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Technological Diffusion and Asset Prices

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"Technological Diffusion and Asset Prices"

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Abstract

In this paper we demonstrate that the gradual diffusion of technology causes the stock market to exhibit a cyclical behavior. More importantly, we attribute sharp declines and increases in the stock market such as the ones that occurred in the early 1970s and mid 1990s in the United States to expected rapid technological diffusion.

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1 Introduction

The late 1960s and mid 1970s witnessed a sharp decline in stock prices in the United States. In Figure 1 below, we illustrate the inflation adjusted price/earnings ratio using the S&P 500 index for the 1950-2009 period.¹ Recent work attributes the substantial fall in the stock market to the information technology revolution of the late 1980s and early 1990s. For instance, Greenwood and Jovanovic (1999) contend that the stock market declined in the 1970s because many firms were not expected to adopt the new technology.²

In this paper, we provide an alternative explanation to the sharp decline in the stock market in the 1970s based on technological diffusion. That is, based on how fast a new technology spreads into the economy. In particular, we argue that investors ex-ante may have anticipated the information technology to diffuse very quickly, which explains the discrete drop in the stock market between late 1960s and mid 1970s. However, the information technology did not diffuse very quickly at first as anticipated, which explains the surge in asset prices over a long period of time from the early 80s until the late 1990s. As it can be seen in Figure 1 below, it took over a decade for the price earnings ratio to reach its 1966 level (from 1982 until 1995). Afterwards, the stock market increased significantly - a sign that the new technology was spreading pretty fast at that point in time.³

We proceed to provide details of our modeling framework. We examine a version of the Lucas (1978) tree model. After portfolios are made, the market receives a surprise news about a new technology that will be available at some date in the future. The new technology raises firms' (trees') productivity once adopted. Following the literature on technological change, we assume that the market foresees that the new technology diffuses gradually. This assumption serves to characterize the dynamics of new technologies.⁴ As in Aghion (2002), we take the dynamics of technological change to be exogenous.

The news about a more productive technology in the future unambiguously

¹The data used in Figure 1 are obtained from Robert Shiller's website, at Yale Department of Economics.

²See also the work by Hobijn and Jovanovic (2001) and Laitner and Stolyarov (2003). Recent work by Pástor and Veronesi (2009) demonstrates that bubbles form following technological innovations. The size of these bubbles depends significantly on the speed of technology adoption and the degree of uncertainty of the new technology.

³There are ample evidence that the information technology did not spread very quickly between 1980 and 1995. For instance, as indicated in Lewis (1989), only ten percent of businesses around the world used a computer in 1989.

Further, data from the Current Population Survey reveals that the number of employed adults that used a computer at work displayed a significant increase in the late 1990s. For example, 24.6% of employed adults used a computer at work in 1984, compared to 36.8% in 1989, and 69.3% in 1997.

⁴There is a consensus in the literature that new technologies are gradually adopted by firms. See for example Griliches (1957), Shen (1961), Mansfield (1963), David (1990), Parente and Prescott (1994), Aghion (2002), and Dinopoulos and Waldo (2005).

As emphasized by Parente and Prescott (1994), there are several reasons that render firms adopt a new technology gradually. Among those reasons are legal restrictions, regulations, and workers resisting change.

puts downward pressures on asset prices in the present. This occurs because risk averse investors discount the future much faster in anticipation of higher income. Interestingly, we demonstrate that investors' expectations about the degree of intensity of technology adoption are important factors for the effects of the new technology on equity markets. In particular, they affect the time of recovery in the stock market and more importantly, the speed of decline in asset prices before the new technology is adopted (once the news about the new technology becomes available). The slower the diffusion of the new technology, the milder the impact on asset prices in the present and the slower is the recovery of the stock market when the new technology becomes available.

Notably, accounting for the dynamics in the diffusion of technological change renders the stock market behave in a cyclical manner.⁵ Before a new technology is adopted, the stock market falls over a certain period of time. Once the new technology becomes in operation, the stock market starts to recover. The speed and the duration of the downturn as well as the recovery depend on the anticipated diffusion of the technology in the future. If the market perceives that the new technology will diffuse relatively quickly, the stock market will fall sharply before the new technology is in operation as in the late 1960s and early 1970s. If agents expectations about the diffusion of technology hold ex-post, one would anticipate a significantly fast recovery in the mid 1980s. However, this did not happen as observed in Figure 1. In particular, the market recovered relatively slowly then exhibited a sharp increase in the mid 1990s. Finally, the sharp decline in the stock market since early 2000 signals the beginning of a new cycle in the stock market. Specifically, investors may be anticipating a new technology that will revolutionize the economy. More importantly, this new technology is expected to be adopted fairly quickly by different sectors in the economy.

⁵Helpman and Trajtenberg (1998) demonstrate that the stock market may behave in a cyclical manner due to the time it takes to develop complementary inputs that are necessary for the adoption of the new technology. However, they only focus on the impact of technological diffusion on labor markets.

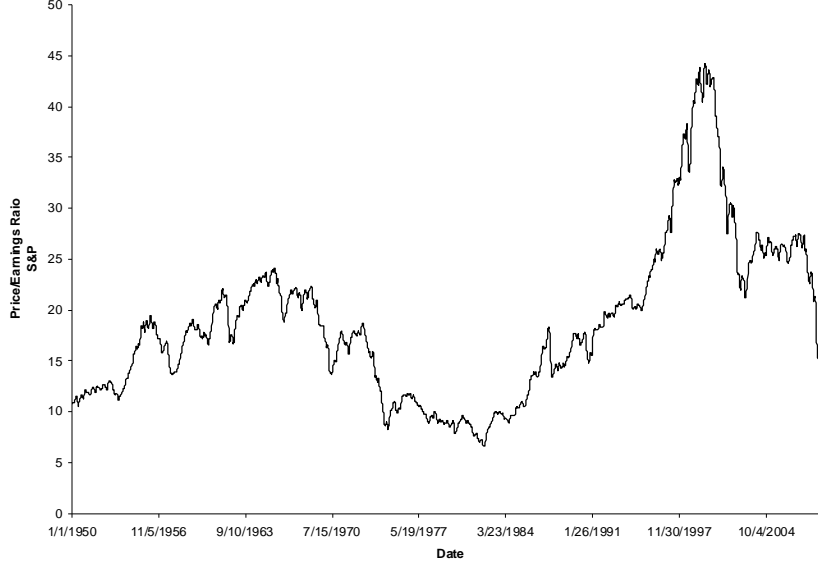


Figure 1: Price/Earnings Ratio (S&P 500)

2 Model

Consider a simple endowment economy as in Lucas (1978). The economy is populated by identical infinitely lived agents. Agents do not receive periodic endowments. However there are n homogenous infinitely lived trees. Each tree i , produces a deterministic stream of perishable fruits (dividends), $d_{i,t} = 1$ per period throughout its life. Fruits are assumed to be the only source of consumption to individuals. An agent's preferences in period t are summarized by $U(c_t) = \frac{c_t^{1-\theta}}{1-\theta}$, where $\theta > 1$ is the coefficient of risk aversion.

Each representative consumer can acquire a share, $s_{i,t}$ in tree i at a price $p_{i,t}$. The representative consumer maximizes

$$\sum_{t=0}^{\infty} \beta^t U(c_t) \quad (1)$$

subject to

$$c_t + \sum_{i=1}^n p_{i,t} s_{i,t} = \sum_{i=1}^n (p_{i,t} + d_{i,t}) s_{i,t-1} \quad (2)$$

where β is a time invariant discount factor.

In equilibrium, the price of a tree in period t is expressed by :

$$P_t = \sum_{\tau=0}^{\infty} \beta^\tau \frac{U'(c_\tau)}{U'(c_t)} d_t = \frac{1}{1-\beta} \quad (3)$$

and

$$c_t = d_t = y = 1$$

Since the amount of output per period, y is one, (3) also reflects the price/earnings ratio and the value of the stock market in period t .

Next, suppose agents unexpectedly receive information in period zero that a new technology will be available in period T . The new technology permits each tree to generate $(1+z)$ units of fruits per period upon its adoption. Further, suppose that only an exogenous fraction, $X \in [0, 1]$ of trees adopts the new technology in period T . The remaining $(1-X)$ trees adopt the technology in period $T+1$.⁶ In this manner, the model allows us to examine the impact of intensity in technology adoption on asset prices. Clearly, $X=1$ implies an instantaneous adoption of the new technology by all firms in period T . No other news is received in period zero or in future periods.

As a benchmark, suppose the technology is instantaneously adopted in period T by all firms (trees). The price of an asset in period $t \leq T-1$ and $t \geq T$ is respectively:

$$P_{t \leq T-1} = \frac{1-\beta^{T-t}}{1-\beta} + (1+z) \frac{U'(1+z)}{U'(1)} \frac{\beta^{T-t}}{1-\beta} \quad (4)$$

and

$$P_{t \geq T} = \frac{1+z}{1-\beta} \quad (5)$$

Since the technology is instantaneously adopted, there is always one type of trees traded. Thus, P_t also reflects the value of the stock market in period t . The impact of the technology shock on asset prices in the present is summarized in the following lemma:

Lemma 1. *Asset prices decline for all $t < T$ in response to an unanticipated positive technology.*

The proof of Lemma 1 is straightforward and therefore we omit it. The new innovation has two effects on asset prices. First, each asset will generate a higher level of consumption beyond period T , which reduces the marginal utility from future consumption. Higher future consumption leads to faster discounting of future income and thus lower asset prices in the present. Additionally, each tree will pay its owners higher dividends beyond period $T-1$, which raises its

⁶We extend the model below to allow for the diffusion of technology over a longer period of time.

present value. As agents are highly risk averse, $\theta > 1$, it is easy to verify that the first effect dominates and that the stock market exhibits a *discrete drop* in period zero. Once the new technology becomes in operation, the value of the stock market increases significantly to $\frac{1+z}{1-\beta}$.

Next, consider the case where technology is gradually adopted over two periods. As a result of the technology shock, the level of consumption (output) of individuals is:

$$\begin{aligned} c_t &= 1 && \text{for } t \leq T-1 \\ c_t &= 1 + Xz && \text{for } t = T \\ c_t &= 1 + z && \text{for } t \geq T+1 \end{aligned}$$

Further, for all $t \leq T-1$, we have two types of trees traded: X early adopters and $(1-X)$ late adopters. The price of each type of tree in period t is respectively:

$$P_t^{early} = \frac{1 - \beta^{T-1-t}}{1 - \beta} + \left(\frac{U'(1 + Xz)}{U'(c_t)} + \frac{U'(1 + z)}{U'(c_t)} \frac{\beta}{1 - \beta} \right) \beta^{T-t} (1 + z) \quad (6)$$

$$P_t^{late} = \frac{1 - \beta^{T-1-t}}{1 - \beta} + \left(\frac{U'(1 + Xz)}{U'(c_t)} + \frac{U'(1 + z)}{U'(c_t)} (1 + z) \frac{\beta}{1 - \beta} \right) \beta^{T-t} \quad (7)$$

Clearly, trees that adopt the technology early are valued at a premium, with:

$$P_t^{early} - P_t^{late} = \beta^{T-t} \frac{U'(1 + Xz)}{U'(c_t)} z \quad (8)$$

In addition, the value of the stock market, S_t for all $t \leq T-1$ is a weighted average:

$$S_t = X P_t^{early} + (1 - X) P_t^{late}$$

Upon substituting (6) and (7), the stock market value is:

$$S_{t \leq T-1} = \beta^{T-t} X z \frac{U'(1 + Xz)}{U'(c_t)} + \frac{1 - \beta^{T-1-t}}{1 - \beta} + \beta^{T-t} \frac{U'(1 + Xz)}{U'(c_t)} + \frac{U'(1 + z)}{U'(c_t)} (1 + z) \frac{\beta^{T+1-t}}{1 - \beta} \quad (9)$$

Additionally, for all $t = T$ and $t \geq T+1$:

$$S_{t=T} = 1 + Xz + \frac{\beta}{1 - \beta} \frac{U'(1 + z)}{U'(1 + Xz)} (1 + z) \quad (10)$$

and

$$S_{t \geq T+1} = \frac{1 + z}{1 - \beta} \quad (11)$$

We proceed to examine the impact of the adoption rate, X on the stock market in a particular point in time. By differentiating (9), we get:

$$\frac{dS_{t \leq T-1}}{dX} = \left(\frac{1 + Xz}{(1+z)} - \theta \right) \frac{(1+z)}{(1+Xz)^{1+\theta}} \frac{\beta^{T-t} z}{U'(c_t)} < 0$$

The following proposition summarizes the result:

Proposition 1. $\frac{dS_t}{dX} < 0$ for all $t \leq T-1$ and $\frac{dS_t}{dX} > 0$ at $t = T$.

In words, if investors anticipate the new technology to diffuse very quickly upon its introduction, the present value of the stock market will fall significantly. However, once the new technology is in operation, asset prices increase sharply if a significant number of firms adopt the new technology.

A change in the parameter X has two effects. First, a faster diffusion of technology (higher X) enables investors to increase their consumption in period T . The lower marginal utility of consumption lowers the price of both types of assets. Additionally, a higher X implies a higher number of firms that adopt the new technology early. This effect raises the value of the stock market. As the intertemporal elasticity of substitution is relatively low, $\theta > 1$, the first effect dominates. In this manner, the impact of technological change on asset prices is mitigated by a lower intensity in the adoption of the new technology.

While the simple model above provides an insight into the impact of the intensity in technology adoption on asset markets, it hinges on the assumption that technology diffuses over two periods. Thus, it does not account for the dynamics in the number of adopters over time. Specifically, previous work on technological diffusion such as Aghion (2002), points out that the diffusion of new technology resembles that of an infectious disease. The number of adopters increases slowly at first, then accelerates over a certain time range, and finally it decelerates as the number of adopters gets saturated.

We proceed to examine how the dynamics in the diffusion of a new technology affect asset prices. In contrast to the previous setting, suppose that it takes $j+1$ periods for all firms to adopt the new technology. Define δ_t to be the number of firms that adopt the new technology at $t \geq T$. The dynamics of δ are such that:

$$\begin{aligned} \delta_t &= a \left(\frac{1}{1+j} \right)^{\frac{1}{t-T+1}} \quad \text{for } t \in [T, T^*) \\ \delta_t &= a \left(\frac{1}{1+j} \right)^{t-T+1} \quad \text{for } t \in [T+\Delta, T+j] \end{aligned}$$

where $a > 0$ is a scaling factor determined by the model such that:

$$\sum_{t=T}^{T+j} \delta_t = \sum_{t=T}^{T+\Delta} a \left(\frac{1}{1+j} \right)^{\frac{1}{t-T+1}} + \sum_{t=T+\Delta}^{T+j} a \left(\frac{1}{1+j} \right)^{t-T+1} = 1$$

In this manner, the number of trees adopting the new technology increases exponentially over Δ periods. The number of adopters levels off beyond period

$T + \Delta$. In particular, the diffusion of technology has an "S" shape as illustrated in Figure 2 below.

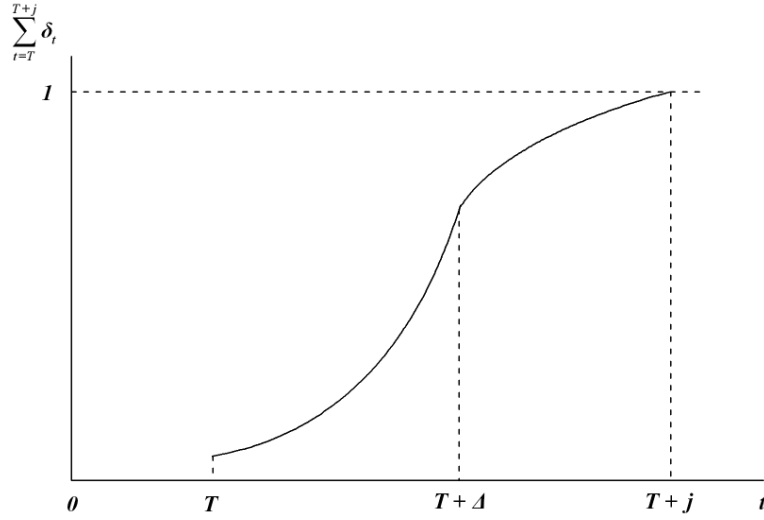


Figure 2: Technological Diffusion

The consumption stream is as follows:

$$\begin{aligned}
 C_t &= 1 && \text{for } t \leq T - 1 \\
 C_t &= 1 + \delta_T z && \text{for } t = T \\
 C_t &= 1 + (\delta_T + \delta_{T+1}) z && \text{for } t = T + 1 \\
 &\cdot \\
 &\cdot \\
 C_t &= 1 + (1 - \delta_{T+j}) z && \text{for } t = T + j - 1 \\
 C_t &= 1 + z && \text{for } t \geq T + j
 \end{aligned}$$

For all $t < T$, the market classifies firms into $1 + j$ types depending on their speed of adoption. The price of a tree that adopts the technology in period $T, T + 1, \dots, T + j - 1$, is respectively:

$$\begin{aligned}
P_t^T &= \frac{1 - \beta^{T-t}}{1 - \beta} + (1+z) \sum_{\tau=T}^{T+j-1-t} \beta^\tau \frac{U'(c_\tau)}{U'(1)} + (1+z) \frac{U'(1+z)}{U'(1)} \frac{\beta^{T+j-t}}{1 - \beta} \\
P_t^{T+1} &= \frac{1 - \beta^{T-t}}{1 - \beta} + \beta^T \frac{U'(1 + \delta_T z)}{U'(1)} + (1+z) \left(\sum_{\tau=T+1}^{T+j-1-t} \beta^\tau \frac{U'(c_\tau)}{U'(c_t)} + \frac{U'(1+z)}{U'(1)} \frac{\beta^{T+j-t}}{1 - \beta} \right) \\
&\vdots \\
P_t^{T+j-1} &= \frac{1 - \beta^{T-t}}{1 - \beta} + \sum_{\tau=T}^{T+j-2-t} \beta^\tau \frac{U'(c_\tau)}{U'(c_t)} + (1+z) \left(\frac{U'(1 + (1 - \delta_{T+j}) z)}{U'(1)} + \frac{U'(1+z)}{U'(1)} \frac{\beta^{1-t}}{1 - \beta} \right) \beta^{T+j-1}
\end{aligned}$$

Further, the stock market in period t is a weighted average of $1 + j$ firms:

$$S_t = \delta_T P_t^T + \delta_{T+1} P_t^{T+1} + \dots + \delta_{T+j} P_t^{T+j}$$

Interestingly, the response of the stock market to technological change depends on investors' expectations about the diffusion of the new technology. If agents expect the new technology to diffuse quickly over a short period of time (small Δ or j), then its impact on current asset prices is significant. In contrast, if investors expect the new technology to diffuse gradually, as it is the case for all innovations, the stock market will behave in a cyclical manner and gradually adjusts to the new information as illustrated in Figure 3 below.

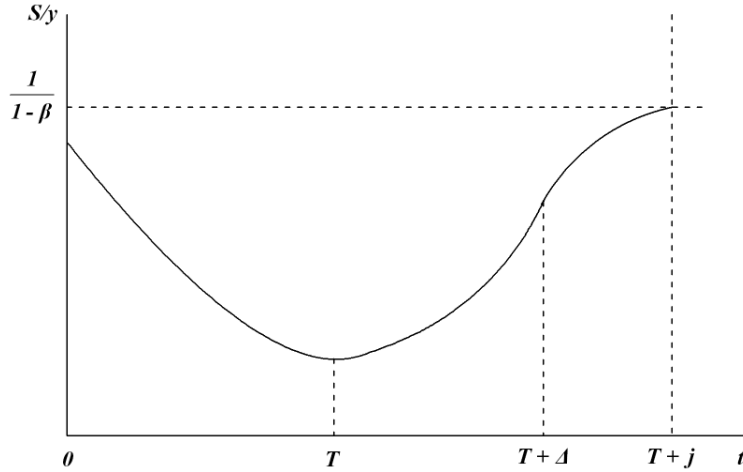


Figure 3: Stock Market to Output Ratio

3 Conclusion

Recent work by Greenwood and Jovanovic (1999) attributes the sharp decline in the stock market in the 1970s to the information technology revolution of

the 1990s. Specifically, Greenwood and Jovanovic (1999) show that the stock market declined due to a wave of new entrants in the 1990s and a large number of firms that did not adopt the new technology. The authors use *ex-post* data as evidence for their hypothesis.

In this manuscript, we present an alternative explanation based on investors' expectations about firms' adoption rate of the new technology. The stock market declined significantly in the late 1960s and early 1970s in the United States because investors anticipated that the information technology was going to diffuse rapidly. However, this did not happen *ex-post*, which explains the long surge in equity markets from 1982 until 2000. Notably, the analysis provided in this paper can be extended by empirically forecasting the rate of diffusion of the information technology post 1970. This would shed light on investors' expectations about firm's adoption rate of the information technology at that point in time.

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