The *New Economy*: Some Macroeconomic Implications of an Information Age[*]

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Abstract

We study the macroeconomic implications of three key features of an *information age*: i) the information technology revolution favors information production and hence information compared to other inputs of production becomes relatively cheaper; ii) information is an intermediate input that, once produced, can be reused at no extra cost (the marginal cost of using information is almost zero); iii) information production is human capital intensive. These features are incorporated into a dynamic general equilibrium model and the implications of an information revolution for productivity, distribution and welfare are analysed.

VERY VERY PRELIMINARY

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1 Introduction

The past two decades have witnessed extraordinary changes in the way we work, live, and communicate with one another. The spread of information and knowledge now occurs at speeds that would have been unthinkable only thirty years ago. In the past decade, these changes were accompanied by strong economic growth and rising productivity. One view of these developments holds that we are in the midst of a new industrial revolution driven by information technology and that in this "new economy" the conventional wisdom of the old bricks and mortar economy no longer applies. A more modest view is simply that technology has changed in important ways and all that is needed is an analysis of how these changes in technology affect pricing, markets, and productivity. A more skeptical view is that the information technology boom does not even rank with the great innovations of the twentieth century.[1] Our goal in this paper is to analyze explicitly and formally how an information technology revolution affects an economy, with a particular emphasis on how it changes productivity, income distribution, and economic welfare.

To make progress on this question one needs to understand the role of information and its availability in the economy. We approach this issue by treating information as a central attribute of goods. The key feature of information is that, once it is produced, it can be used repeatedly without much additional cost - the marginal cost of using information after it is produced is almost zero. Software that costs hundreds of millions of dollars to develop can be copied on a CD for a few cents, 100-million dollar movies can be copied on a videotape for a few dollars. Similarly, a 100-million dollar sports event —an NBA final or a soccer match— can be enjoyed by an additional sports fan with almost no extra cost. Tens of millions of dollars are spent for the development and maintenance of professional corporate Web sites through which an additional customer can be served at zero marginal cost. The cost of producing the first copy of an information-intensive good is often substantial, but the cost of producing (or reproducing) additional copies is negligible. These features of information-intensive goods have been stressed by other authors.

The production of information itself is human capital intensive. This means that, in an information age, human capital will become a more important determinant of economic success. Human capital investment decisions play an important role in the nature of the goods that are produced and have important implications for the distribution of income.

To capture these ideas we proceed by characterizing all goods in terms of their

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[1] See for example Frances Cairncross (2000) for a very rosy view of the "new economy", Shapiro and Varian (1999), for an example of the more modest view and Robert Gordon (2000), for the most skeptical view.

information content. On this view, information is an input to the production process. We can think of goods as being produced with two types of intermediate input: information inputs and non-information inputs. The criteria for classifying inputs is the marginal cost of usage: the marginal cost of information inputs is zero while the marginal cost of non-information inputs is always non-zero. This framework implies a very broad notion of information. Essentially, anything that, *once produced,* can be *reproduced costlessly* is information. For our purposes books, databases, software, magazines, music, stock quotes, Web pages, scientific knowledge, are all information. It is obvious that in an information age, information will become more important than other "bricks-and-mortar" type inputs, and will be a larger part of the production of consumption goods.

Given this notion of information, we can characterize all products in terms of their information intensity. Consider, for instance, the production process for delivering knowledge by teaching. Teaching involves non-information inputs like buildings and equipment that need to be provided to a marginal student at a positive —probably, at the optimal size, constant or increasing— marginal cost. The teaching activity itself, though, is an information input which is performed once regardless of the number of students in a classroom or on a network. When the shares of information and non-information inputs in the total cost of teaching is considered, the share of information inputs (cost of teachers) outweighs the share of non-information inputs, i.e. teaching is information intensive. In an information age, when access to students is less limited by the need for physical inputs, the information intensity of teaching increases increases. In contrast, consider more traditional bricks-and-mortar manufacturing goods like consumer durables and producer durables. For these goods a larger portion of total inputs are likely to be non-information intermediate inputs so that manufacturing is a less information intensive production process.

In subsequent sections we analyze some of the macroeconomic implications of an information revolution. In particular we illustrate the consequences of an increase in the information intensity of production, given the main feature of information that, once it is produced, it can be reproduced costlessly. We begin by offering a precise definition of information goods. We proceed to define a general equilibrium environment in which agents choose the human capital investments that will determine the kinds of goods they produce and have incentives to create new goods. We then show how an economy changes with an information revolution that increases the efficiency of information production.and distribution.

We find that an information revolution, has important implications for the evolution of the economy and that these changes play out over many decades. In particular, an information age will lead to an increase in income inequality, a long fall and then a sharp rise in measured productivity, an increase in concentration, sharp declines in the prices of high-information goods, a fall and a subsequent increase in the value of the stock market, and an increase in the speed of diffusion of new products to households. All of these features are consistent with observations over the past two and half decades.

Before describing the economic theory and the model economy we employ to study the role of information it is useful to describe about some of the features of the *new economy* that seem to distinguish it from the recent past. We turn to that discussion in the next section.

1.1 Some Observations

There have been some noteworthy changes in the economic environment in the past two decades that go well beyond the proliferation of computers and the spread of the internet. Many of these have been widely discussed in the press and elsewhere. Here we focus attention on those that seem most directly relevant to the question we are addressing: How does an information revolution affect the economy?

- **There has been a surge in product innovation. The "new economy" has been characterized by a dramatic increase in the number of new products.**

Households get utility from the variety of goods and services they can consume. But, determining what makes a good a different variety is somewhat difficult. There are two primary ways of measuring innovation of new goods. One alternative is to use patent data. Patent data has some drawbacks. First, patents don't represent economically successful innovations, i.e., many patents may not see the final application stage where they are used to produce a new good. On the other hand, there are patents which are successfully used in development of many new goods. Secondly, there can be a relatively long period of time between patenting an innovation and its usage in a new product. Further, patents can be issued for both product innovations and process innovations.

The alternative we follow is to use trademark data.[2] There are some drawbacks to trademark data as well, for example new trademarked goods and services might not really represent different varieties. Nevertheless trademarking a product or a service is a relatively costly and time-consuming process so that a business will not trademark its product unless the probability that the trademark can be used to distinguish the product from the rival products is high enough. The cost of trademarking a product is

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[2] According to the definition used by the USA Patent and Trademark Office, a *trademark* "is a word, phrase, symbol, or design, or combination of words, phrases, symbols, or designs which identifies or distinguishes the source of the goods and services of one party from those of others."

the same order of magnitude as patenting cost. The other difference between patents and trademarks that might be important is that, unlike copyrights and patents, trademark rights can last indefinitely if the owner continues to use the trademark to identify its goods or services and he is willing to pay additional fees. The term of a federal trademark registration is 10 years, with 10-year renewal terms. These renewals are also costly and at the time of renewal some kind of proof that the trademark is actively used is necessary. So, trademark data always tracks economically successful goods or services. That may not be the case for the patent data. Another important advantage of the trademark data is that the average length of time for processing a trademark application is usually no more than ten months.

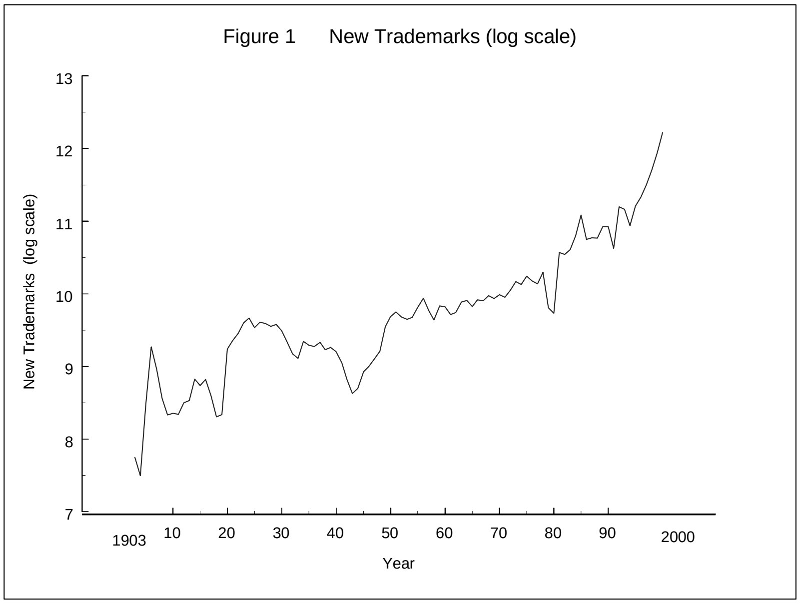


Figure 1 New Trademarks (log scale)

The number of new trademarks issued between 1903-1997 is shown in Figure 1 on a log scale. The number of new trademarks showed periods of growth both before and after World War I but then declined for nearly twenty years during the Great Depression and World War II. It was relatively level until the 1980's when it began to increase dramatically. One can also look at the stock of trademarks that are active over this period. Although they are not measured directly they can be proxied using the flow of new trademarks issued and a hazard function for existing trademarks. Following these steps Figure 2 plots the estimated stock of active trademarks between 1903-1997 on log scale.

Figure 2 Active Trademarks (log scale)

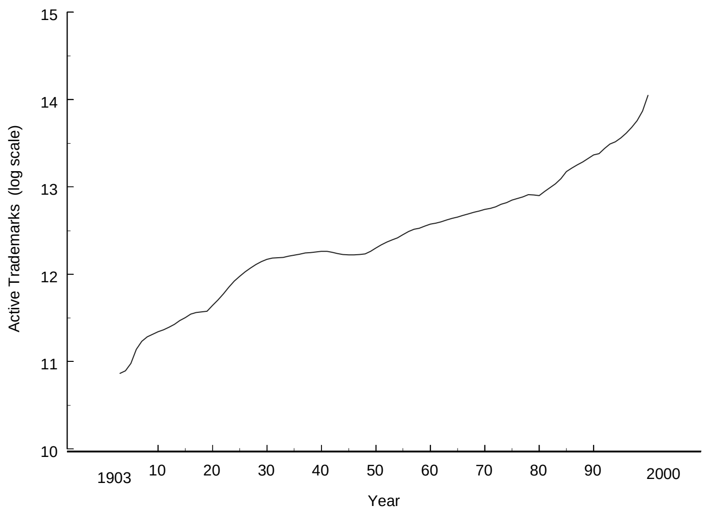
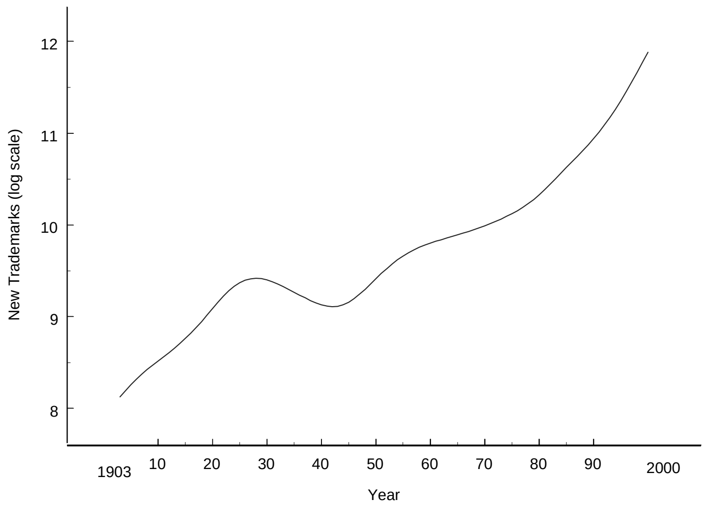


Figure 3 Trend in New Trademarks (log scale)



Finally, Figure 3 shows the trend in new trademarks. Again, we can see the dramatic increase starting in the 1970's and 1980's and continuing to the present.

It is worth noting that patent data show the same surge in the recent decades as does the data on the number of new firms entering. Jovanovic and Rousseau (2001) focus attention on the firms dynamics of the past two decades and compare it to the period before and after World War I which is the period of innovation associated with the spread of electrification and the automobile.

- **A rise in income inequality across groups and the growth of winner-take-all markets.**

Beginning in the 1970's and continuing in the 1980's and 1990's inequality of wages in the U.S. increased dramatically. Similar patterns have been observed in other OECD countries. These basic observations have been carefully documented (see e.g. Gottschalk (1997) and Gottschalk and Smeeding (1997) for useful surveys) and do not bear repeating here. Some of this rise in inequality has been due to an increase in the wage premium for skilled workers. Greenwood and Yorukoglu (1997) link this observation to an information technology revolution beginning in 1974 and note that similar patterns were observed in previous industrial revolutions. Many seem to have settled on the explanation that this rise in inequality across skill groups is largely due to skill biased technical change.

Since the basic observations about a rise in inequality are undisputed, we want to focus attention instead on a slightly different interpretation of the rise in inequality that is linked to information. This phenomenon is the growth in winner-take-all markets as has been described for example by Frank and Cook (1995) . The notion of winner-take-all markets has been around for a long time. Such markets have been described analytically by Sherwin Rosen (1981) and others. Rosen predicted that new technologies, by increasing the scope of the market for the most talented performers, would increase the inequality of incomes. Frank and Cook argue that this has happened on a broad scale. Their argument is that information inputs allow markets to expand in scope and the rewards for the most successful competitors increase dramatically. Thus, the rise in inequality is directly linked to growth in the information content of goods. There are many examples of this; here we present one drawn from professional sports.

Figure 5 Revenue of Football Teams in British Premier League

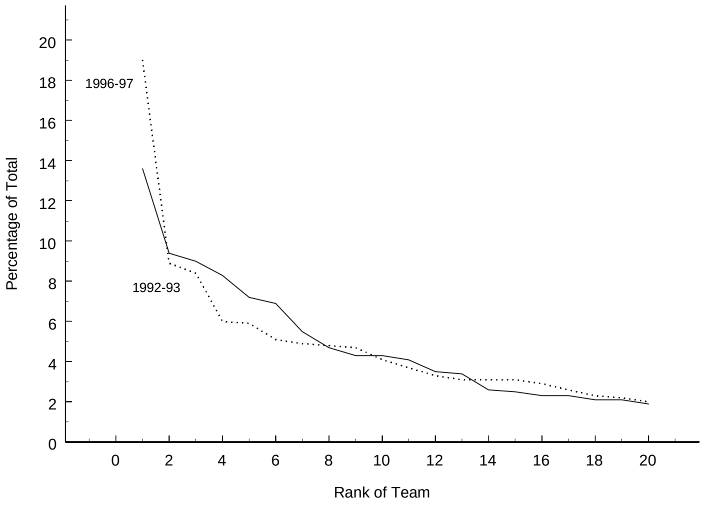


Figure 4 shows the revenues of teams in the British Premier Football League for the period 1992-1993 and 1996-1997. The data are in the accompanying Table. Evident from the figure is that this is an example of market which has become increasingly winner-take-all in that more of the revenues go to the most successful teams. Here the standard deviation of revenues increased from .32 to .39 between the two periods. What changed between 1992-1993 and 1996-1997? The information content of the product changed with the introduction of a sports channel, that made the games of all teams more accessible to the viewing public. This increased the exposure of the most successful teams and resulted in their having a larger share of the revenues. Similar phenomena are prevalent in other professional sports and in many other markets.

	1992 – 93 Revenue (£m)	1992 – 93 %	1996 – 97 Revenue (£m)	1996 – 97 %	Growth in revenue %
Team					
Manchester U.	25,177	13.6	87,939	19.0	249.3
Newcastle U.	8,743	4.7	41,134	8.9	370.5
Liverpool	17,496	9.4	39,153	8.4	123.8
Tottenham H.	16,594	9.0	27,874	6.0	68.0
Arsenal	15,342	8.3	27,158	5.9	77.0
Chelsea	7,891	4.3	23,729	5.1	200.1
Middlesborough	3,968	2.1	22,502	4.9	467.1
Aston Villa	10,175	5.5	22,079	4.8	117.0
Leeds U.	13,324	7.2	21,785	4.7	63.5
Everton	7,994	4.3	18,882	4.1	136.2
Leicester City	4,775	2.6	17,320	3.7	262.7
West Ham U.	6,571	3.5	15,256	3.3	132.2
Notts Forest	7,651	4.1	14,435	3.1	88.7
Sheffiled W.	12,806	6.9	14,335	3.1	11.9
Blackburn R.	6,305	3.4	14,302	3.1	126.8
Sunderland	3,806	2.1	13,415	2.9	252.5
Coventry City	4,592	2.5	12,265	2.6	167.1
Derby County	4,183	2.3	10,738	2.3	156.7
Wimbledon	3,556	1.9	10,410	2.2	192.7
Southampton	4,306	2.3	9,238	2.0	114.5
Total	185,256	100.00	463,949	100.00	150.4

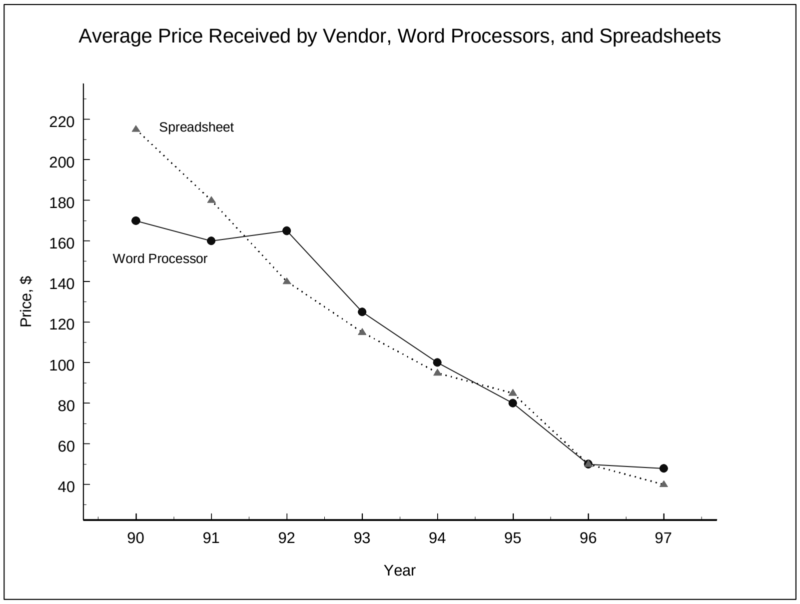
- **A dramatic decline in reproduction and distribution costs of information intensive goods.**

One of the striking changes of recent years is that information intensive goods (like lectures) can be rapidly desseminated to many people at very low cost. There have been decisive changes in the cost structure of media through which information goods are distributed. The following table provides estimates of the share of production, reproduction, and distribution costs as a percentage of total cost for various types of media. By definition these are all high information content goods. What is most remarkable is the dramatic drop in the costs of disseminating information as one moves across media types.

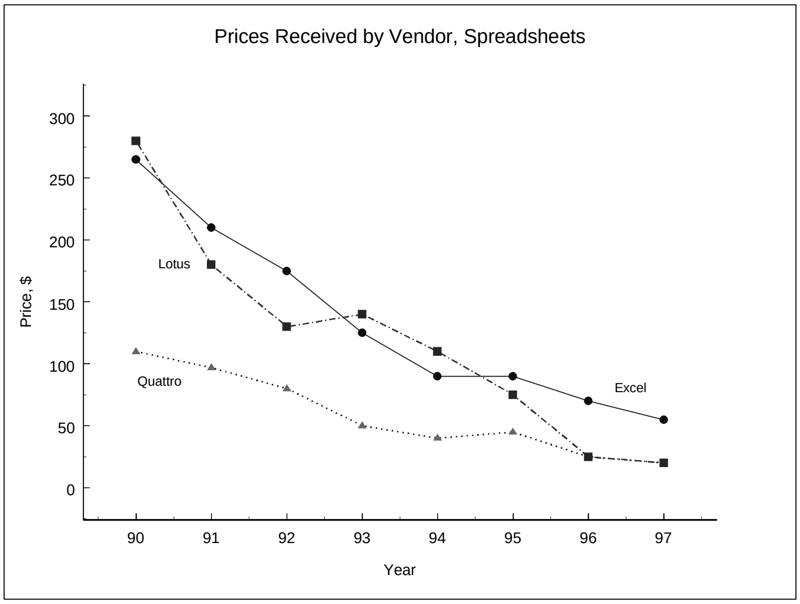
	Production Cost	**Reproduction Cost**	**Distribution Cost**	**II+III**
Type of Media				
Newspapers	20.0	39.5	19.0	58.5
Magazines	29.5	28.1	6.6	34.7
Public service television	55.9	0	9.2	9.2
Commercial television	68.9	0	7.1	7.1
Internet	99	0	1	1

- **Rapidly declining prices of information intensive goods.**

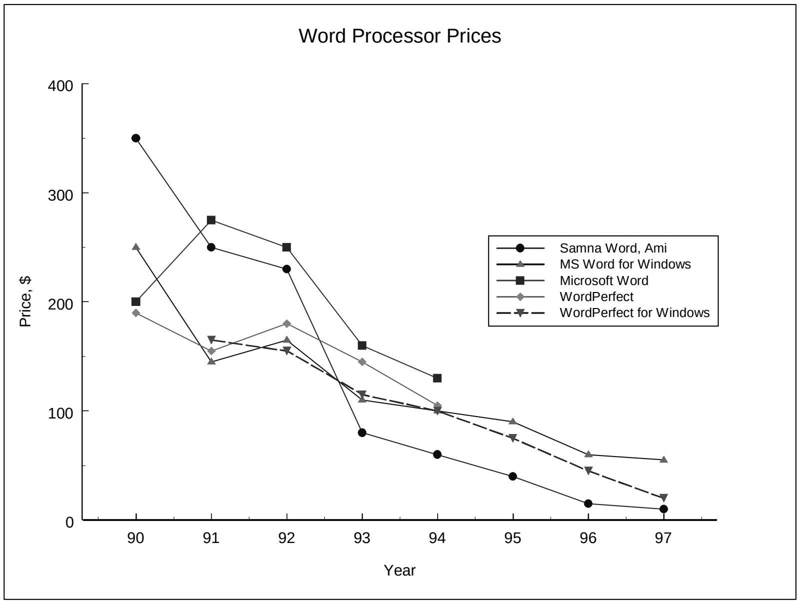
One of the striking features of information intensive goods has been the rapid decline in their prices. Robert Gordon (2000), among others, has documented the rapid declines in the price of computer hardware and peripherals. He estimates that between 1987 and 1995 prices **declined** at an average four quarter rate of 14.7 percent and from 1996-1999 this increased to a rate of decline of 31.2 %. Software is another good example of an even more information intensive good. For most categories of software the price declines very rapidly after its development. The following three graphs illustrate the evolution of prices for some of the most widely used software products - spreadsheets and word processors. These prices are not adjusted for quality improvements or inflation hence they understate the real decline in software prices. The quality improvements in software have been enormous as anyone who experienced DOS versions of WordPerfect of early 90's and recent versions of WordPerfect for Windows would know.



Average Price Received by Vendor, Word Processors, and Spreadsheets



Prices Received by Vendor, Spreadsheets



- **More rapid diffusion of new information intensive products into household's consumption bundles.**

An observation that is less well documented but is entirely in keeping with the rapidly declining prices of information intensive goods is that new products find their way into household's consumption bundles more rapidly. Table 1 below shows the time elapsed from the date of important ninnovations to the point at which 25% of households have them as part of their consumption bundles.[3]

Years To Adoption By 25% of Households

Invention	Year Invented	Years
Electricity	1873	46
Telephone	1876	35
Automobile	1886	55
Airplane	1903	64
Radio	1906	22
Television	1926	26
VCR	1952	34
Microwave Oven	1953	30
Personal Computer	1975	16
Cellular Phone	1983	13
Internet	1991	7

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[3] Source: Cox and Alm (1999).

What is striking in this Table is that time to adoption has declined dramatically for more recent innovations. Many of these, like the VCR, took many years to be commercially available, but once they were adoption was very rapid. Households are able to consume the newest goods more rapidly.

All of these observations are related to the information technology revolution. In the next sections we show more precisely how they are related.

2 The Economy

2.1 Information Goods

We begin by assuming there are two types of goods defined on the set $G = \left\{\underline{\theta}, \overline{\theta}\right\}$, $0 < \underline{\theta} < \overline{\theta} < 1$. [4]One unit of a type θ good of age τ can be produced according to the technology

$$g_\tau(\theta) = \left\{(i, m) \mid s_\tau i^\theta m^{1-\theta} = 1\right\}, \qquad \theta \in G, \tag{1}$$

where s_τ denotes the productivity with which an age-τ good can be produced, i is the information input and m is the non-information input used in producing this good. Here $g_\tau(\theta)$ is the set denoting all possible (i, m) input couples which produce one unit of age-τ good of type θ. As θ increases the good becomes more information intensive. We assume that all goods require both non-information and information inputs. Age-specific productivity s_τ is exogenously increasing in age at a decreasing pace. This captures the effects of learning by doing, productivity increases due to further R&D, on so on. We assume $s_{\tau+1} > s_\tau$, $0 < s_1 < 1$, $\lim\limits_{\tau \to \infty} s_\tau = 1$, and $\frac{s_{\tau+1} - s_\tau}{s_\tau - s_{\tau-1}} < 1$.

The intermediate information input is produced at time t via the production function

$$i = z\gamma^t h,$$

where $z > 0$ and $\gamma > 1$ are productivity coefficients and h is the human capital of the producer.

The intermediate non-information input is produced according to the production function

$$m = \gamma^t n,$$

where n is the amount of labor used.

2.2 Agents

A new generation of agents is born every period and lives for M periods. Each agent is born with a fixed ability level, λ, which is distributed over the population according

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[4] We consider the case of two types of goods, high-information and low-information, for simplicity. The extension to a continuum is straightforward.

to the cumulative distribution function $\Lambda(\lambda)$. Each period agents must decide how much time to invest in their human capital accumulation and what type of good to produce. The human capital of an agent depends on his ability level and on his investment in the following way

$$h' = H(\lambda, e)h, \tag{2}$$

where e is the amount of investment the agent makes in his human capital. Here, H is homogeneous of degree one in λ, $\frac{dH(\lambda,e)}{de}$, $\frac{dH(\lambda,e)}{d\lambda} > 0$, $\frac{d^2H(\lambda,e)}{de^2} < 0$, and $H(\lambda, 0) = 1$, for all λ.

This is an economy in which agents have a taste for variety. That is, the ability to consume new types of goods gives them utility. For simplicity, we assume symmetry across different types of goods in terms of the utility that they bring to the agents. Thus, agents value different types of goods the same way, i.e., they do not prefer more information intensive goods to the less, per se, and vice versa. Let $u_i(c)$, $i \in G$, denote the amount of utility that the agent receives from consuming ith type of product and $U(\{c_i\}^N)$ denote the total utility the agent receives from consuming the set $\{c_i\}^N$. Then assume

$$u_i(c) = u_j(c) \text{ for all } i, j \in [\underline{\theta}, \overline{\theta}] \text{ and all } c,$$

and

$$U(\{c_i\}^N) = \log\left(\int_0^N u_i(c_i)di\right)^{\frac{1}{\phi}}$$

where $u_i(c_i) = c_i^{\phi}$, N is the number of goods available, and c_i is the consumption of the ith good.

Each period a new generation of agents is born with initial human capital level h_o which is normalized to one. The decision problem of an age-j agent with the ability level λ and initial human capital h and assets a is

$$W_j(\lambda, h, a) = \max_{\theta,\tau,(m,i),a',\{c_i\}^N,e} \left[U(\{c_i\}^N) + \beta W_{j+1}(\lambda, h', a')\right] \tag{P1}$$

s.t.

$$\int_0^N p_k c_k \, dk \; + a' = a(1+r) + [p_\tau(\theta) - f_\tau(\theta)]\, y_\tau(\theta), \tag{3}$$

$$c_k \in \{0, [\underline{c}, \infty)\} \text{ for all } k, \tag{4}$$

$$h_{j+1} = H(\lambda, e_j)h_j, \tag{5}$$

$$s_\tau i^\theta m^{1-\theta} = 1, \tag{6}$$

$$i = z\gamma^t h, \text{ and } m = \gamma^t n,^{5}$$

$$ny + G_\theta(y) + e = 1. \tag{7}$$

where y is the amount of the product that the agent produces, e is the time that he spends for human capital accumulation and N is the total number of distinct goods available in the economy. On the production side, depending on his human capital, the agent decides which type of good to produce, that is, he chooses a θ. Having decided on θ, the agent chooses the optimal (i, m) couple. Finally given the market price of his product $p_\tau(\theta)$ he decides the quantity of his output to produce. On the consumption side each agent decides how much of each product to consume. The budget constraint, equation (3) says that consumption plus assets carried into the next period must equal the return on assets from the previous period plus the return from producing output y. That return is simply the revenue from selling y, minus $f_\tau(\theta)$ which represents the patent fee that must be paid to the owner of a patent for a type θ product of age τ. We describe this patent fee further below. Equation (5) is the human capital accumulation equation, while equation (6) ensures that $(i, m) \in g(\theta, j)$. Finally, (7) is the agent's time constraint.

Because of the form of the utility function every agent would like to consume some of each variety of goods. Here we assume that there must be at least a minimum level of consumption of each good, $\underline{c}$, due to the constraint (4). This means that not all agents will be able to consume all goods.

Notice that in (7) an agent has to spend n units of time to produce the non-information input for each unit of the good y that he produces whereas he does not need to spend any time at all to produce the information input. The amount of information input he produces depends on his human capital and he has to produce the information input only once regardless of the amount of output, y. This is the crucial difference between the information and non-information input. The cost of distributing goods to consumers is explicitly modeled. In fact, one of the important changes that is shaping the information age, we will argue, is the diminishing cost of distribution of products to customers. In the time constraint (7), $G_\theta(y)$ denotes the cost of distributing y units of type θ good. For simplicity let's normalize distribution cost for non-information goods to zero, i.e., let's assume $G_{\underline{\theta}}(y) = 0$.

Assumption: *Let* $G_{\overline{\theta}}(y) > 0$, $G'_{\overline{\theta}}(y) > 0$, $G''_{\overline{\theta}}(y) > 0$ *and* $G_{\overline{\theta}}(0) = 0$.

This assumption says that the marginal cost of distributing information goods is increasing with the amount distributed.

The state of an agent in this economy will be given by $s = (j, \lambda, h, a)$, the agent's age j, his ability level, λ, his human and physical capital h,and a respectively. Let the measure of agents with state s be denoted by $\phi(s)$.

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[5] Time subscripts are omitted in other equations for simplicity of notation.

Consider an age-j agent with state $s = (j, \lambda, h, a)$. Let his best product type be θ. The efficiency condition for his human capital accumulation decision is

$$\frac{dW_{j+1}(\lambda', h', a')}{dh'} \frac{dH(\lambda, e)}{de} = \frac{[p_\theta - f_\theta]}{n_\theta(s)} \tag{8}$$

where $n_\theta(s) = \left(\frac{1}{\gamma^t z^\theta h^\theta}\right)^{\frac{1}{1-\theta}}$. The left hand side of (8) gives the benefit from an additional unit of time invested in human capital. The right hand side of the equation gives the opportunity cost of time for that individual.

Notice that the product-type decision —which type of product to produce— is a static decision. Given the human capital of the individual he just picks the type and the age of good, θ, and τ that maximize his current net profit,

$$\max_{\theta,\tau} \left[p_\tau(\theta) - f_\tau(\theta)\right] y_\tau(\theta) \tag{9}$$

where $p_\tau(\theta)$ and $f_\tau(\theta)$ are given. Here the amount of type θ good that the agent can produce, $y_\tau(\theta)$, depends on his human capital. By (6) and (7), $y_\theta(s) = \frac{1}{n(s)} = (1 - e(s))(\gamma^t z^\theta h^\theta)^{\frac{1}{1-\theta}}$, where $e(s)$ is the optimal human capital investment given the state of the individual, s. Observe that $y_\theta(s)$ is strictly increasing in θ if $zh > 1$.

3 New Product Creation

Let the number of products of type θ be denoted by N_θ. New products can be produced by incurring a product development cost. Assume that an amount $\frac{\omega_\theta}{\gamma^t}$ of the composite labor (one unit of labor-time from each ability level) is necessary for product development. Therefore, a product development cost of $\frac{\omega_\theta}{\gamma^t} \int_\lambda w_\lambda d\lambda$ is incurred for every new product developed. Let the number of agents producing a type θ good be denoted by η_θ.

Anyone who develops a new product enjoys patent protection for their innovation. We assume the owner of a patent has protection rights for T periods. During the period when the patent owners have protection, the patent can be licensed to others and the problem is to decide how much to charge each producer that produces the product. The period profit for the patent owner of a $\tau-$period old product of type θ is

$$\Pi_\tau(\theta) = \max_f f D_\theta(p_\theta(f); \mathbf{p}, \boldsymbol{\phi}), \quad \tau \leq T \tag{10}$$

where f is the amount per unit that the manager of the patent charges the producers, $D(p_{\theta,\tau}(f); \mathbf{p}, \boldsymbol{\phi})$ is the demand function for a product of type θ given the price of the product, $p_{\theta,\tau}(f)$, price of all other products $\mathbf{p}$ and the distribution of individual measures $\boldsymbol{\phi}$ (aggregate measure). Hence $D_\theta(p_\theta; \mathbf{p}, \boldsymbol{\phi})$ will be given by

$$D_\theta(p_\theta; \mathbf{p}, \boldsymbol{\phi}) = \int d_\theta(s; p_\theta, \mathbf{p}) d\phi. \tag{11}$$

Here $d_\theta(s; p_\theta, \mathbf{p})$ is the optimal demand function of an agent with state $s = (j, \lambda, h, a)$ for a type θ product given the prices p_θ,and $\mathbf{p}$. The optimization problem for an owner of a patent of a type θ good at age τ is given by

$$V_{\theta,\tau} = \Pi_{\theta,\tau} + \frac{V'_{\theta,\tau+1}}{1+r}, \quad 1 \leq \tau < T \tag{P2}$$

Here $V_{\theta,\tau}$ gives the value of an age-τ good of type θ. Let χ_θ denote the number of type θ product innovations at a point in time. Obviously, if there is innovation in equilibrium for a type θ product the no-profit condition should hold,

$$\frac{\omega_\theta}{\gamma^t} \int_\lambda w_\lambda d\lambda - V_{\theta,1} \begin{cases} > 0 & \text{if } \chi_\theta = 0, \\ \leq 0 & \text{if } \chi_\theta > 0. \end{cases} \tag{12}$$

So, the investments needed to create a type θ product will only be undertaken whenever the present value of innovation is non-negative. Since anyone can innovate, in equilibrium, there must be zero rents from doing so.

The patent owner picks the patent charge f that maximizes her profit which is given in (10). Notice that the decision about f is a static problem, it does not affect the owners future choices. Hence the efficiency condition to (10) is given by

$$\frac{d\Pi_\theta}{df} = D_\theta(p_\theta(f); \mathbf{p}, \boldsymbol{\phi}) + f \frac{dD_\theta(p_\theta; \mathbf{p}, \boldsymbol{\phi})}{dp_\theta} \frac{dp_\theta(f)}{df} = 0. \tag{13}$$

Since there is a mass of agents producing each product, the market for each product is competitive. Therefore $\frac{dp_\theta(f)}{df} = 1$, any increase in the patent charge will be reflected one for one in the price of the product . Hence the solution to the problem (10) will just be the monopolist's solution,

$$f_\theta = -\frac{D_\theta(p_\theta(f); \mathbf{p}, \boldsymbol{\phi})}{\frac{dD_\theta(p_\theta; \mathbf{p}, \boldsymbol{\phi})}{dp_\theta}}.$$

Patent management is a cost-free activity that can be undertaken by any agent. Since it is a cost-free activity it does not use up any economic resources and since anybody can do it there are no profits from patent management activity. The agents who manage patents finance the cost of product development by selling the shares of the patents of their products to the people. Each period they pay out patent profits in dividends. Total current dividends will then be given by $B = \sum_\theta \sum_{\tau=1}^{T} \Pi_{\theta,\tau} \mu_{\theta,\tau}$. The value of patents in the economy is given by $Q = \sum_\theta \sum_{\tau=1}^{T} V_{\theta,\tau} \mu_{\theta,\tau}$. It is clear that the no-arbitrage condition, $1 + r = \frac{Q'+B'}{Q}$, should hold in equilibrium.

4 Equilibrium and Balanced Growth

The aggregate state of the world in this economy is given by, $\mathbf{s} = (z, \boldsymbol{\phi}, \boldsymbol{\mu})$,where z is the relative productivity of information production, $\boldsymbol{\phi}$ is the distribution of individuals across states, $\boldsymbol{\mu}$ is the distribution of products across types. The equilibrium prices p_θ, interest rate r, dividend payments and the share price of patents can all be expressed as a function of the aggregate state of the world, s.

Definition: A competitive equilibrium is a set of allocation rules $\theta_i(s) = \Theta(s;\mathbf{s})$, $a'(s) = A(s;\mathbf{s})$, $e_i(\lambda) = E(\mathbf{s})$, $h'(s) = I(s;\mathbf{s})$, $\mu'_\theta = \Psi_\theta(\mathbf{s})$, together with a set of pricing functions $p_\theta = P_\theta(\mathbf{s})$, $r = R(s)$, $f_\theta = F_\theta(\mathbf{s})$ such that

1. Agents solve their utility maximization problem $(P1)$ with the equilibrium solution to this problem satisfying $\theta(s) = \Theta(s;\mathbf{s})$, $a'(s) = A(s;\mathbf{s})$, $h'(s) = I(s;\mathbf{s})$
2. Patent managers charge patent fees to maximize their profits in (9), with the equilibrium solution to this problem satisfying $f_\theta = F_\theta(\mathbf{s})$.
3. Product distribution across types as given by $\mu'_\theta = \Psi_\theta(\mathbf{s})$ is determined in accordance with the innovation and renewal criteria (12) and (13).
4. Markets clear, for the goods market implying

$$\int \Omega_\theta(s)\frac{y_\theta(s)}{\mu_\theta}\eta(s)ds = \int d_\theta(s; p_\theta, \mathbf{p})d\phi + \frac{\varphi N}{\mu_\theta} + \frac{\kappa}{\mu_\theta}\int_{\underline{\theta}}^{\overline{\theta}} \chi_\theta d\theta \text{ for all goods.} \tag{14}$$

where $\Omega_\theta(s)$ is an indicator function $\Omega_\theta(s) = \begin{cases} 1 & \text{if } \Theta(s;\mathbf{s}) = \theta, \\ 0 & \text{otherwise.} \end{cases}$ and for the financial market implying

$$\sum_{i=1}^{M} \int a'_{i+1}(s)\eta(s)ds = Q'. \tag{15}$$

where $\eta(s)$ denotes the number of agents with state s. The left hand side in (14) is total output for each good. The first term on the right hand side gives total consumption and the second and third terms give total amount of the good used for product innovation and patent renewal respectively.

4.1 Balanced Growth

Along a balanced growth path the amount of output that each individual can produce $y(s)$, the total number of goods, N, the value of patents Q, and total dividend payments B will all be growing at rate γ.

5 Discussion

In this section we describe some of the properties of the economy with information goods. In the next section we will illustrate these features quantitatively.

Proposition 1 There will be a surge of innovation of new products in an information age.

The key feature of information is that it can be reused costlessly. Because of this, the markets for information intensive goods will have the winner-take-all feature. These markets will not be thick, because there will be a smaller and smaller mass of producers producing a product as the product becomes more information intensive. As the technology to produce information improves —as information becomes cheaper and cheaper— more agents will be willing to produce more information intensive products. However because the market becomes less thick as the product gets more information intensive, the economy will create more products. An *information-age* economy will be one that supports a large variety of products—in fact asymptotically as many products as the number of agents. This is in sharp contrast to a mass production economy that would produce a few products with great efficiency. Because of this, traditional productivity measures will be very misleading in an information intensive economy and will not be closely related to welfare. Here we will propose a new measure of well-being that is robust for the information age economy. Those issues will be formally discussed below.

To highlight the above argument more let's consider two extreme cases: a non-information good only economy ($\theta = 0$), and an information good only economy ($\theta = 1$).

Let's normalize for the moment γ^t to unity. In the non-information good only economy, $y = n$. Let the price of a unit of good be p. Let the product owners charge each producer f. Then $\eta(1) = \frac{(1-\alpha)}{N}$ and $c_i = \frac{(1-\alpha)}{N}$. —**to be continued**.

Proposition 2 *Let $\Theta(h)$ denote the product choice of an individual with human capital level h. Then in equilibrium $\Theta(h)$ is strictly increasing in h.*

This proposition states that high human capital agents will choose to produce more information intensive products in equilibrium. The following proposition is a corollary to the above proposition. Since the human capital accumulation function $H(\lambda, e)$ is strictly concave in e and there is no depreciation in human capital as individuals age, their human capital increases and they choose to produce more human capital intensive products.

Proposition 3 *Let* Γ_i *denote the distribution of types of products that the* i *period old agents produce. Then* Γ_{i+1} *stochastically dominates* Γ_i*, i.e., as they age, individuals choose to produce more information intensive products.*

The following proposition states that the equilibrium prices for goods and the patent fee charged by the patent owners are strictly decreasing through time. Also, the second part of the proposition states that information intensive good prices decline faster.

Proposition 4 *Equilibrium good prices,* $p_{\theta,\tau}$*, and patent fees,* $f_{\theta,\tau}$*, are strictly decreasing in* τ*. Furthermore* $\frac{p_{\theta_i,\tau}}{p_{\theta_j,\tau}}$ *,*$\theta_i > \theta_j$*, is monotonically decreasing in* τ*.*

As information production becomes more efficient, a larger fraction of the goods will be information intensive. Also, since high human capital agents produce information intensive goods in equilibrium, this improveent in information technology increases the income of high human capital individuals. The effect of this is to increase income inequality.

Proposition 5 *Let* $\widehat{\mu}(\theta)$ *denote the measure of products of type* θ*. Consider two economies identical except* $z' > z$*. Then, i)* $\widehat{\mu}(\theta)$ *stochastically dominates* $\widehat{\mu}'(\theta)$*; ii) income distribution is more unequal in the primed economy.*

As the information intensity of a good increases, its marginal cost of production decreases. This makes the market for information intensive goods thinner, with fewer producers as the good becomes more information intensive. This is stated in the following proposition.

Proposition 6 *The number of agents producing a type* θ *good,* $\eta(\theta)$*, is decreasing in* θ*.*

In equilibrium, depending on the human capital distribution across agents and the production functions, a compact subset of the set for good types, G will be produced. As information production becomes more efficient this subset will shift to right. This is expressed in the following proposition.

Proposition 7 *At a steady state with constant* z*, and* A *there exists* $\theta_l, \theta_u \in G$*,* $\theta_l < \theta_u$ *such that*

$$\chi_\theta \begin{cases} = 0, & \textit{if } \theta \notin [\theta_l, \theta_u], \\ > 0, & \textit{if } \theta \in [\theta_l, \theta_u]. \end{cases}$$

Furthermore $[\theta_l, \theta_u]$ *will be monotonically shifting to right as* z *increases or* A *decreases.*

6 A Quantitative Example of An Information Revolution

In this section we describe quantitatively what happens as an economy undergoes an information revolution.

6.1 Parameter Values and Functional Forms

The model is calibrated under the assumption that a period in the model is 4 years. Accordingly, the discount factor is $\beta = 0.97^4 = 0.8853$. The growth rate of productivity and output γ is assumed to be 1.5% a year, i.e, $\gamma = 1.015^4 = 1.0614$. The elasticity, σ, in the utility function is taken to be 0.5.

For computational simplicity we are going to assume that there are two types of products, low-information goods, and high-information goods, rather than a continuum. The elasticities in the production function for high-information and low-information goods are assumed to be 0.1 and 0.9 respectively. Hence $\overline{\theta} = 0.9$ and $\underline{\theta}= 0.1$. The learning-by-time process s is assumed to improve 10% per period for 5 periods and stay constant from then on such that the final value is 1. Therefore $s_1 = 0.6561$, $s_2 = 0.729$, $s_3 = 0.81$, $s_4 = 0.9$, and $s_\tau = 1$, $\tau \geq 5$.

The relative productivity of information good production, z, is taken to be 1. The functional form for the human capital investment equation is assumed to be

$$H(\lambda, e_j) = 1 + \chi\lambda e_j^\sigma$$

where $\chi = 1$ and $\sigma = 0.5$.

The duration of patent rights, T, is assumed to be 5 periods (20 years). The fixed R&D costs for the creation of new high-information and low-information goods are assumed to be $\kappa_{\overline{\theta}} = 0.08$ and $\kappa_{\underline{\theta}} = 0.03$ respectively. These are determined so that the share of R&D cost to the present value (at the time of R&D) of total R&D, production, and distribution costs for that product is around 20% for the high-information good and around 5% for the low-information good.

The functional form for the distribution cost of high-information goods is assumed to be

$$G_t(y) = \frac{A}{\gamma^t} y^\psi$$

where $A = 0.1$, and $\psi = 2$. This has the implication that, before the information age, distribution costs represents around 20% of total cost for high-information goods.

Empirically, the tail of the income distribution can be well approximated by a Pareto distribution, which is also easy to work with. For that reason the income distribution function $\Lambda(\lambda)$ is represented by the Pareto distribution,

$$\Lambda(\lambda) = 1 - \lambda^{-\delta}, \text{ for } \lambda \geq 1,$$

with $\delta = 8$ which approximates U.S. income distribution reasonably well.

6.2 The Steady State

We first describe how this economy behaves in a steady state. In this economy the prices of new products decrease monotonically as they get older both because the patent rights disappear after T periods (20 years) and because of the exogenous productivity increases due to learning and other factors, i.e., the $s-$process. Even during the first T periods a patent owner has an incentive to charge less per unit of his product produced because of the single peaked shape of income distribution. The patent owner prefers higher volume rather than a higher price as the product moves down the income distribution. Because of the form of the utility function, agents prefer variety but do not prefer any given product over another. The lower bound constraint on consumption, which requires a minimum level of consumption, $\underline{c}$, of each good, prevents most of the agents from consuming all of the goods available. Since, by assumption, monopoly rights disappear after T periods and there is no learning-by-time beyond T periods, equilibrium product prices after age T are all identical. That is $p_{\overline{\theta},i} = p_{\overline{\theta},j}$ for all i, j, and $p_{\underline{\theta},i} = p_{\underline{\theta},j}$ for all i, j. Figure xx illustrates how the average age of products an agent consumes changes across income levels in the steady state. Those in the lowest percentiles of the income distribution consume a subset of the products that are more than T periods old. Since agents are indifferent about which products we assume they just randomly sample among the old products. In this model economy agents in the lowest three deciles of the income distribution have the same consumption patterns. Agents above 30th percentile have enough income to buy newer products. Since newer products are more expensive, higher income agents consume newer products on average .

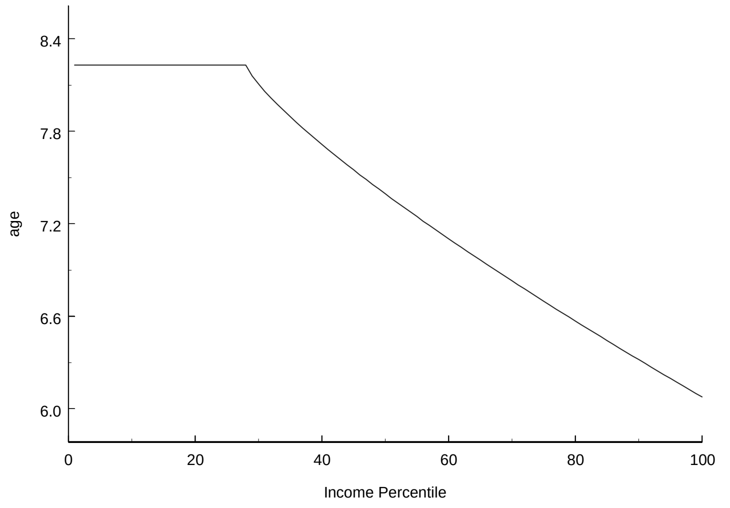
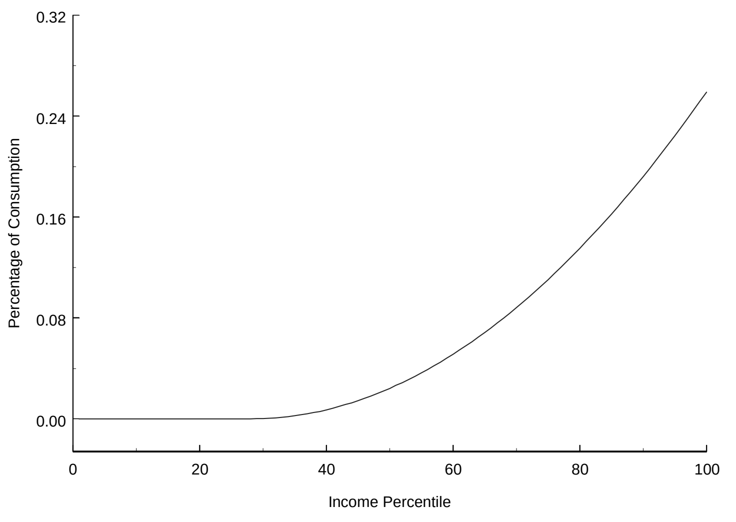


Figure 6   Average Age of Products Consumed

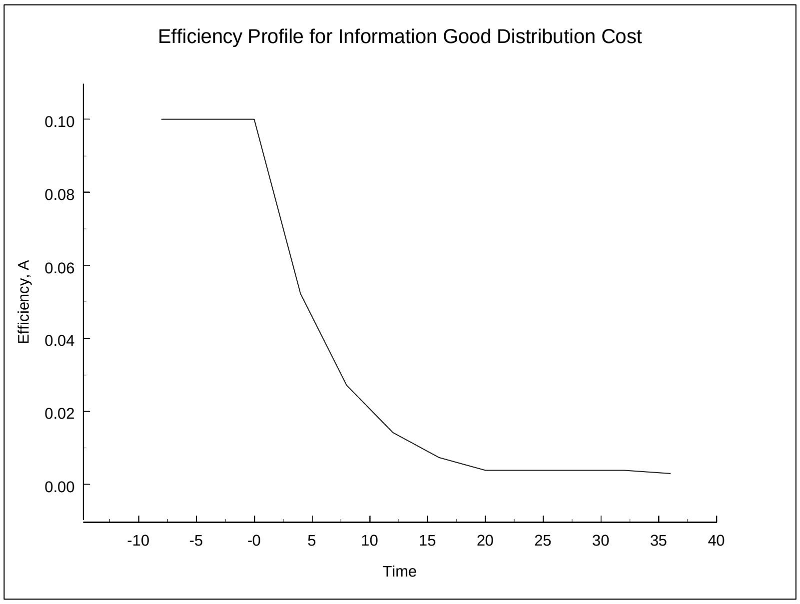
In equilibrium newer goods are more expensive and they include a larger patent fee in their price. The patent fee paid to the patent owner, in turn, covers the product development cost. Agents who consume newer products with higher patent fees in them are making the product development investments for the whole society. Figure 7 shows the fraction of total consumption expenditure of agents across income levels that goes to finance the development of new products in the economy. Since those in the lowest percentiles do not consume any products younger than $T+1$ periods they pay no product development costs. All of their consumption expenditure covers the production and distribution cost, with no contribution to product development costs. Agents above the lower percentiles consume newer products and pay higher patent fees. In this example around 27% of the total consumption expenditures of the richest 1% goes to pay the product development costs. Since these products eventually raise the utility of every agent this has an aspect of social investment.

Figure 7 Investment in Product Development



6.3 The Information Age

Our main exercise is to consider what happens to an economy that experiences an information technology revolution. Consider an economy in steady state, growing on a balanced growth path. The production technologies for information input production, $i = z\gamma^t h$, and for non-information input production, $m = \gamma^t n$, are both improving at rate γ. The distribution technology for the information goods, $G_t(y) = \frac{A}{\gamma^t} y^\psi$ is also becoming more efficient at rate γ. Agents expect the economy to evolve in this fashion indefinitely. Assume, at some date, there is an unexpected breakthrough in the technology of information production and distribution and agents have perfect foresight about the future improvements in information delivery that result from this. In reality, one would expect that, with an information revolution, both of the efficiency parameters z and A would improve. However, since any improvement in z can also be replicated by an improvement in A, to keep the exercise simple we only consider improvements in A. Assume that the technological breakthrough lowers the distribution costs by 15% a year —A declines at rate of 15% a year— for 20 years (5 periods). This rate of improvement may seem high, but when one considers the kind of technological improvements information technologies brought, 15% a year is a conservative figure. The German media estimates cited in a previous section suggest around a 50 fold decline in the share of reproduction and distribution costs between newspapers and the Internet, and a 9 fold decline between TV broadcasting and the Internet. Figure xx plots the assumed evolution of A for the simulation of an information age. The transitional dynamics of the economy undergoing this change are described next.



Innovation

When the breakthrough in information technology occurs agents realize that providing information-intensive goods to the market will be cheaper in the future. This creates an opportunity to make more profits from the ownership of patents on high-information goods. As a result, investment in new good product creation increases dramatically after the breakthrough. This is shown in Figure xx. The ratio of investment in new product development to output rises from an initial level of 5.5% to above 15% . This high level of investment continues for nearly 20 years, after which it falls back to its initial steady state level. These large investments in new product development cause the growth in the number of new products to surge from an initial 1.5% level before the breakthrough to more that 7% after the breakthrough. Again, this boom in new product creation continues for more than 20 years, going back to 1.5% level afterwards. Growth in number of new products is plotted in Figure xx.

Figure 8 Growth in Number of Products

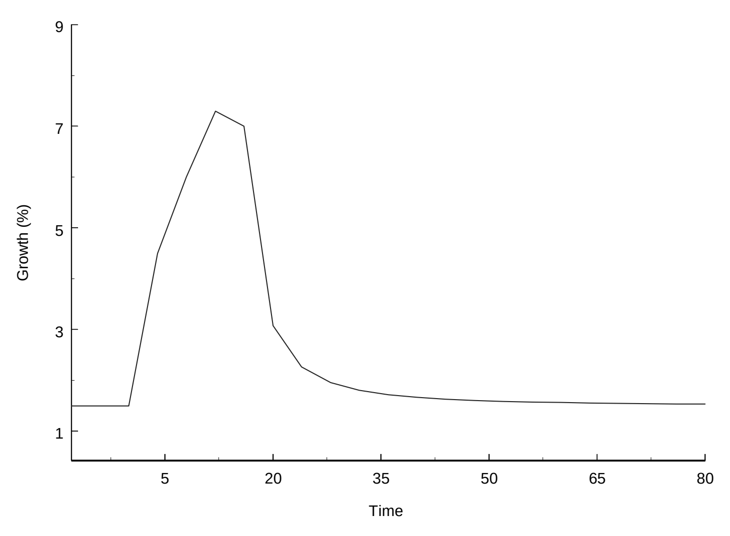
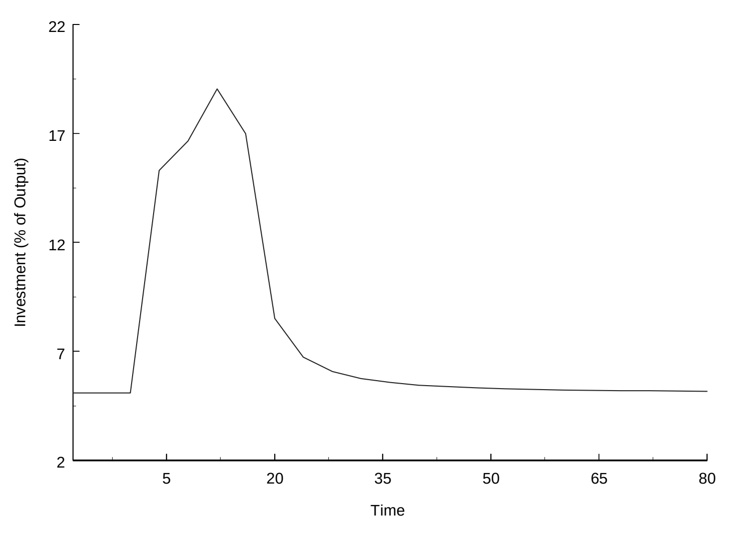
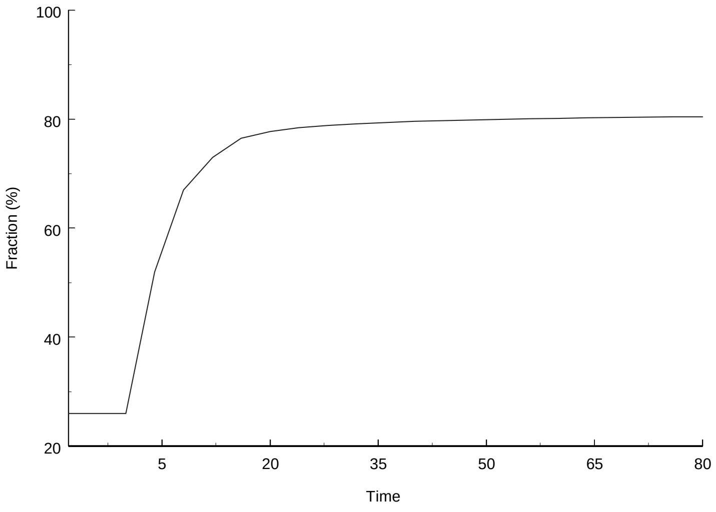


Figure 9 Investment in New Product Development



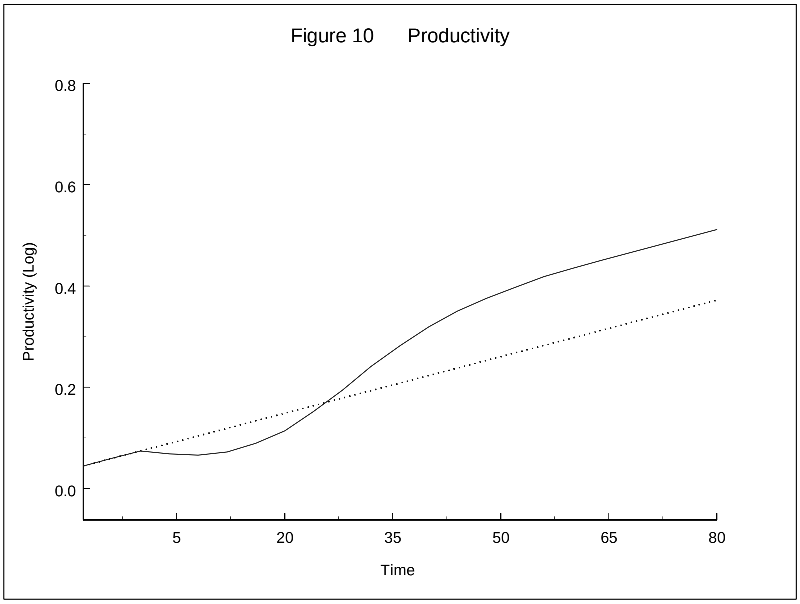
Most of the new goods introduced will be information-intensive goods.Figure xx shows that the fraction of new goods that are information-intensive increases from roughly 25% of new goods to 80% following the breakthrough.

Figure 11 Information Goods as a Fraction of New Goods



Productivity

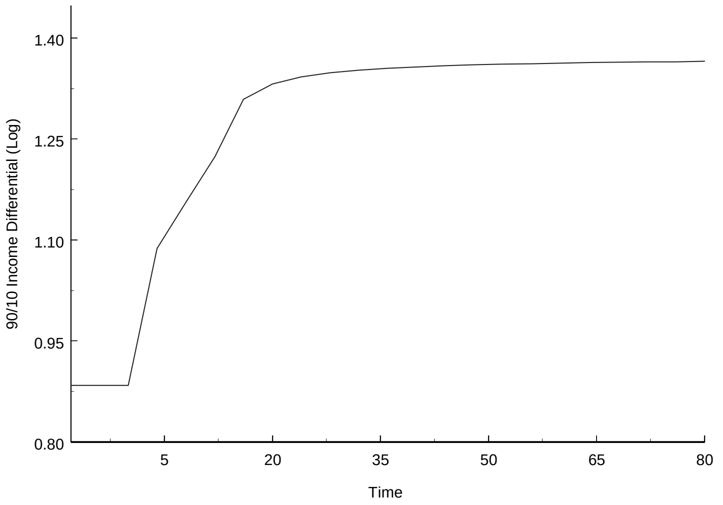
New product development uses economic resources. The increase in the amount of labor allocated to new product development is an investment in future output and welfare. But, the investment in creating new information-intensive goods is not taken into account in conventional productivity measures, leading to an observed slowdown in measured productivity. This slowdown in measured productivity growth continues for almost 20 years. After this temporary slowdown in measured productivity, the cost lowering benefits of the breakthrough in information technology kick in resulting a 20 year period of high growth in measured productivity. Eventually, measured productivity continues to grow at the initial 1.5% a year level. However the gains in measured productivity are permanent. Measured productivity is shown in Figure xx. Greenwood and Yorukoglu (1997) also argue that there will be a slowdown in measured productivity after a technological revolution. In their model learning the new technology takes time and is accomplished by investments made by firms which are not taken into account in productivity estimates.



Inequality

With the improvements in the distribution technology for high-information goods, producers of these goods, i.e. agents with high human capital become more productive as a group compared to the low human capital agents who produce the low-information goods . Accordingly, the income gap between these two groups will increase. More importantly, among the high-information good producing agents the distribution cost is most binding for the agents with the largest output because the distribution cost function is convex. This means that the efficiency increase in the distribution technology benefits the highest output, highest income, highest human capital agents the most. In other words, the reduction in the information good distribution costs reinforces the winner-take-all nature of the information-intensive goods markets. After the technological breakthrough, the income gap between the rich and the poor widens. Figure xx plots the logarithm of the ratio of average income of the highest and lowest deciles in the income distribution. By the time 25 years have elapsed, the income gap between these two groups has increased by about 35%.

Figure 12 Income Inequality



New Product Diffusion

In this economy the important difference between the consumption of the rich and the poor is not that the rich consume more in terms of quantity but that they consume the high price new varieties of goods that the poor cannot afford. Over time as the goods get older the price falls and the income of the poor grows so that they can afford the newer goods. The poor follow the rich in terms of their consumption pattern —the variety of goods consumed— with a certain time lag. The welfare difference between the rich and the poor naturally then depends upon how closely the poor follows the rich. Figure xx displays the difference in the average age of the consumption goods of the richest 10% and poorest 10%. After the information breakthrough with the boom in new high-information goods, the average age of goods consumed by the rich falls. These new goods are too expensive for the poor. Hence, the differential in the average age of consumption bundles increases for a while. As this wave of new goods get older, the prices fall and the prices of high-information goods fall faster than the prices of low-information goods. As this effect kicks in, the poor begin to catch up to the rich. After a few years the price of high-information goods falls sufficiently that the poor can afford them. After the economy converges to the final steady state the gap between rich and the poor is permanently narrowed.

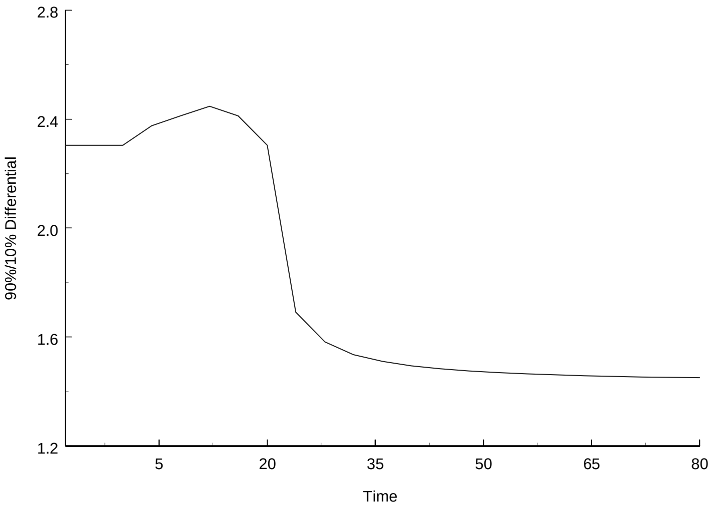
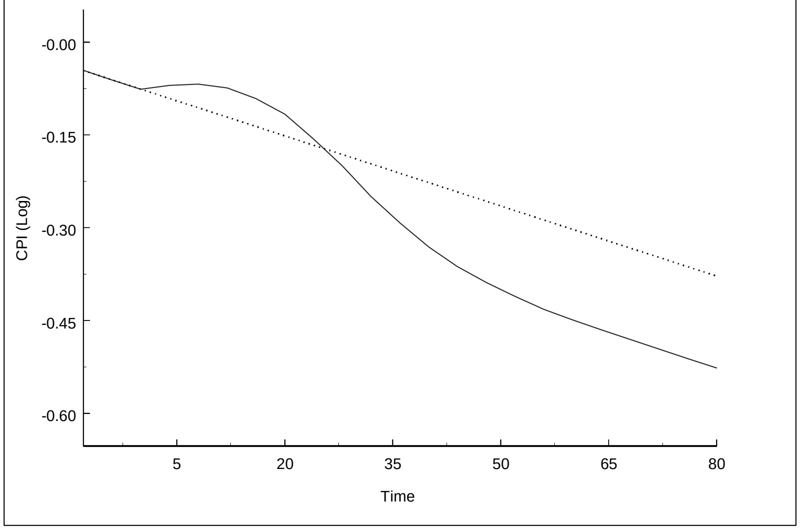


Figure 13 Differential in Average Age of Consumption Bundle 90%-10%

Prices

Although this is not a monetary economy, one can come up with a measure that mimicks the consumer price index by the average time cost of producing goods. This is, of course, closely linked to the productivity measure. Figure xx shows the evolution of this measure. Before the breakthrough, when the economy was evolving at the initial steady state this measure declines at the rate of output growth, $\gamma = 1.5\%$ a year. With the increasing number of new information goods produced after the breakthrough this slows down, even increases for a while (inflation). But as these new information goods age, consumer price index falls sharply, leading to an era of 30 years of strong disinflation. After things cool down the economy sinks into the final balanced growth path with an average rate of disinflation of $\gamma = 1.5\%$ a year again.

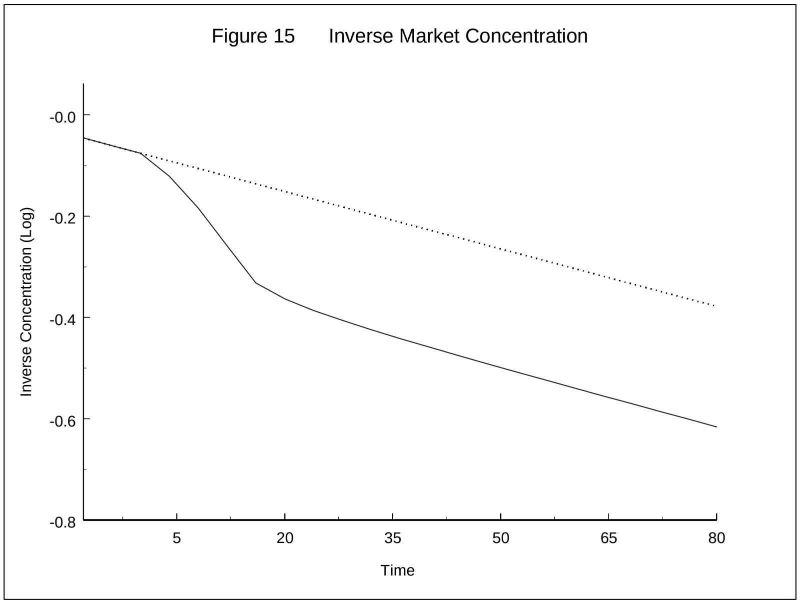
Figure 14 Consumer Price Index



Market Concentration

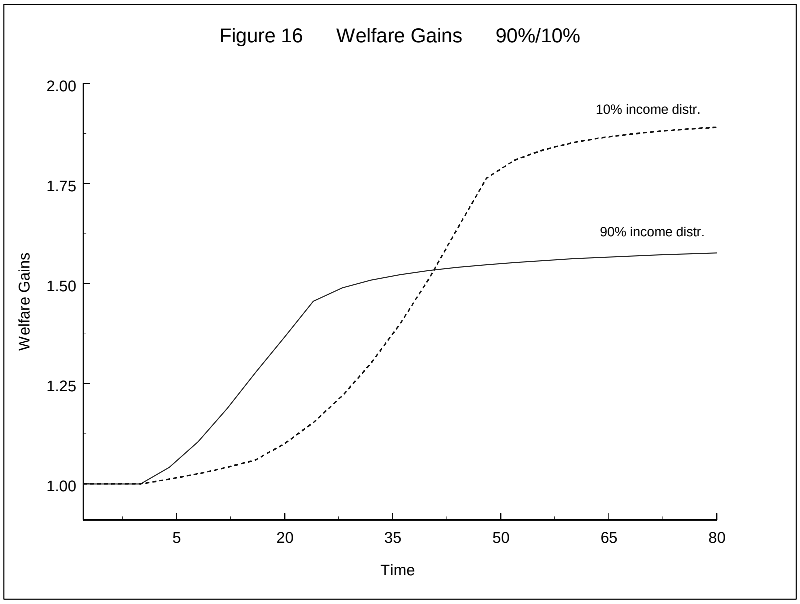
With the breakthrough in information technologies,the economy will display higher levels of market concentration. This is mainly due to the near-zero-marginal-cost feature of the high-information goods which become more apparent after the dramatic decline in distribution costs. The markets for the high-information goods are thin with a small number of producers producing a specific good. Figure xx plots the logarithm of the average number of producers producing each good through time. This we denote as the *inverse market concentration.* In this economy the number of products is growing over time whereas the number of agents in the economy is constant. Therefore, this measure will be declining through time. Notice, however, that the markets for high-information goods will be relatively more concentrated than those for low-information goods because of the high fixed cost near zero marginal cost nature of the goods. After the information breakthrough, the boom in the number of new high-information goods increases the average market concentration in the economy dramatically. This can be seen in the Figure xx.

Figure 15 Inverse Market Concentration

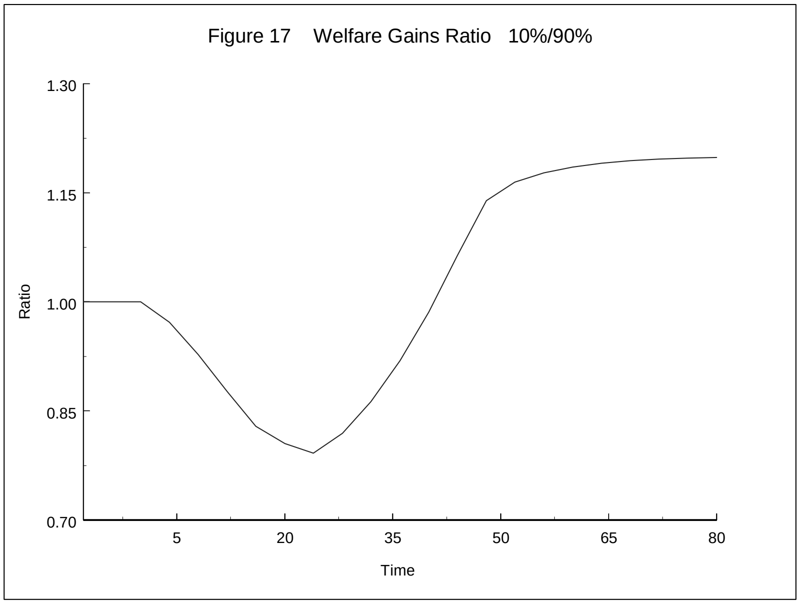


Welfare

The results so far have shown that an information revolution, by easing the constraints that prevent the more able from capturing a larger market and a bigger share of the pie, increases income inequality. Does this imply that the poor are made worse-off? Figure xx shows the average welfare gains of the richest 10% and the poorest 10% of the population. The welfare is calculated by figuring how much compensation as a percentage of their income, each group would require to be indifferent between being an agent in the information age at that point and an agent in the extended path of the old economy (with assumed productivity growth continuing). This will measure how much better or worse-off each group of agents are made with the breakthroughs of the information age. The well-being of the rich increases sharply starting from the early days of the information age. There are two channels through which the rich are benefitting early on. First, as producers of high-information goods, they are becoming more productive with the improvements in the distribution technology. Second, they get to consume these new high-information toys right away. For those in the lowest decile of the income distribution things do not change very dramatically at the beginning. Their welfare is improving, but the benefits are coming slowly. At the beginning the new high-information goods are expensive and beyond the reach of the poor. The only benefit for the poor during the early years is that the old information goods are becoming cheaper. As time passes, the mass of new high-information goods produced at the beginning of the information age become cheaper, and the poor start to benefit from them. After almost 20 years from the dawn of the information age, a long era of 30 years begins during which the welfare of the poor increases sharply. The increase is so dramatic that after 40 years or so the welfare gains of the poor outstrip those of the rich. It is important to note that the rise in welfare is due entirely tot he fact that those in the upper tail of the income distribution paid the development costs of this shower of new high-information products.

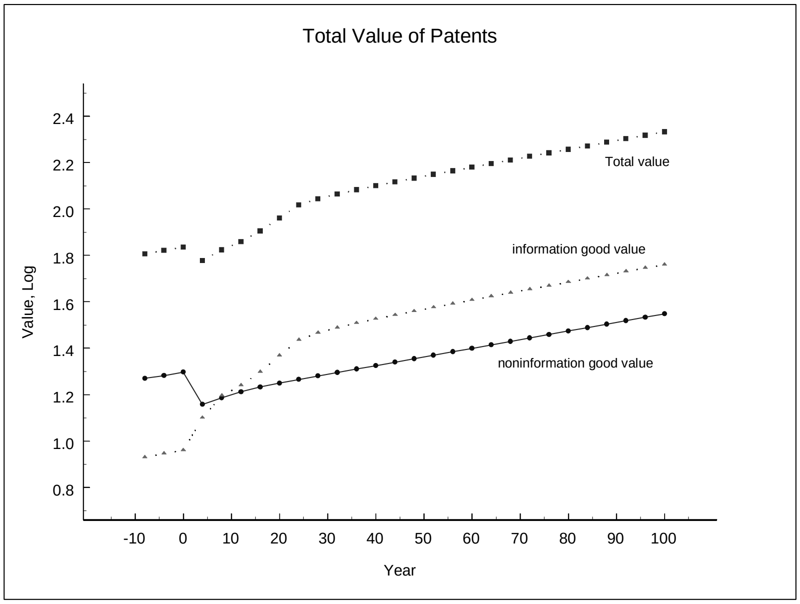


The ratio of the welfare gains of the bottom decile to the top decile is shown in Figure xx. If the poor have keeping-up-with-the-Jones type preferences, they might feel worse-off in the early days of the information age.



The Stock Market

The final figure plots the evolution of the total value of patents which, in this economy, is equivalent to the total value of the stock market. At the date of the technological breakthrough it becomes apparent to agents that the future goods prices and optimal patent fees will be declining dramatically. This lowers the expected profits for the low-information good patents. The value of the low-information good patents jump down at the date of the breakthrough. However, for high-information goods the increase in efficiency increases expected output and expected patent fees of the patent owners. As a result, the average value of high-information good patents jumps up at the date of the breakthrough. Before the breakthrough the low-information good patents accounted for the larger part of the total patent values in the economy. However after the breakthrough value of high-information good patents quickly surpass the value of the low-information good patents. This fall in the value of existing firms and subsequent rise in the value of new firms is exactly the pattern discussed by Greenwood and Jovanovic (1999) and documented further by Jovanovic and Hobijn (2000).



7 Conclusions

Much has been written about the "New Economy" and the consequences of the information technology revolution. It is clear that, the skeptical views of economists like Robert Gordon (2000) notwithstanding, the characteristics of our economy have changed in important ways. In this paper we treat information formally as an intermediate input to the production process and show that an information revolution, that is an improvement in the production and distribution of information inputs, has dramatic implications for the evolution of the economy that play out over many decades. In particular, an information age will lead to an increase in income inequality, a long fall and then a sharp rise in measured productivity, an increase in concentration, sharp declines in the prices of high-information goods, a fall and a subsequent increase in the value of the stock market, and an increase in the speed of diffusion of new products to households. All of these features are consistent with observations over the past two and half decades.

In spite of the sharp increase in inequality associated with an information age, our analysis implies that the welfare of all groups in society will increase with an information revolution precisely because of the increased speed of diffusion of new products throughout the economy. Perhaps even more striking about these findings is the implication that the effects of the information revolution will continue to be felt and influence economic well being for decades to come.

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