before the tunnel to Arna). At 25 minutes from Byparken, Nesttun is isochronically located as some remote pedestrian areas of Sentrum, for instance Fjellsiden Sør. A commuter only considering time-costs would be indifferent between these two locations. Further than Nesttun begins gradually the third ring and the area of influence of the SBD of Lagunen. The Bybanen is an important motor of economic activity in the zones between the CBD and the SBD.

Key Findings

Bybanen is not made to be the fastest link from the 3rd ring to the CBD. The slow speed of the Bybanen is one of its major critics. However, the model clearly shows that the role of the Bybanen in the third ring is to foster the SBD not the CBD. Like predicted by NEG models, it is precisely because of its slow speed that this dispersion effect arises.

Bybanen differs from express bus lines because the seriousness of its commitment (read substantial investments) has more potential to shift the expectations about the future. Light rails are making a permanent improvement in the time-cost of commuters, whereas bus lines and schedules can be modified. A bus system adapts to the evolving structure of the city while the light rail can also shape the city. Light rails seem also to be perceived differently than buses (greener, more comfortable, faster, etc.). While certainly quite frequent, Bybanen is not faster than buses. Being perceived as faster than the bus can bolster certain adoption of the Bybanen but is very unlikely to promote this mode towards automobile commuters.

The actual share of collective transport is lower than the model predicts. Since, car ownership is a major deterrent to other forms of commuting, efforts to promote collective transport should be targeted towards new dense residential areas that are made possible by the Bybanen.

Bergen does not have all the conditions under which the full potential of the Bybanen can be fulfilled. The von Thunian Ideal is the highest and best use (HBU) of land as though vacant (Wolverton, 2004). The main limitation is the lack of available lands along its route especially in the second section. In the ideal scenario, all stations would be surrounded by high and dense residential buildings with commerce at ground level to become at least a TBD. Some dense residential projects were undertaken where land was available. Future routes and lines of the Bybanen should go through a mixture of undeveloped areas and existing commercial centers (TBDs).

The extension of the Bybanen lines to Flesplassen, Fyllingsdalen and Åsane will foster the polycentricity of Bergen. The share of commuting by car will remain high but perhaps travel time and distances might be reduced.

4.4.2 Framtidens byer – Cities of the Future

"Because there is no optimum city shape per se, a city shape can be "improved" only in relations to priority objectives. Priorities, however, may change with time, while cities shapes are very resilient." –Alain Bertaud

Multiple spatial equilibriums are feasible in urban systems; what discriminate between them can be tiny variations that are self-reinforcing. New spatial configuration can be also be induced by a central planning authority. The Bybanen in Bergen is an example of urban planning that will transform a city where history has dominated the development. Uncertainty is inherent in urban sprawl, but there are predictable traits shared by commuters that can describe how this new infrastructure can influence the structure of the city. A special attention to commuter's behavior and future needs should be at the center of urban planning, because today's decisions and priorities influence the future shape of city (Bertaud, 2004). Von Thünen was in favor of public intervention for railway and highway construction because encouraging mobility is an everlasting priority. He also condemned distortions that prevent the best use of land. Our Thünian model of commuting time-minimization showed that Bergen could improve in this objective.

5. Conclusion

Before the First Industrial Revolution, traditions had a prevailing influence on the economic organization of society. The quest of Johannes Heinrich von Thünen was to break free of past traditions, and find new principles to improve society through rationality and experimentation. His key insight was the central influence of transportation costs in relation to land use. As a practical estate manager, he fully understood the potential of market forces guiding a better rational allocation of land towards its highest and best use. Unfortunately, there are many distortions preventing the best use of land under existing conditions, and previous historical developments are a prime resistance to change. Unlike many of his contemporaneous (the Historicist school), von Thünen was optimist that "natural" principles could help to overcome the dictate of history.

Spatial hysteresis is a strong phenomenon shaping urban areas. Even the initial establishment of a city is often the result of historical "accidents". The initial existence of a market centre or infrastructures will act as an attraction force which is self-reinforcing. Events and developments of each epoch will influence the successive ones. The structure of the city is the result of its history. Paul Krugman stated that history usually dominates expectations in shaping the spatial economy; this is particularly true in urban areas where there are substantial adjustments costs.

Changes in transportation costs will modify the spatial organization of the economy. Such is the claim of von Thünen and his successors in the various branches of spatial economics, who analysed spatial frictions in diverse forms at different scales of observation (local, regional and international). Urban studies both in sociology and in economics were greatly and directly inspired by von Thünen's concentric model. Commuting is phenomenon that can still be explained by a monocentric model while most of the economic activities are nowadays globalised. Dramatic reductions in transportation costs have been seen as evidence of the "death of distance" which is perhaps true for commodities (between cities) but not for people. Moreover, commuting frictions play an increasing role in shaping the global spatial economy because transportation costs within the cities are determinant of a city's structure and therefore of its specialization, which ultimately determine its relative hierarchy in the world's economy network.

The structure of urban systems has also a large and direct influence on energy use and emission of pollution; the main challenges in the 21st century. According to the United Nations, 60% of the world's population will live in cities by 2030, which translates by the addition of 1.4 billion more urban dwellers. Mobility and density are crucial spatial aspects that must be scrutinized and improved over the next decades.

Urbanization is not only occurring in developing nations but also in wealthier regions, because contrary to the previous negative views about urban areas, cities are attractive to humans. Edward Glaser has called urban economists to inquire about non-market interactions that the driving forces behind cities. Transportation and behavioural researches have revealed the salience of time in choosing a mode of transport for commuting, and its growing importance as a society becomes richer.

At the dawn of what could be the Third Industrial Revolution (Rifkin, 2011), von Thünen remains a prodigious source of inspiration. His methods are adaptable to various scales and contexts of spatial analysis. As Fujita asserted, von Thünen's theories are novel even today. A careful reading of his magnum opus, *The Isolated State*, has brought to light surprising elements such as the concept of Thünian Land Rent which greatly differs from the Ricardian Rent that was adopted by the economics corpus. The legacy of von Thünen is an impetus to affranchise from traditions and historical configurations by understanding and improving the spatial organization of society. A von Thünian approach is particularly apt to describe mobility patterns and recommend a new equilibrium for historical cities.

The spatial model presented in this thesis explained the existing structure of Bergen and proposed how the city might evolve with the development of the light rails network (Bybanen). Many researches and policies were aimed at discouraging the use of cars. The approach taken here is was not to force conversion from present automobiles drivers into collective transport users, but to make sure **new commuters** will predominately choose more sustainable modes of transport in the future. The key aspect is the appropriate location of new dense residential developments. Monocentric "compactness" does not necessarily result in a higher energy efficient city; it was shown that polycentricity with secondary cores (SBD) could also improve efficiency by reducing commuting time and distances. The finding concurs with many researches in favor of "*Decentralised Concentration*" as the more sustainable urban form (Holden, 2007). Considering that further densification of Bergen Sentrum is not a feasible political/physical option, we showed how densification would

occur along the Bybanen route. It was demonstrated that the Bybanen creates a corridor of lands isochronally equivalent to the Sentrum. Following the least commuting principle, new commuters would choose this mode of transport from these locations. Spatial distortions such as a lack of available lands were identified as a critical barrier that Bergen must address for its future Bybanen routes. Light rails (Bybanen) are regarded has having more potential to overcome historical spatial configurations than the bus system. As strong sustainable symbol and a profound political and financial commitment, the Bybanen can transform expectations and attitudes. Ultimately the Bybanen will reshape the city and has the potential to reduce GHG emissions as well as increase the societal welfare through (green) mobility.

Demand for mobility will remain high, but possibly the nature of this demand will evolve. "*Generation Y, the so-called millennials now in their 20s and early 30s who have come of age in the digital era, seem less wedded to possessions than their baby boomer predecessors. Surveys show that the one object that is prized is the smartphone, and the future of transport is likely to be based not on individually owned cars but on "mobility as a service.*" (Moss, 2015). This generation is the first to acquire less driving licenses than the precedent one (Thompson & Weissmann, 2012). It constitutes probably a major shift from the desire of suburban ownership lifestyle to a more densely urbanized fast-paced living (Newman & Jennings, 2008) (Rifkin, 2000).

The emergence of a sharing economy has the potential to redefine transportation habits. Car sharing networks are being established in many regions, and allow using a car for less frequent travels than commuting. Other initiatives such as Uber are competing with taxi oligopolies. Carpooling is encouraged and becoming more popular. Capacity utilization of vehicles is a key factor to reduce CO2 per passenger kilometer (Eskeland & Lindstad, 2015).

Commuting is also redefined by mobile technologies in altering the perceived time and disutility of mobility. Mobile phones can now display collective transport schedules adapted in real time with GPS coordinates. The outcome is a reduced waiting time: making more attractive even less frequent secondary bus lines. In addition, mobile technologies allow a different use of in-vehicle time by allowing work or educational and leisure activities. In sum, commuting could be perceived as less of a burden; perhaps stimulating the use of collective transport, but also inciting travels from farther afield (TheEconomist, 2014).

Shape and sizes of the rings evolve with society but the core theory persists. Light rails such as the Bybanen are permanent improvements in urban mobility and have a great potential in reshaping the structure and the history of 21st century cities.

6. Appendices

6.1.1 Appendix I - Full Titles

The Isolated State in its Relation to Agriculture and National Economy

Part I: The Effect of Grain Prices, Fertility and Taxation on Agriculture (1826)

Part II: The Natural Wage and Its Relation to the Rate of Interest and To Land Rent (1850 & 1863)

Part III: Principles for the Determination of Rent, the Most Advantageous Rotation Period and the Value of Stands of Varying Age in Pinewoods (1863)

German Original Titles:

Der isolierte Staat in Beziehung auf Landwirthschaft und Nationalokonomie.

Volume 1: *Untersuchungen iiber den Ein-fluss, den die Getreidepreise, der Reichtum des Bodens und die Abgaben auf den Ackerbau ausüben* (1826).

Volume 2: Der *naturgemasse Arbeitslohn und dessen Verhdltnis zum Zinsfuss und zur Landrente* (1850 & 1863).

Volume 3: *Grundsdtze zur Bestimmung der Bodenrente, der vorteilhaftesten Umtriebszeit und des Wertes der Holzbestdnde von verschiedenem Alter fiir Kieferwaldungen* (1863).

6.1.2 Appendix II – Von Thünen's Publications and Translations

Year	City	Parts/Editions	Content
1826	Hamburg	Part I	Agricultural Intensity, location of agricultural systems and crop zones
1842	Rostock	Part I, Second Edition	Improved and Extended Edition
1850	Rostock	Part II, Section 1	Wage theory
1850	Death of von Thünen		
1863	Rostock	Part II, Section 2	Taxation, customs duties, settlement policies, the consequences of improved roads and railways
1863	Rostock	Part III	Collection of papers on forestry
1875	Berlin	Complete Work	The only existing edition regrouping all parts

Source: Hall, P. 1996, *Von Thünen's Isolated State*

English Translations

Year	Author/Editor	Parts/Editions	Title
1960	Bernard Dempsey	Part II, Section 1	*The Wage Frontier*
1966	Peter Hall	Part I; Extracts from Part II, sections 1 and 2	*Von Thünen's Isolated State*
2009	Ulrich van Suntum	Part III	Isolated State Part III: Rotations of Pinewoods

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