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ON THE CAUSES AND EFFECTS OF SPECIALIZATION

A MATHEMATICAL APPROACH

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On the Causes and Effects of Specialization
A Mathematical Treatment

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Sammanfattning

Fördelning av arbetsuppgifter och kunskap är något så viktigt i dagens samhälle att det nästan är omöjligt att föreställa sig hur samhället skulle kunna se ut annars. Man kan också genom enkla observationer se att arbetsdelningen verkar fortsätta öka inom många områden. Ett exempel är matindustrin där halvfabrikat blir mer och mer vanligt och både färdigskivad ost och färdigskivat bröd har börjat dyka upp i matbutikerna de senaste åren. Antalet personer som är inblandade i att se till att det finns bröd att köpa i butiken är enormt. Man måste odla säd, tillverka jäst och utvinna salt och sedan ska det fraktas, bakas och fraktas igen. Vart och ett av dessa moment är uppdelat i flera delmoment, som i sin tur utförs av olika personer. I tillverkningen och transporten används också ett stort antal maskiner, vilket i förlängningen innebär att ännu fler personer blir inblandade i att tillverka och underhålla dessa maskiner.

Att arbetsdelning är väldigt viktigt för ekonomin har man vetat om länge: arbetsdelning tog upp en stor del av Adam Smiths klassiska verk *The Wealth of Nations*, som kom ut 1776. Ekonomer har sedan dess studerat relationen mellan marknaden, transaktionskostnader och arbetsdelning samt hur arbetsdelning ökar produktionseffektiviteten. Ett aktuellt exempel på hur transaktionskostnaderna påverkar arbetsdelningen i Sverige är skattereduktionen för hushållsnära tjänster. Den gör att transaktionskostnaden för dessa tjänster minskar och därmed ökar arbetsdelningen, det vill säga färre personer städar själva.

Kulturell evolution är ett forskningsområde som studerar hur samhällen och idéer föds, sprids och dör, ofta genom att använda sig av matematiska modeller. Man tar dock ytterst sällan tar hänsyn till hur denna utveckling påverkas av arbetsdelning och fördelning av kunskap. Jag vill med denna avhandling visa att dessa faktorer är av stor vikt för kulturell evolution.

Avhandlingen består av tre delar. Först kommer en introduktion till de matematiska modeller som ekonomer normalt använder för att studera relationen mellan marknad och arbetsdelning. Sedan kommer en omfattande litteraturöversikt av den forskning som har gjorts om arbetsdelning i ekonomi,

historia, sociologi och många andra ämnen. Denna översikt fokuserar på att ta ut de delar av denna forskning som är mest intressanta för dem som studerar kulturell evolution. Man kan se den som både ett argument för varför man måste ta hänsyn till arbetsdelning när man studerar kulturell evolution och som en introduktion till vad som har gjorts. Den sista delen studerar hur specialisering, i det här fallet utbildning, kan leda till social stratifiering, det vill säga löneskillnader, i ett samhälle. Det är både en teoretisk och en empirisk studie, där en matematisk modell tas fram och sedan testas mot statistik från ett antal olika länder och visar sig förklara skillnaderna väl.

Abstract

Division of labor and division of knowledge are so important and common in society today that it is almost impossible to imagine a society where everyone knows the same things and perform the same tasks. This would be a society where everyone grows, or gathers, and prepares their own food, makes their own tools, builds their own house, and so on.

Cultural evolution is the field of research that studies the creation and diffusion of ideas and societies. It is very uncommon for these studies to take into account the effects of specialization. This thesis will show that specialization is of great importance to cultural evolution.

The thesis is divided into three parts: one introduction and two papers. The introduction covers the mathematical models used by economists to study the relation between the market and division of labor. The first paper is an interdisciplinary survey of the research on division of labor and specialization, including both theoretic and empirical studies. The second paper is a mathematical model of how specialization of knowledge (i.e. higher education) leads to social stratification. The model is tested against statistical data from several countries and found to be a good predictor of the differences in income between people of high and low education.

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Table of Contents

Chapter 1

Introduction

The human capacity for culture allows us to divide tasks between individuals and specialize to an extent unlike any other species. Division of labor often greatly increase productivity, opening up for the possibility of doing other things than collecting food, such as exploring the world we live in. Adapting to local conditions, i.e. specializing, helped us inhabit just about every place on earth.

1.1 Background

In most theoretic work, division of labor is assumed to have appeared because of the benefits associated with it. Most importantly it opens up the possibility for specialization in tasks that are not directly associated with food gathering, which allows us to make use of comparative advantages. If one person is better at making arrowheads than hunting and another person is better at hunting, they can specialize, so that they both make the best use of their skills. Specialization makes sure we can utilize individual differences, both genetic and learned skills. Someone who makes arrows to trade for food does not have to learn advanced hunting skills; he can spend more time learning how to perfect his arrowheads instead. When he spends a lot of time making arrows he will become even more proficient and maybe even invent new tools or techniques to produce them faster.

While everyone is better off because of the increased production in this example, there is also an inherent risk with specializing and especially with dividing knowledge between individuals. The arrowmaker does not know how to hunt, at least not very efficiently. If the hunter were to die unexpectedly, not only would his knowledge be lost, the arrowmaker would not be able to trade his arrows for food, so he is dependent on another individual for

his survival. This increased risk can be avoided by increasing the size of the market, having several hunters and arrowmakers. A market with several specialists of the same kind opens up for competition: the best arrowmaker will likely be able to charge more for his services. There is now an even bigger incentive to make better arrows. The larger market also makes it possible to have a wider range of goods: when the demand is high enough, merchants will be able to travel farther to acquire products not available locally.

That some goods are imported means that individuals within the society are somewhat dependent on strangers, even people that they have never met. The trade network has extended way beyond what could be achieved by just a few individuals. This does not only lead to an increased risk, but also prevents some other risks. A local drought will not be quite as severe when some food can be obtained by trading with other societies that have not been affected, or have other ways of gathering food.

When the efficiency in food gathering goes up there are more time for other pursuits, such as technological development and educating the population. Teachers help preserve and distribute knowledge efficiently in the society. As technology advances, even more occupations are introduced, since much technology requires learning and it is no longer necessary for everyone to have all knowledge available in the society.

1.2 Integrating Data and Theory

The description above of the evolution of specialization is based largely on theoretic studies. How does this relate to what has been found in empirical studies? Only by testing the predictions of theoretical models against actual data can we verify that they are correct. This is unfortunately not that common. In the study of specialization, much theory is put forward by economists and sociologists, while the empirical studies are done by anthropologists, historians and archaeologists. This results in a dichotomy between theory and data. Bringing theory and data together is the aim of Paper I, where, together with Anna-Carin Stymne, I provide an extensive interdisciplinary survey of both theoretic and empirical work on division of labor and specialization.

Paper II is also a good example of how theory and statistical data can be integrated. The model is based upon real world observations and the predictions are tested with statistical data and found to fit very well.

1.3 Mathematical Analysis

The study of division of labor and specialization is an area which lends itself well to mathematical analysis. The interconnection between specialization and most areas in society is so complex that it is very hard to get an overview. A formal method of reasoning that can show exactly what result a specific set of assumptions lead to, and at the same time requires all the assumptions to be made explicit, is a great help. Mathematical modeling also allows us to focus on just one part of the whole system, ignoring others, to see exactly how this particular part influences the whole. This is done in Paper II: "Why Social Stratification is to be Expected", where social stratification is explained, just using education and temporal discounting, ignoring things such as individual differences.

As specialization is greatly influenced by the market, this is also a field of interest to economists, who have a long tradition of using mathematical modeling. The next chapter will give an introduction to the models used by economists to study the relationship between specialization and the market.

Chapter 2

Basic Model for Division of Labor

This chapter will present a model for when specialization can occur in a population, it can be seen as a supplement to Paper I, which is written for an audience which is not necessarily familiar with mathematical models. The model presented here has been developed for this thesis in order to have a consistent notation and a basic model to work with across the different situations, but it is very similar to many of the models available in the literature. See Becker (1981); Rosen (1983); Yang and Borland (1991) for examples of models, or Yang and Ng (1998) for a more comprehensive review.

We will begin by looking at a very basic situation where there is no available market and agents in the population simply find a trading partners at random. The model will then be extended to include a market.

2.1 Model

The model used throughout this chapter will have two different fields which one can have a proficiency in exploiting to receive some kind of resource. The fields are called A and B.

- *Strategy*: A strategy is a choice of what effort to make into developing one's skill in each field. This results in an ability profile. Simplest case is that effort always gives an ability profile (a_A, a_B) where abilities sum to 1.

- *Productivity*: From the ability profile, a productivity profile $P_x = (p_A, p_B)$ for agent x is determined. This is the amount that is actually produced by the agent in each time step. Simplest case is $p_y = a_y$.

- *Exchange*: If someone has a lot of A and someone else has a lot of B they will prefer to make an exchange (if they are able to find each other). The exchange rate may be something they negotiate, or it may be determined in a market. A final possession profile $P'_x = (p'_A, p'_B) = (p_A - t, p_B + rt)$ is computed, where t is the amount of the A goods that is transfered from this agent to others (possibly negative) and r is the exchange rate which, together with t gives the amount of resources that is received from the trade.

- *Payoff*: From the possession profile a payoff or fitness, w, is computed. Simplest case is $w = p'_A \cdot p'_B$.

2.2 Specialization with Random Trading Partners

When everyone produce the same goods, so that there is no division of labor, there is no reason for trade. It seems highly unlikely that humans have ever been in this situation, since at least some kind of exchange or sharing exists in many other species. Still, when trade is uncommon, there will not be any markets, so a situation where finding trading partners is hard might be a good place to start modeling the origin of specialization.

Assume we have the previously presented model with two types of agents and that they meet at random in each time step, in every meeting there are just two agents involved. Set the productivity profiles to $P_1 = (A_1, B_1)$ and $P_2 = (A_2, B_2)$. The exchange rate is set depending on the availability of each type of goods in the interaction

$$r = \frac{B_1 + B_2}{A_1 + A_2}.$$

To find out how much of the goods that is traded we maximize the payoff function and solve for t

$$w'(P_1) = 0 \Rightarrow t = \frac{A_1 B_2 - A_2 B_1}{2(B_1 + B2)},$$

maximizing $w(P_2)$ yields the same result for t, so both agents agree on the amount to be traded. Inserting this back into the payoff function gives the final payoff

$$w'(P_1) = \left(A_1 - \frac{A_1 B_2 - A_2 B_1}{2(B_1 + B2)}\right)\left(B_1 + \frac{A_1 B_2 - A_2 B_1}{2(A_1 + A_2)}\right)$$

$$w'(P_2) = \left(A_2 + \frac{A_1B_2 - A_2B_1}{2(B_1 + B2)}\right)\left(B_2 - \frac{A_1B_2 - A_2B_1}{2(A_1 + A_2)}\right).$$

To see what is required for a specialist strategy to invade a population where everyone is a generalist, set the productivity profile $P_1 = (s, 0)$ (specialist which only produce A) and $P_2 = (g, g)$ (generalist which produce the same amount of both goods). Let $w(P_x, P_y)$ be the payoff received by a P_x agent when interacting with a P_y agent. In a game where agents are paired off at random, a new type of strategy y can invade a population using strategy x if $w(P_x, P_y) \leq w(P_y, P_y)$ or $w(P_x, P_x) < w(P_y, P_x)$. Since $w(P_2, P_x) \geq g^2$ is true for all strategies x and $w(P_1, P_1) = 0$, the first inequality cannot be satisfied. Specialists can then invade if and only if $w(P_2, P_2) < w(P_1, P_2)$, inserting the values yields

$$w(P_1, P_2) = \frac{s^2 g}{4(s + g)}.$$

We can assume $g = 1$ without loss of generality and then simplify, which yields

$$s > 2 + \sqrt{8}.$$

In this case, with no available market, a specialist would have to produce about 2.4 times more than a generalist to be able to invade.

2.3 Specialization on a Market

Since a situation where you might end up not being able to trade and not getting any payoff is very unfavorable for specialists, we extend the idea of the trade situation from a random meeting of two agents, to a market. Now all agents meet in one place to exchange their good, thus no one takes the risk of meeting an individual which they cannot trade with, they will always be able to trade if there is someone in the population to trade with..

Let q_1 be the proportion of P_1 agents and q_2 be the proportion of P_2 agents, so $q_1 = 1 - q_2$. The productivity profiles of the agents are $P_1' = (A_1, B_1)$ and $P_2' = (A_2, B_2)$. An exchange rate r, is set depending on the amount of each good that is available on the market, and therefore also on the proportion of each agent type.

$$r = \frac{q_1B_1 + q_2B_2}{q_1A_1 + q_2A_2}$$

t_1 is the amount of A resources that a P_1 agent trades for for rt_1 B resources. t_2 is the amount of A resources that P_2 agents gives in exchange for rt_2 B

resources. The payoff for the agents is therefore:

$$w(P_1) = (A_1 - t_1)(B_1 + rt_1)$$

$$w(P_2) = (A_2 + t_2)(B_2 - rt_2).$$

To find the amount that is traded we take the derivative and find the maximum for each agent type

$$w(P_1)\frac{d}{dt_1} = 0 \Rightarrow t_1 = \frac{A_1 r - B_1}{2r}$$

$$w(P_2)\frac{d}{dt_2} = 0 \Rightarrow t_2 = \frac{-A_2 r + B_2}{2r}.$$

By inserting the expression for r and simplifying, it is possible to show that $q_1 t_1 = q_2 t_2$, so the supply and demand on the market is always equal. The model can be analyzed using a dynamic system based on the replicator equation:

$$\dot{q_1} = q_1 \left(w(P_1) - (q_1 w(P_1') + q_2 w(P_2))\right) = q_1(1 - q_1)(w(P_1) - w(P_2)),$$

which have one fix point with only P_1 agents and one with only P_2. In some cases there is also an interior fix point where $w(P_1) = w(P_2)$. Solving this equation for q_1, yields:

$$\left[q_1 = 1 + \frac{1}{2}\left(\frac{A_1}{-A_1 + A_2} + \frac{B_1}{-B_1 + B_2}\right), q_1 = -\frac{A_1 B_2 + A_2(B_1 + 2A_2)}{2A_1 B_1 - 2A_2 B_2}\right]$$

If we have a closer look at the second equation, we can see that, in order for q_1 to be positive, it has to be true that $A_2 b_2 > A_1 B_1$. Since q_1 is an interior fix point, we also know that the absolute value of the nominator has to be less than the absolute value of the denominator. This means that $A_1 B_2 + A_2 B_1 + 2A_2 B_2 < |2A_1 B_1 - 2A_2 B_2)|$, but since $A_2 B_2 > A_1 B_1$, it has to be true that $2A_2 B_2 \geq |2A_1 B_1 - 2A_2 B_2|$, which is a contradiction. We can conclude that this is not a fix point of the dynamic system.

In order for the system to have an interior fix point, the first root has to be between 0 and 1, which means that the expression within the parentheses have to be between 0 and -2. So, we have an interior fix point if and only if:

$$-2 < \frac{A_1}{-A_1 + B_2} + \frac{B_1}{-B_1 + B_2} < 0$$

Now we can see that an interior fix point can exist only if $A_1 > A_2, B_2 > B_1$ or $A_2 > A_1, B_1 > B_2$. This show that agents which are inferior or just as

good in both fields will be eliminated by competition. More importantly, as we will see, this means that specialists can invade a population of generalists as soon as there is a slight advantage in total productivity from specializing.

Assume we have an original population of generalists, with productivity profile $P_2 = (g, g)$. If a specialists with productivity profile $P_1 = (s, 0)$ were to appear in the population, they would be able to invade if and only if:

$$-2 < \frac{g}{-g+s} + \frac{g}{-g+0} < 0$$

This inequality is satisfied when $s > 2g$ i.e. as soon as specialization yields an advantage in total productivity, or when the function from ability to productivity profile grows faster than linearly.

2.4 Discussion

This was a brief presentation of two basic models for specialization, one without a market and one with a perfect market. The next step would be to include a transaction efficiency, to model an imperfect market. That will result in a trigger value, above which specialization will be worthwhile. By using more complex payoff functions or several fields with different productivities, the level of specialization can be decided by the transaction efficiency. If efficiency is assumed to increase with time, due to accumulation of new technology, increasing population density, laws or similar, the model will show an increasing specialization over time.

Many theoretic papers on the origin of specialization build on models very similar to this example. These kind of models illustrate that technology and population increase can drive specialization as suggested by several authors (e.g. Becker and Murphy, 1992; Durkheim, 1893). However, they do not take into account any codependency between specialization, population and technology. It is clear that there is a need for more models to explore this relationship.

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Chapter 3

Paper I: Theoretic and Empirical studies of Division of Labor and Specialization— An interdisciplinary survey

With Anna-Carin Stymne

The extensive division of labor in human societies is one of the aspects that make them unique. There are many areas that are influenced by this division. The most obvious one might be the economy, where division of labor yields much higher production. However, as we will show in this survey, a lot of other areas that affect society are influenced by division of labor, such as population size and density, technology, trade, accumulation of knowledge, social stratification, political organization, and institutions. Even the size of the family is argued to be linked to division of labor and specialization.

This review will discuss how specialization evolved, including both theoretical and empirical studies from several disciplines. We will also study different kinds of specialization, as well as how and in which areas specialization has an influence.

3.1 Introduction

Many authors (e.g. Smith, 1776; Young, 1928; Yang, 1994) argue that understanding division of labor and specialization is very important for understanding increasing returns and even basic economy. This however is still a very narrow view of the influence of division of labor. The increased efficiency that can be had by dividing a task into smaller tasks performed by

different individuals is one of the main reasons that cooperation is beneficial. Understanding how cooperation generates benefit might be one way to solve or avoid problems such as free riding (Calcott, 2008).

Some even go as far as to argue that modern humans' capability for division of labor is the cause that Neanderthals became extinct when modern humans spread across the world (Horan et al., 2005). They present a model which is based on the assumption that individuals can be either skilled or unskilled hunters. Skilled hunters obviously are more efficient. Since humans traded to a larger degree than Neanderthals, they could make greater use of their skilled hunters by allowing them to become specialized on hunting and therefore receive more food, which results in more offspring.

Even though there are a large amount of studies on division of labor, there are still many areas of this phenomenon that remain unstudied, or where results in different studies contradict each other. For example, what is the relation between specialization, population density and technological development? Adam Smith's *The Wealth of Nations* (1776) covered many aspects of division of labor, but since then, there has been a lack of interdisciplinary work on this subject. In this paper we will provide an interdisciplinary overview of some of the most interesting studies, both theoretical and empirical. We will try to answer questions such as: in what form did division of labor and specialization first establish among humans? How did it evolve, in what order did specialists appear? How did and do different human societies and cultural groups deal with division of labor and how does it vary across societies?

3.2 What is Specialization and Division of Labor

The terms *specialization* and *division of labor* are commonly used in the literature. Yet, the terms are not very well defined and are sometimes used as synonymous. Here we suggest and use the following definitions:

Specialization refers to an individual or another single entity such as a clan or a nation. Such an entity specializes if it focuses on one or a few tasks or options and neglect others. For example, a society or an individual can be specialized in fishing, which would mean that they do not hunt extensively. We can distinguish between:

- Temporary and consistent specialization
- Unskilled and skilled/trained specialization

Division of labor can only occur in a group of individuals or in a group of some other entities like a group of states. Division of labor occurs when separate entities perform different tasks with some coordinated aim. We can distinguish between:

- Temporary and consistent division of labor
- Whether the division of labor utilizes specialists or not

A separation of task specialization and individual specialization is suggested by Gorelick et al. (2004). Some tasks are done by a single or a few individuals (such as cave-painting, healing or horn-playing), but the individual performing the task is not an individual specialist because he also perform a lot of other tasks for subsistence such as hunting and gathering. In this case, the task is specialized for a specific individual, but the individual perform a lot of other tasks and is not individually specialized in one or a few tasks.

It is also common to distinguish between *independent* and *attached* specialists. Independent specialists produce goods independently and often for a market, usually they also acquire the raw materials for themselves. Attached specialists on the other hand work for some patron or elite, usually for a wage. They are often provided with raw materials and a workshop by their employer.

3.2.1 Organization and Division of Labor

Division of labor can be organized in different ways. In the famous needle fabric example by Adam Smith, a work process is organized by dividing the labor of manufacturing needles into seven separate tasks, performed by seven individuals. When dividing the labor efficiently, the seven workers produce much more than if everyone would produce needles on their own.

All kinds of division of labor among humans requires some kind of agreement (a deal or commitment) and organization, even though no one is in charge of the whole process, especially not in modern complex societies (see Seabright, 2004). There are tasks that require cooperation and there are tasks that individuals can do alone. Some tasks are more difficult to divide than others, especially those that are dependent on season, such as many agricultural tasks. Division of labor within tasks that require cooperation, such as advanced hunting or boat- and house building likely appeared earlier than division of labor that require some kind of organized exchange systems such as a market. Organization within a firm, a community or even a family is of course important when studying division of labor. In all societies there

are areas that would gain on division of labor but yet are not divided, or divided in an inefficient way, in the absence of leadership, proper organization or regulation.

3.2.2 Different Kinds of Division of Labor

Division of labor within family is an important, elemental economical unit of society (Becker, 1981; Johnson and Earle, 2000; Sahlins, 1978) and is a broad line of research with many studies. The division by sex is universal, but differ a lot from society to society (Murdock and Provost, 1973). In most human societies there are norms, taboos and rules for division of labor by sex. Many tasks are associated with a specific sex. These norms and rules are either explicitly formulated, sometimes in written laws, or implicitly learned and transmitted (Murdock and Provost, 1973; Hadfield, 1999).

Becker discuss sexual division of labor, assuming different comparative advantages for men and women. His theory is applied to families, regarding them as small firms that produce goods for self-consumption or the market (Becker, 1981). The theories, however, are applicable also in a wider sense as there is no reason that a small community or even an entire country cannot be regarded in the same way.

Another well studied subject is the social division of labor between agriculture and crafts. Marx and Engels stimulated research on the division of labor of those who organize labor (intellectual work) and those who perform it (manual work). Different authors often make their own categories. For example, Gershuny distinguishes between division of labor by different industries and trades, paid and unpaid activities and between different kinds of people Gershuny (1983).

3.3 Implications of Division of Labor

In his book *The Company of Strangers*, Paul Seabright discusses how our economic system can work the way it does. Today a simple shirt is assembled by perhaps a hundred persons scattered throughout the world and each of them perform their small part of the work. This process, with an extreme division of labor and specialization, works without someone being in charge of the whole process. Seabright calls this “tunnel vision”; each person is paid for his small contribution and does not see, or care about, the whole process (Seabright, 2004). Adam Smith also commented the fact that a worker will have lesser insight in a common goal of society, and that division of labor and extreme specialization by routinizing work leads to alienation

and uninformed workers (Smith, 1776).

3.3.1 Productivity

Increased productivity is a well known effect of division of labor and is axiomatic in just about every theoretic paper on division of labor. Smith attributes this increase to three things. First, when someone is doing the same task all day, he will become better at it than if he had other tasks to perform as well. The second reason is that time is lost when moving between different tasks; workers tend to idle for a while when they change. Finally division of labor facilitates the use of machinery, which greatly improves productivity (Smith, 1776).

3.3.2 Societal Development

Increasing division of labor and specialization tend to go hand in hand with societal development. As Adam Smith puts it: "what is the work of one man in a rude state of society being generally that of several in an improved one" (Smith, 1776). Carneiro suggests that several specialists, such as merchants, architects, craft specialists, as well as traits that help increase specialization, such as code of laws, roads connecting settlements and markets are required to maintain a certain population density. He also performs an empirical study which clearly show that these traits appear as society develops (Carneiro, 1967). This was also noted by Tainter, who lists decreased division of labor as one of the signs of a collapsing society (Tainter, 1988). Money is of course another consequence of division of labor, since there is no reason for it before trade. It is also something that makes trade much more efficient and results in more division of labor.

In many cases, specialization also lead to social stratification. The first signs of marked social stratification in archaeological studies are from the bronze age, when specialized leaders gain control over common resources (Gilman, 1981). See also paper II of this thesis for social stratification due to specialization in knowledge in modern societies.

It has also been suggested that division of labor is behind the decrease in average family size that we can observe in industrialized countries. Since families produce less resources for their own consumption and instead buy the necessities on a market, their benefit from economies of scale decreases and one of the reasons for having a large family disappears (Locay, 1990).

Several studies using mathematical models conclude that specialization increases average income (Zhou, 2004; Yang and Borland, 1991). This is

of course because these models generally assume some advantage in total production when specializing.

3.3.3 Social Optimum

It is common for models of specialization to assume that individuals incur some personal cost for choosing to specialize. Davis suggests that there might be an external cost for specializing. In modern societies it is not uncommon for the government to pay for at least part of the education. When society provide for the education, there is a risk that individuals will tend to over specialize to earn higher wages, causing higher than optimal costs for society (Davis, 2006).

Kim (1989) published a model in which the level of specialization is lower than the social optimum. Workers in the model make two choices. The first is how much time to spend on education and the second is how many areas to study during this time. The amount of time spent on learning each activity determines the workers productivity within that activity and a higher number of activities increase the chance to find a suitable job. When firms hire employees with skills that don't match that firms profile, they incur a cost for reeducating the new employees, so they prefer to hire employees with a matching education.

The amount of available jobs, which is decided by market size and demand for labor, will have a big impact on the individual's choice of specialization in this model. With many available positions, individuals will focus on learning a few activities well since they likely will be able to find work anyway and a higher skill in a specific activity increase their wage. If there is a lack of available work, individuals will try to learn many activities instead, to maximize their chance of finding a job. Because much of the time spent on learning several activities is just to be able to get a job, it is wasteful from the society's perspective. It would be better if more time was spent on increasing individual skill instead (Kim, 1989). This is also indicates that coordination costs are what limits division of labor, if there was a better way to coordinate, the individuals could spend more time on specializing within one field instead.

The model might explain variations over time in the number of professions held by individuals as mentioned in studies of the history of farming and the history of firms (Britnell, 2001; Bengtsson and Kalling, 2007). In periods of recession, there is usually a lack of available work, so specialization should go down somewhat. In booming times there are plenty of work, so very specialized individuals will make a lot of money. On the other hand, it is common for universities to see a higher number of applicants during recession.

3.3.4 Increased Population and Population Density

There are some empirical surveys analyzing the relationship between population size, population density and the amount of occupations in society, all coming to the same conclusion, population density and the number of occupation in society have a high correlation (e.g. Carneiro, 1987, 1967; Naroll, 1956; Bonner, 1993, 2006; Denton, 1996)

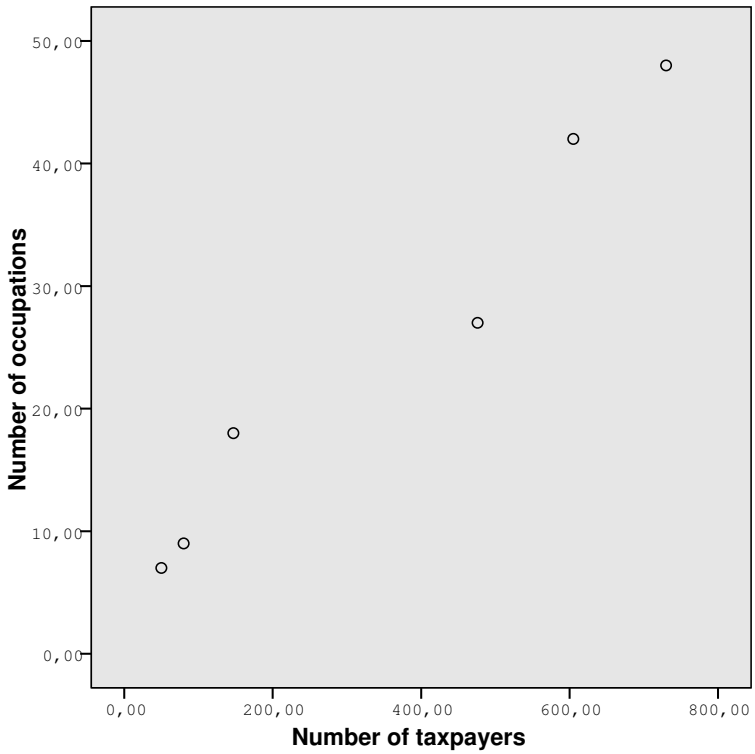

Figure 3.1: The correlation between the number of taxpayers (population size) and the number of occupations (indicated by occupational surnames) in medieval towns (Copenhagen, Malmö, Husum, Tönder, Sönderborg and Schwabstedt) in Denmark 1504-1577 (data from Hybel and Poulsen, 2007).

According to Spencer, specialization rate increases when society becomes more voluminous and covers different climate and geographical conditions

(from Durkheim, 1933, p. 206). One of the most quoted insights from Adam Smith's text is that the extent of the market depends on the division of labor. This insight was later added to by Young (1928), who argue that "the division of labour depends upon the extent of the market, but the extent of the market also depends upon the division of labour".

Emilé Durkheim concludes that the population volume causes division of labor and not vice versa. Just as the differentiation process into different species allowed more individuals to coexist, division of labor in human society makes higher population densities possible. When the population density becomes high enough, there is a requirement for specialization, to find new niches and be able to inhabit new areas (Durkheim, 1933).

Baumgardner (1988a) created a model that shows how demand, size of the local market and competition affects the degree of specialization in workers. In his model, workers can choose the amount of different goods to produce and it is assumed that a higher specialization (fewer types of goods) yields higher production. Workers want to produce as much as possible, and therefore would like to specialize, but there is also only a certain demand for every type of goods, which gives a limit for how specialized an individual can be. Thus, if there is only one worker in the market, his level of specialization will increase with the population while it will decrease if the worker has more time. Baumgardner shows that cooperation will result in a higher level of specialization than competition, which result in overlapping activities. However, competition might result in a higher consumer surplus. Specialization will increase with population, regardless of cooperative or non-cooperative behavior. If the population increases while the demand is held constant, specialization will still increase if the workers cooperate, but decrease if they compete.

Baumgardner also performed an empirical study to compare the results with his model. The study shows a significant relation between population and the number of physicians and their level of specialization, which was determined by counting the number of different conditions they treated. He also tried to determine which of the cooperative and the competitive setting matched reality best, but was unable to do so as some tests indicated cooperative and other indicated competitive behavior (Baumgardner, 1988a,b).

3.3.5 Innovation

Increased innovation rate is also considered to be an effect of division of labor. This is because individuals are more likely to come up with ideas for machines or tools that simplify their work when they spend all day doing the same thing. Innovator as a profession is also discussed. It is believed

to have come after industrialization, when producing machines became a separate industry and machines became too advanced, so that single individuals could not design them themselves (Smith, 1776). Of course, there is a codependency between technology and specialization. Many technological innovations created by specialists create new professions, which requires more specialists (computers for example).

There is also an intricate relation between population size and technological advances, that might be due to specialization. Specialization is required to keep a high level of technological advancement, since at a certain level it is impossible for every single individual to have all the knowledge available in the society. If the specialists were to disappear, the technology would likely be difficult to maintain. There are several examples of a decline in technological advancement correlated with a fall in population density, and likely also specialization, such as the Eastern Island and Tasmania (Diamond, 1999; Tainter, 1988; Kremer, 1993). One very extensive study tries to determine the rate of technological change, population size and density over a long time (one million years) and find a very clear correlation (Kremer, 1993).

Since it is not uncommon for innovations within one field to make use of technology developed for another purpose, if specialization increase the chance of making new innovations, the rate will be increased even further by new innovations that combine the different fields. Mokyr give some examples of such cross-fertilization: "Advances in metallurgy and boring technology made the high-pressure steam engine possible; radical changes in the design of clocks and ships suggested to others how to make better instruments and windmills; fuels and furnaces adapted to beer brewing and glassblowing turned out to be useful to the iron industry; technical ideas from organmaking were applied successfully to weaving" (Mokyr, 1990, p. 281).

3.4 The Increasing Amount of Specialization

The increased differentiation of functions in society is often commented in the literature (e.g. Smith, 1776; Durkheim, 1933). The increasing number of specialists in society is so obvious that there has been few surveys actually measuring this universal fact. The studies that measure division of labor over time usually do so as a part of a larger study on economic development, social complexity or social mobility. However they are all coming to the same conclusions: increased occupational differentiation in society over time (e.g. Carlsson, 1966; Hybel and Poulsen, 2007; Lindberg, 1947; Denton, 1996).

Most of these studies count the number of occupations or surnames that indicate a specific occupation, which of course has some problems. The

largest of those problems is that it is very hard to know what an occupational title really says about what tasks are performed by that particular individual. It is also common for workers to have several occupations, but just one of them might appear in the data, and this fluctuates over time, as shown by the history of farming and the history of firms (Britnell, 2001; Bengtsson and Kalling, 2007). The occupational surnames might also stay even if their bearers do not have that profession. The surnames show increasing differentiation, but this is not necessarily the same thing as increased specialization (Britnell, 2001).

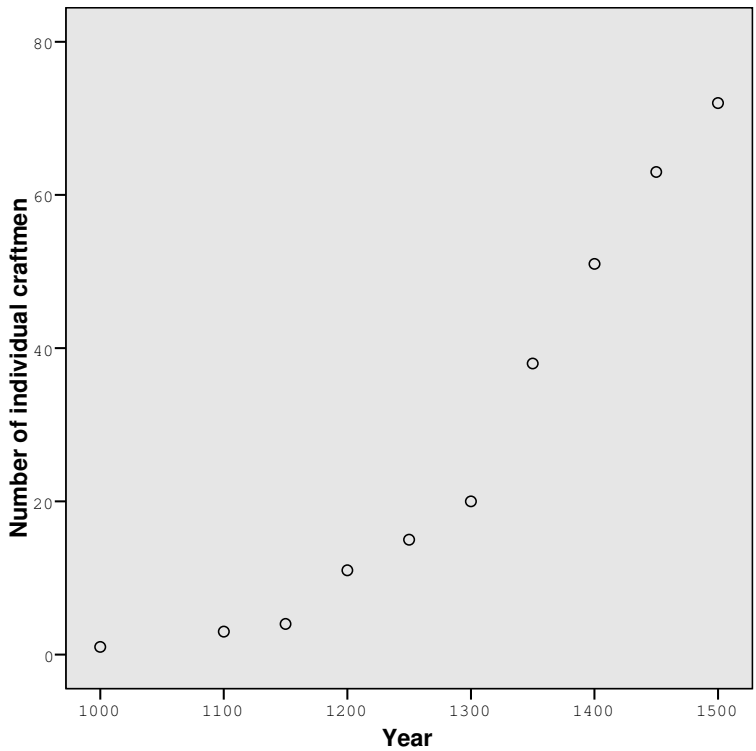

Figure 3.2: Differentiation process. Number of different occupations accumulating in Denmark, counted as they become visible in historical sources from 1000-1520. Plotted after Hybel and Poulsen 2007 (data from Hybel and Poulsen, 2007).

Figure 3.2 shows the increasing division of labor over time. This graph illustrates the diffusion process for the craft professions by counting the proffessions as they become visible in the historical sources, starting with the smith (data from Hybel and Poulsen, 2007). The new occupations are added as the name shows up in different kind of historical sources. This is one way to show the direction of the differentiation, studying the differentiation over five hundred years, into more and more different specializations of the professions (unfortunately there is no reliable data available on the population size for the same period).

As can be seen here, there is no sign of a decrease in the number of occupations, even during the 14th century, when there was a big decline in the European population. There is a lack of sources that show the number of occupations over time, especially from collapsing societies and periods when the population decrease. There are also few projects trying to combine empirical data from different surveys, especially across disciplines, to get a broader picture of long-term universal trends of specialization.

To our knowledge, there is no empirical evidence that the number of occupations drop significantly just due to population decrease, such as famine. Specialization seems to be linked to the internal organization of a society and if the organization and number of institutions of a society is intact, most occupations would be able to survive even if population density falls. If on the other hand there is a collapse of political order and institutions, such as when a society is divided into smaller parts, there will likely be loss of occupational specialization and technology (Tainter, 1988).

3.4.1 Limiting Factors

Transaction cost, or market efficiency, is determined by many factors, such as laws that aid or hinder trade, existence of money, supply and demand. One of the most important factors is distance, both in terms of transportation time and cost, which means that population density and technology will have a large part in determining how much specialization can be observed in a specific area. This was also noted by Adam Smith, who observes that areas with a higher population density, as well as coastal areas, will have more specialists (Smith, 1776).

Becker and Murphy argue that since it is very common to find several persons with identical specialization within the same city, division of labor cannot be limited mainly by the extent of the market. That would imply that these people with the same specialization should divide the tasks between them whenever possible. They take this as evidence that the main reason for the ever-increasing level of specialization is the increase in knowledge and

that *coordination costs* is what limits it (Becker and Murphy, 1992).

3.5 Origin of Division of Labor

After Adam Smith, it is the effects of division of labor, positive, as economical growth and negative, as social stratification, that have been given most attention. Much fewer studies on the origin of division of labor are available.

Adam Smith believed that humans have a propensity to trade, which according to him is a necessary consequence of reason and speech. It is this propensity that gives rise to division of labor. When an individual makes some product, such as bows and arrows, better than others, people will offer to trade with him. He will then gradually spend more time at producing bows and arrows instead of hunting. After some time, he will realize that he will receive more meat from trading his products, than if he goes out to hunt himself.

Smith stresses that individual differences are not the cause of division of labor, but rather a result. In Smith's view there is some variation in human behavior or randomness that initiate the specialization process, then the variations reinforces into real differences in skill and knowledge. Some kind of predisposition or human drive for dividing labor and trading are also mentioned by several other authors (Ridley 1997, from Johnson and Earle 2000; Durkheim 1933).

Some argue that human reason and problem solving abilities give rise to the insight of the advantages of division of labor (e.g. Bonner, 2006). Most common of all is to assume that it is just a consequence of the fact that it is advantageous in many cases, making division of labor the natural consequence of technological development or economic progress (e.g. Becker, 1981; Yang and Ng, 1998). Becker was first to use mathematical models and formal reasoning to show how these advantages result in division of labor. He covered comparative advantages, economies of scale and learning costs (Becker, 1981).

Much of the recent work on the evolution of division of labor, expanding on Adam Smiths theories is from Yang and coworkers, (Yang and Ng, 1998; Cheng and Yang, 2004; Sun et al., 2004). Their work often contains models where individuals in a society both consume and produce goods, some of which they might buy or sell at a market. These models mostly depend on trade efficiency and some kind of economies of scale. Thus, production increase with division of labor, but it will be limited by transaction efficiency. With a very low efficiency, the society will be in autarky and with extremely high efficiency there will be a total division of labor. With the assumption

that efficiency increase over time, e.g. due to increasing population density or technological development, these models will exhibit increasing division of labor over time, from autarky to a total division of labor.

There is one model that can explain the evolution from autarky to a society with highly specialized individuals, by means of learning by doing. The process begins with a society where everyone provides for themselves, since transaction costs are too high for specialization to be advantageous. Learning by doing results in a higher productivity, which will eventually make some specialization worthwhile. When the number of activities performed by each individual decrease, the accumulation of skill by learning by doing will accelerate, resulting in more and more specialization (Yang and Borland, 1991).

3.5.1 In What Order do Specialists Appear?

The Origin of Individual Specialists

Anthropological and archaeological research has been dealing with the transition from subsistence economy to production for a market. Empirical data indicate that this process often begin with a slow transition from attached or part-time specialists to independent, full time specialists. There are variations though, in Ancient Mesopotamia indications are strong for independent and attached specialists to have evolved simultaneously (Brumfiel and Earle, 1987). For the development in Denmark there are observations of a transition during the period 1000-1500 from attached craft specialists and female artisans working within a household (e. g. weavers), to independent male craftsmen (Hybel and Poulsen, 2007).

Specialization by Industry

A lot of research has been dealing with the appearance of specialized craftsmen. The appearance of full time artisans and the differentiations and development or adoption of different industries, such as agriculture, pottery and metallurgy often indicate economical growth and social development. Ethnographic data implicate that healers (shamans) are the only specialist in low-density family band societies. In societies with higher population density the second specialist to evolve is the leader (Coon, 1948; Seabright, 2004).

Gordon Childe argued that prehistoric bronze smiths were the first attested full time specialists (Chapman, 1996). The adoption of advanced metallurgy required specialists. The first metal items seem to be more sym-

bols of wealth and prestige and as such defined as luxury goods rather than substantial (Anthony, 1996).

Do Specialists Evolve from Geographic Specialization?

One of Childe's interests was the rise of a more advanced division of labor and especially craft specialization. He studied the exchange between cultures, were the production often was dependent of geographical location, and the access of products such as salt, chert, gemstones and shells. According to Childe, this production did not resemble anything that could be called specialization. Most of the members in the societies were active in the production and the production was not substantial (Wailes, 1996). Trade with this kind of geographically determined products, in the literature often called "valuable goods", is universal (Coon, 1948). Areas often specialize in manufacturing and processing locally found valuables for trade, such as shell beads (e.g. California, Arnold, 1994).

3.6 Division of Labor and Specialization in Different Kinds of Societies

To see how specialization is influenced by what kind of subsistence is used by a society, Lenski and Lenski (1978) used anthropological data to compile a table over the proportion of specialists in different fields grouped by subsistence type in the society.

Table 3.4 clearly show that the amount of specialization increase when societies become more advanced. It also supports the hypothesis that metal working is a field that requires specialists. In just about all cases where metal working is present, it is also performed by a specialist.

We will here present how division of labor appears in societies in different evolutionary stages. The categorization by Johnson and Earle in their book *The Evolution of Human Societies* will be used, but our survey will only cover the first two, which are of the most interest for studying the origin of specialization. The different stages are defined by socio-political organization and correlate well with population size, they are: The family level group, local group and region polity (Johnson and Earle, 2000).

3.6.1 Family Level Group

The social organization on the simplest institutional level is the family level group, or what Service calls "simple family bands". These societies are char-

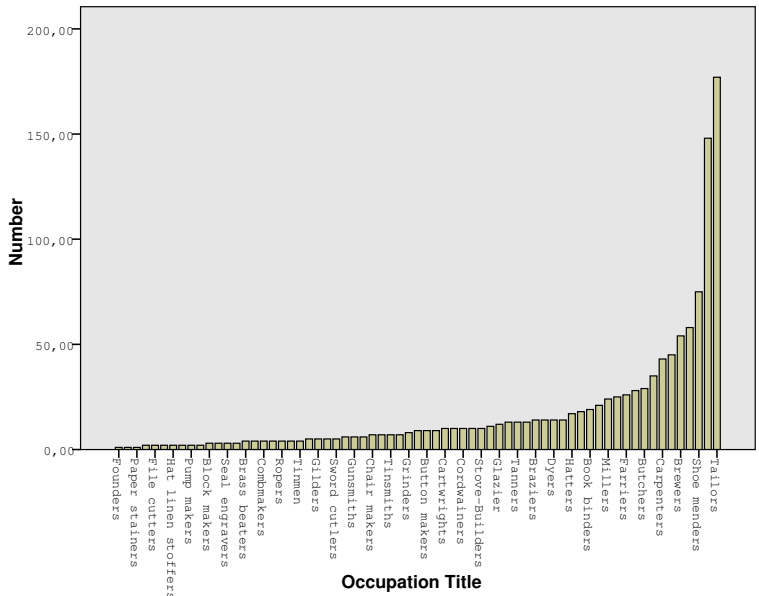

Figure 3.3: One interesting measurement is the frequency of each occupation. Of course, some occupations are more common than others. Large cities have a greater number of uncommon occupations. In Stockholm $1740-1741$ there were 177 tailors, but only 2 sailmakers. (data from Söderlund, 1943).

acterized by division of labor based almost exclusively on age and sex. Modern societies of this type are living in areas with low population density and are mostly hunter and gatherers, but some are farmers, as the Machiguenga (horticulturists, living in the rain forest of the Amazon in Peru) and the Nganasan (living in Siberia, with domesticated animals) (Johnson and Earle, 2000, p. 90).

Division of labor, other than according to sex and age, seems to occur only when absolutely necessary or when the advantages are great and the distribution of surplus is regulated and supervised. In other situations, it seems as if the losses from fighting over surplus will be greater than the gain in production and efficiency that would have been the outcome. In general, mostly families provide for themselves, both food and tools. The only exception seem to be healing.

Sustinence Type	Metal Working	Weaving	Leather Working	Pottery	Boat Building	House Building	Average
Hunting and Gathering	*	0	0	0	0	0	0
Simple horticultural	*	0	3	2	4	2	2
Advanced horticultural	100	6	24	4	9	4	28
Agrarian	100	32	29	18	5	18	38
Industrial	100	100	100	100	100	100	100
Fishing	*	0	0	0	9	4	2
Herding	95	11	22	*	*	0	21

Figure 3.4: * The activity in question is seldom found in this type of society. The figures for industrial societies are not form the original data, but are added simply for comparative purposes by Lenski and Lenski (table from Lenski and Lenski, 1978, p. 99).

Division of Labor by Sex and Age

What distinguishes division of labor by sex in mobile, family-level foraging societies is that there is usually a strict separation of tasks into a female sphere and a male sphere. Exactly what tasks are performed by men and which are performed by women vary from society to society, but there are a few trends. For example hunting large game is almost exclusively done by men in foraging societies and most gathering and childcare is done by women (Murdock and Provost, 1973; Johnson and Earle, 2000, p. 76).

Individual Specialists

Carleton Coon suggests that a healer is a part-time specialist in family band societies. The healer in these societies takes care of a combination of religious, social and medical functions. The way shamans and healers in family group societies are described in ethnographic sources (Coon, 1948), they are certainly task specialists, as the tasks they perform is only done by a few individuals. They are not full time specialists however, they also have to

perform other tasks for self subsistence, even though they often receive gifts and privileges in exchange for their services.

Exchange

The !Kung share meat in the camp, which consist of several families living together. Hunting parties consist of 1-4 men. Sharing is important and prestigious among !Kung. Arrows are exchanged among hunters, so that a hunter can let another hunter make an arrow for him, but there are no specialized arrow makers. If a hunter is successful he is supposed to share meat with others. Highly skilled hunters that over a longer period share more meat than others will have greater respect and enjoy certain privileges, such as being allowed to have more than one wife (Johnson and Earle, 2000).

The sharing in small-scale societies is usually not associated with any requirement for reciprocity. This can however still be regarded as some kind of trade, as each individual is expected to contribute after ability (Sahlins, 1978, p. 194-200).

The most commonly traded goods in these societies are body-paint materials and other valuables for rituals, feasts or aesthetic objects. Trade can be long-distance, especially for societies living in harsh climate such as Inuit's that trade soapstone for lamps from great distance (Coon, 1948).

Complex Division of Labor

The Machigunega fish-poisoning involves between two and ten households, a leader controls the activities, men build dams, women construct weirs all with a complex division of labor (Johnson and Earle, 2000, p. 108-109). Cooperation on tasks both between and among families seems to occur only if absolutely needed or when bonds are very close. Families among the Machiguenga have their own gardens, prepare their own food etc. (Johnson and Earle, 2000, p. 107).

3.6.2 Local Groups

Local groups are societies organized in larger groups that extend simple family bands. Population size and density are higher than in family level groups, the groups are divided into subgroups, differing in number from two to twenty (Johnson and Earle, 2000, p. 123). The society becomes more sedentary; villages or hamlets are established, were the inhabitants, in most cases, live the entire year. Division of labor becomes common in large-scale projects, warfare and ceremonies (Johnson and Earle, 2000, p. 123-124).

Division of Labor by Sex and Age

Division of labor by sex increases in the sense that the society gets more divided in male and female spheres and masculinity and power is glorified. The division is not quite as strict however, it is more a matter of who is in charge of different tasks. Ceremonies of different kinds are important and men and women have different roles and contribute in different ways. Warfare and weapons manufacturing are exclusively male areas. Women make a greater contribution to food production and manage the household economy (Johnson and Earle, 2000, p. 129-131).

Individual Specialists

Leadership is getting more formalized in settlements with higher population densities and larger groups living together than in family group level societies. Task specialization, especially ceremonial activities, is linked to specific individuals and formalized.

The leaders in local group societies are still dependent on charisma and are somehow chosen by the group. The leader have a function as a coordinator in ceremonies, which become more important. The ceremonies also require more and new kinds of goods, such as shells, feathers and food. New services, such as tattooing, are also required. The ceremonies are financed through an intensified production and division of labor. Several other tasks associated with the ceremonies, such as tattooing, music and decoration are also formalized and assigned to specific individuals (Johnson and Earle, 2000; Spielmann, 2002).

Exchange

Internal exchange of goods is rare, but larger ceremonial meetings that also involve other groups occur more often and at these meetings there are some exchange of goods (Johnson and Earle, 2000). In some cases there is geographical specialization due to availability of resources, or just by choice. There are no specialized merchants, though the leader of a group often has an important role in trade and in distribution of food and valuables.

3.6.3 Chiefdoms

Division of labor in larger and more complex chiefdoms is characterized by a big increase in the amount of administrative positions. Administrative and craft specialists emerge at an increasing rate when the society gradually becomes more complex and population density increases. To be able

to maintain this in the more complex chiefdoms, the subsistence is usually provided by intensive agriculture.

The division of labor by sex continues to be important among peasants, as the base of the subsistence economy continues to be the family (Johnson and Earle, 2000).

3.7 Discussion

There is research on division of labor and specialization in a wide array of fields, unfortunately there has been little communication between these fields. There is also a big discrepancy between the theoretical and empirical studies. There are theoretical studies which simulates the development of division of labor by assuming a benefit in production and a high transaction cost that is lowered over time, while the empirical studies talk about the first specialists as mostly catering to spiritual needs and that the first craft specialists are attached to a leader.

3.7.1 Evolution

The first specialists were part time only, still having to provide for their own sustainment and their function was either that of a healer or an organizational leader. As the society evolves, the healer and organizational leader gains more influence and ceremonies become more important. The ceremonies requires new goods, only a few individuals are assigned, or allowed, to produce these new resources, they become part time specialists, the roles become more formalized. Most of these tasks require very little work and are not associated with basic needs, such as food and shelter. The goods are still distributed among the group without any expectation of direct reciprocity, no market exists. Some of the ceremonial items are not available locally and have to be traded for with other groups, geographical specialization and trade appears.

When the group grows, the food gathering has to be intensified. While there had been some sharing between families, the food was generally gathered by the same individual who ate it, or a close relative. Now cooperation becomes more important, there is a limit on how long from the group individuals can travel to gather food, so the area does not increase as fast as the population density and more food have to be gathered per acre. Many of the advantages of hunting in a group are due to division of labor. For example a couple of individuals could drive the prey into a trap set by others. These roles can be assigned differently for every hunt, so they are not necessarily specialized. As there is still no market, the organizational leader has an

important task in assuring that everyone get some of the surplus, otherwise there would be fights and the cooperation would break down and the society would have to be divided into smaller parts.

When the group settles down and starts a village, population density grows even more and food gathering has to be intensified further. Some crafts specialists might start appearing, usually they are attached to some leader or other elite, receiving food and housing as pay for their work. The increasing specialization allow the group to accumulate more culture and utilize new technology. There is evidence that metal working is so complex that it requires a specialist. Eventually the attached specialists will break free and become independent, some groups skipped the attached specialists and received independent specialists right away. When the leader no longer have control over the specialists, they have to trade their goods for food and other resources. Specialized traders appear.

From this point and on, specialization keeps increasing, much of the new technology will require specialists, the population density increase and the society becomes more complex, which in turn requires new specialists.

3.7.2 Specialization, Technology and Population Density

It is clear that there is a complex relationship between specialization, technology and population density. Exactly how this relationship is built up is still unclear however. This is one area that has not been studied very extensively and more theoretical work is necessary. Most likely the population keeps increasing by itself and when the population density becomes high, the society either has to be divided or find more efficient ways to gather food and organize itself. First dividing labor helps with this increased efficiency, then specialists and new technology. In more advanced societies specialists are required just to uphold the current level of technological advancement.

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Chapter 4

Paper II: Why Social Stratification is to be Expected

Social stratification is present in all modern societies and humans have developed systems where individuals can greatly improve their lot through strategies such as education. Thus social stratification in modern societies presents us with a dilemma: why don't people with low income simply change their strategies to mimic the high earners?

This paper uses a mathematical model with minimal assumptions that show how social stratification might evolve from education when people are equal and discount their future payoffs. The model is shown to fit well with statistical data on income and education in several countries, suggesting that the kind of social stratification that we observe is to be expected to appear endogenously, whether or not individuals have equal chances. Furthermore, the results yield concrete suggestions on how to increase the proportion of educated people in society.

4.1 Introduction

Social stratification has existed for a long time and is present in all modern societies. Evidence from burials suggest that marked differences between social classes emerged at least four to five thousand years ago (Gilman, 1981; Childe, 1958; Gimbutas, 1965). Unequal shares of commonly produced goods have likely been common long before that.

Many researchers have offered explanations as to why this stratification exists. Functionalist explanations (e.g. Sahlins, 1972; Cohen and Service, 1978) suggest that the ruler class emerges because of a need in society for some kind of organization. For example they might act as redistributors of

goods produced by specialists, facilitate construction of irrigation systems or other costly constructions that benefit society, or act like military leaders. This view has been criticized (Gilman, 1981) for lacking empirical evidence. Gilman suggest that many resources that generate long term utility such as dams, irrigation systems, large boats, plantages with olive trees or vines are constructed by the workers without supervision from a ruler. Instead the rulers occur as protectors of these resources and as such often receive control over them.

It is also common to assume that access to resources, such as land, and other valuables is inherited. This is supported by archaeological evidence (Shennan, 1975). This however, does not fully explain stratification in modern societies where knowledge is very valuable and education is fairly cheap and commonly available.

Other explanations include individual differences and genetic or cultural group selection. Henrich and Boyd (2008) suggested in a recent paper that with limited possibility of moving between groups, but with frequent interaction between groups in a complementarity game, social stratification might evolve. Basically it would be a way of solving the coordination problem.

There are of course a large number of ways to become wealthy, so several of these explanations might be correct. Today many people inherit a fortune, there are also movie and rock stars that become very wealthy because of their talent and some win the lottery. Perhaps the most common way to make more money today is to get an education. Economic theory would then predict that individuals will choose to educate themselves whenever they stand to gain something from it. This would result in an equilibrium where getting an education or going to work straight away has the same expected lifetime monetary income, which of course is not compatible with what we can observe in modern societies.

4.1.1 Temporal Discounting

It is well known that people discount future payoffs in decisions regarding money, items and health (Thaler, 1981; Benzion et al., 1989; Chapman and Elstein, 1995; Pender, 1996). Discounting future payoffs means that lower immediate payoffs, such as getting a job instead of an education, become more attractive than higher future payoffs, such as first getting an education and then a high paying job. The studies show that discount rates may be as high as 50% per year (Thaler, 1981) or as low as 10% (Benzion et al., 1989), depending on individual preferences and situation, larger sums tend to result in lower discount rates. This paper will show how education can lead to social stratification because individuals discount future payoffs.

4.2 Model

The model presented in this paper consists of a repeated game where there are three different strategies, *high, low* and *education*, denoted H, L and E. The high and low strategies correspond to the different levels of education that an individual can have. The payoff for the high strategy will be dependent on the proportion of other high agents, q_H, and a benefit b, which is how much the society values educated workers. d is the *delay*, or length of the education. This is the amount of time a agent have to spend in education to be allowed to use the high paying strategy and the length of one round in the game. Players have to pay a *cost* c, which can be zero, for their education. Playing the low strategy will result in a small, positive payoff, which can be set to 1 without loss of generality. Payoffs are denoted w_x where x is the strategy.

$$\begin{aligned} w_H &= (1 - q_H)b \\ w_E &= -c \\ w_L &= 1 \end{aligned}$$

Thus, w_H predicts how much an educated worker earns, compared to an uneducated, i.e. it measures the society's stratification. When agents decide whether to educate themselves or not, they sum their expected future payoffs and compare the strategies. When performing this calculation they assume a lifetime of l years, or time units, and apply a discount r for every round, or d time units, so that

$$r = 1 - (1 - \delta)^d,$$

where δ is the yearly discount rate. Thereby, they value immediate payoffs higher than those far in the future. For notational simplicity $R = 1 + r$ and $t = \frac{l}{d}$ will be used in the equations. Costs are not discounted, they are incurred early in the lifetime and discounting them would not make much of a difference, but would make the equations more complicated. There is evidence (Loewenstein, 1988; Benzion et al., 1989) of discounting costs, but in this model the qualitative results will not be affected by including that possibility. Also, the studies show that discount rate for future costs is lower than that for gains. Since agents only choose between educating themselves or keep on playing the low strategy, only those two strategies have to be evaluated. Summed future payoffs are denoted w_x^f, where x is the strategy.

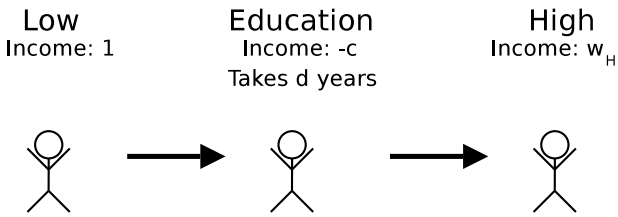

Figure 4.1: Illustration of the steps an agent can go through. New agents play the low strategy, receiving a payoff of 1, but also have the option of going into education. Education costs c and takes d years to complete. When finished, they can use the high strategy, which pays w_H

$$\begin{aligned} w_E^f &= \sum_{n=1}^{t} \frac{(1-q_H)b}{R^n} - c \\ w_L^f &= \sum_{n=0}^{t} \frac{1}{R^n} \end{aligned}$$

In the dynamic system, agents die with probability $\frac{1}{t}$, resulting in an expected lifetime of l time units. Dead agents are replaced with new, naive, agents.

$$\begin{aligned} \dot{q_H} &= q_E - \frac{1}{t} q_H \\ \dot{q_E} &= q_L(w_E^f - w_L^f) - q_E - \frac{1}{t} q_E \end{aligned}$$

Since $w_H = (1-q_H)b$, we just have to solve for b, which has an unique solution, to find the equilibrium for w_H.

$$w_H = \frac{t^2\left(1 - R^t(1+r+cr)\right) + q_H(1+t)\left(R^t\left(t + r(t+ct-1)\right) - t\right)}{t(R^t-1)\left(q_H + t(q_H-1)\right)}$$

Since the death rate is very low, we can eliminate that part of the dynamic system, but still let the individuals evaluate their payoff using the expected lifetime. This gives us an approximation of the results, with a much simpler expression.

$$\begin{aligned} \dot{q_H}^{approx} &= q_E \\ \dot{q_E}^{approx} &= q_L(w_E^f - w_L^f) - q_E \end{aligned}$$

Since there is no death rate in this equation, q_E have to be 0 at equilibrium, therefore we just have to solve $w_E^f = w_L^f$ for w_H which yields

$$w_H^{approx} = \frac{R - R^{-t} + cr}{1 - R^{-t}}.$$

Another benefit from the approximation is that w_H^{approx} is not dependent on b or q_H.

4.3 Analysis

The approximation predicts social stratification whenever $R - R^{-t} + cr > 1 - R^{-t}$, which can be simplified to

$$1 + r + cr > 1,$$

which is true whenever $r > 0$. Thus, as soon as agents value future payoffs lower than immediate, there will be social stratification.

In figure 4.2 we can see how the equilibrium value of w_H is affected by each parameter.

- Retirement age has very little impact on the results when it is fairly high.
- The income for educated individuals increase exponentially with the length of their education.
- Cost of education has a linear effect on income for educated individuals.
- The discount rate has an exponential effect

4.4 Testing the predictions of the model with data

Assuming societies are close to equilibrium, the above analysis yields predictions of the social stratification. We can test these predictions using statistics on retirement age (l), length (d), cost (c) and differences in income according to level of education (w_H) from a few different countries. The data has been gathered from official statistics institutes in each country and also from OECD (2007). First we have to decide on two educational levels to compare. Since upper secondary education is very common throughout the western

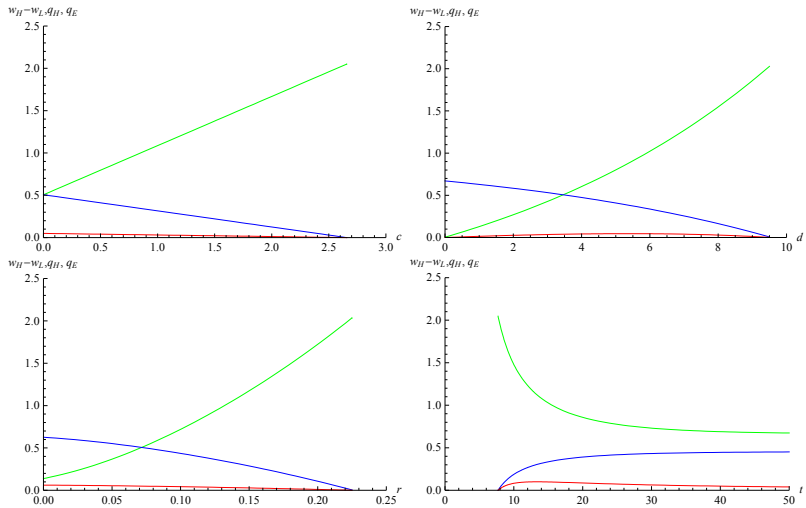

Figure 4.2: These graphs show how each of the variables affect the difference between the payoff for the high and low strategy. The green line is $w_H - w_L$, the blue is q_H and the red is q_E. The graphs have been plotted with $c = 0.5,\ d = 3,\ r = 0.2,\ b = 3,\ l = 45$.

world (OECD, 2007) and the first real decision on whether to continue education or not seems to be at tertiary education, we choose to compare them. Specifically we look at bachelors and masters degrees.

First we use statistics on difference in income between people with upper secondary, but no tertiary education with those who have a bachelor or masters degree. Since $w_L = 1$ and corresponds to the average income of a person with upper secondary education, we normalize the income for both types. Using the same method, we normalize the cost for tertiary education to be relative to w_L.

q_H is calculated by comparing the number of people with upper secondary education with those who have a bachelor or masters degree.

The retirement age is approximately the same in all countries (around 65) which means around 45 years left after secondary education. Since it has very little impact on the results when it is this high, we assume a working lifetime of $l = 45$ for all countries. To find the average length of higher education (d), we studied statistics on the amount of bachelor and masters degrees in a country and used the typical length for each of those. Table 1 shows the values for each country. All predictions of the model have been

calculated using $\delta = 0.102$, or a discount rate of 10.2% per year.

Country	w_H^{actual}	q_H	c	l	d
Canada	1.68^a	0.38^b	0.12^a	45	4.45^b
Denmark	1.42^c	0.33^d	0^a	45	4.06^c
Israel	1.69^a		0.19^a	45	4.56^e
New Zealand	1.44^a	0.4^f	0.08^a	45	3.41^f
Sweden	1.38^g	0.32^g	0^a	45	3.42^g
USA	1.77^h	0.44^h	0.3^a	45	4.54^h

[a]OECD Education at a Glance 2007
[b]Statistics Canada, 2006 Census
[c]Statistics Denmark
[d]Statistics Denmark
[e]Central Statistics Bureau Israel
[f]Statistics New Zealand
[g]Statistics Sweden
[h]US Census Bureau 2008

Table 4.1: Data for comparing with the predictions of the model

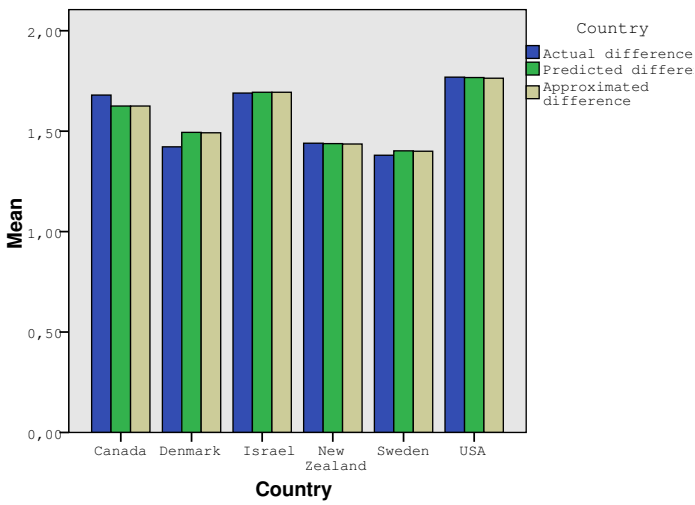

Figure 4.3: Differences in income according to education in some countries, actual and predicted values

There is a strong correlation between the models predictions and the

data ($r = 0.975, p < 0.001$). In figure 4.3, we can see the actual differences in income between people with low and high education compared to those predicted by the model and the approximation. We can also see that there is a very small difference between the model and the approximation. The model seems to be a very good predictor of social stratification in these countries.

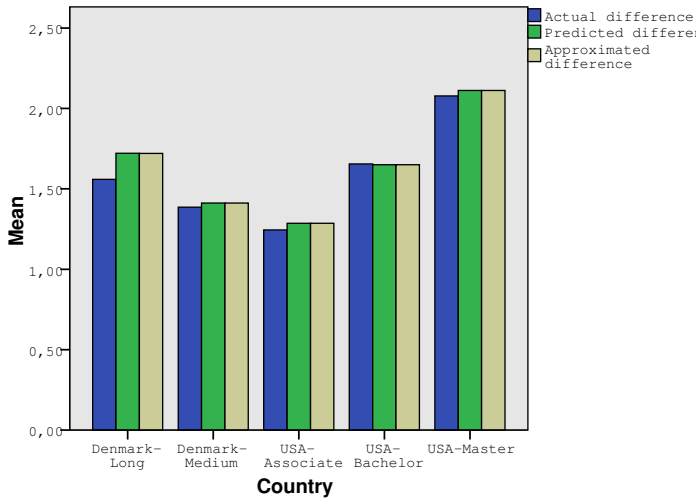

Figure 4.4: Differences in income according to education within some countries, actual and predicted values

The model can also be used to predict differences between different levels of education within a country. Figure 4.4 shows differences between three different degrees in USA and two in Denmark. This graph also shows a clear correlation with the data, suggesting that the model is not just good at predicting differences between countries but also within countries.

4.5 Conclusion

The results from this model show that social stratification in terms of monetary income is expected to appear endogenously as soon as individuals value future payoffs lower than immediate, even when there are no individual differences. This is done by incorporating a discounting of future payoffs to individuals utility function. Individuals simply do not value future payoffs

high enough to pay the immediate cost of studying when the future payoffs decline due to a lower demand of educated workers.

The model has been applied to statistical data and found to be a very good predictor of social differentiation in the tested countries. The discount rate used for fitting the models predictions to the data is also consistent with the results from Benzion et al. (1989). The discount rate is in the lower end of those found in earlier studies, but this is reasonable considering the positive connotations of education and that the desicion is about a large sum of money, which has been shown to lower the discount rate. The model also predicts differences in income according to level of education within countries very well.

Further, the model yields predictions on how to influence the proportion of educated workers. To encourage more people to start studying, lowering the cost would seem very reasonable. This model show that the populations level of education will just increase linearly with a decreased cost. Lowering the discount rate on the other hand, would yield an exponential increase in the proportion of educated individuals. The discount rate might be affected by more information about the benefit of studies and how large the difference in income is over a longer period of time.

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Appendix

$$
\begin{aligned}
w_M^f &= \sum_{n=1}^{t} \frac{(1-q_H)b}{R^n} - c = \\
&= (1-q_H)\, b \left(\frac{1-R^{-t}}{r} \right) - c \\
w_L^f &= \sum_{n=0}^{t} \frac{1}{R^n} = \frac{R-R^{-t}}{r}
\end{aligned}
$$