A Macroecomonic Theory of Technology Adoption:A Vintage Approach

Akiyama, Taro
Nakamura, Tamotsu

(Citation)
神戸大学経済学研究科 Discussion Paper,811

(Issue Date)
2008-06

(Resource Type)
technical report

(Version)
Version of Record

(URL)
https://hdl.handle.net/20.500.14094/81000751

A Macroeconomic Theory of Technology Adoption: A Vintage Approach *

Taro Akiyama[†] Tamotsu Nakamura[‡]

Jun 2008

Abstract

Technological change is one of the major sources of economic growth and fluctuations. However, scientific innovations and findings do not always imply economic innovations and technological progress. If firms in an economy do not adopt new technologies, the productivity in the economy does not increase even when scientific knowledge accumulates rapidly. Productivity grows stagnant when the agents with advanced technologies fail to start up their businesses. Therefore, technology adoption is a key element in understanding the relationship between technological advances and economic activities. This paper studies the macroeconomic factors influencing technology adoption. As a result, we show that asset prices play a crucial role in adopting new technologies: higher prices tend to deter adoption, and vice versa. This suggests that adoption is less active in a period of high asset prices (asset bubble period) than in the period of lower prices (the post-bubble period). Active technology adoptions after the bubble contribute to productivity growth in the recovery period. This is consistent with recent empirical investigations into the Great Depression. The role of financial intermediaries in technology adoption is also investigated.

Keywords: Technology Adoption, Asset Prices, Cleansing Effect of Recessions.

JEL classifications: E32, O31, O40

---

*The authors would like to thank Sercu Piet, Kudoh Noritaka, and Koichi Futagami and participants at the 2007 All-China Economic International Conference and the 2008 Spring Meeting of JEA at Tohoku University for their very helpful comments and suggestions. The research for this paper was financially supported in part by the Kobe University 21st Century COE program of the Ministry of Education, Culture, Sports, Science and Technology and the Grant-in-Aid for Scientific Research. Needless to say, any remaining errors are our own.

[†]Corresponding Author. Graduate School of Economics, Kobe University, 2-1, Rokkodai, Nada-ku Kobe 657-8501, JAPAN. E-mail: 029d251e@stu.kobe-u.ac.jp.

[‡]Graduate School of Economics, Kobe University, 2-1, Rokkodai, Nada-ku, Kobe 657-8501, JAPAN. E-mail: nakamura@econ.kobe-u.ac.jp

1 Introduction

Technological changes play a key role in models of long-term economic growth and short- or medium-term economic fluctuations. [1] However, scientific findings and innovations do not always imply technological progress in economic activities. In order for new technologies to contribute to production, they must be adopted by economic agents, typically by firms. Needless to say, scarcity of resources, which can be employed for by new technologies, and profitability, which can be increased by new innovations, have been the main engines of technology adoption. For example, although the power of steam was fully understood in ancient Egypt, it was not used for production since slave labor was abundant. Even nowadays, some of the new scientific innovations have no immediate impact on the real economy. Therefore, technology adoption is as important as, or even more important in some senses than technological advances or changes in an economy.

In the mainstream approach technologies are assumed to be "disembodied" into capital. In other words, any kind of technology can be introduced into the existing capital in use. Therefore, it is natural to assume that firms adopt new technological innovations constantly and continuously. However, some technologies are "embodied" into capital equipment, and hence those technologies cannot be introduced without abandoning old capital. This important feature of technology adoption is known as vintage capital, which was first analyzed in economic growth thanks to seminal contributions by Solow (1957), Johansen (1959) and others.

The idea of vintage capital makes it possible to clarify the difference between technological changes and technology adoption. Without any technological advances, technology adoption has no role to play. Without its adoption into economic activities, on the other hand, technological progress cannot contribute to overall economic development. However, the recent literature on economic growth and fluctuations focuses mainly on progress rather than on adoption. In contrast, this paper follows the research line of vintage capital to investigate the macroeconomic factors influencing technology adoption as well as the effects of technology adoption on economic growth and its fluctuations.

According to the microeconomic analysis of vintage capital, equipment that no longer earns quasi-rent should be scrapped, and new machines with breakthrough technology should be introduced. With constant technological progress, the machines continually become obsolete. The lifetime of machines depends only on the rate of technical progress: the higher the rate, the shorter the lifetime. At the macroeconomic level, however, due to resource constraints the new technologies are not introduced instantaneously, and

[1] The concept of "technology" includes broad notions in science, research, development, funding, discovery, experience, and skill, etc.

hence the old machines, which become obsolete only if the new machines are scrapped. The purpose of this paper is to highlight the macroeconomic factors influencing technology adoption.

For this purpose, instead of assuming that a single firm has different vintages of capital, we assume that the economy is a continuum of firms, each of which has one particular vintage of capital. Put it differently, the economy as a whole consists of different capital vintages. New firms surely have the latest technology because they have no incentive to enter the market with old technologies. Therefore, introducing new technologies and scrapping old ones takes place largely through the entry of new firms and the exit (or bankruptcy) of old ones. To highlight the macroeconomic aspects of technology adoption, some productive resources or structures such as land are assumed to be exogenously given in the model in this paper. This assumption implies that some resources do not become available to potential entrants except by the retirement of incumbent firms. During boom periods even firms with old technologies can continue to earn profits, and hence those firms do not go bankrupt and do not release their productive resources for use by others. During recessions, by contrast, firms with relatively new technologies might go bankrupt. As a result, many new firms come into existence, which implies that massive adoption of new technologies takes place during economic slumps.

The idea in this paper that technology adoption becomes active in recessions is similar to "the cleansing effect of recessions" in Caballero and Hammour (1994) that show that old machines are scrapped intensively in hard times. In contrast to their analysis, however, we assert that asset prices play a crucial role in the determination of scrapping old technologies and introducing new ones in our model. In other words, this paper sheds light on a different channel leading to the cleansing effect of recessions. A sharp decline in asset prices in recessions forces firms to declare default, which in turn makes the resources owned by such firms available to potential new entrants. Hence, many new firms appear with advanced technologies in the economy. This can be a driving force for economic recovery from recessions. On the other hand, higher asset prices help the incumbent firms with low profitability to survive, and hence discourage the technology adoption during booms. These countercyclical movements of technology adoption are also verified by the recent empirical studies of Gittleman et al. (2006) which estimate the age structure of capital based upon a vintage model. Gali and Hammour (1991) document the supporting empirical evidence for the cleansing effect of recessions.

The results in this paper are also consistent with historical events. For example, the fact is clear from such empirical investigations as those of Solow (1957), Kendrick (1961) and Gordon (2000) that productivity growth rates are high during the Great Depression of the 1930s. Recently, reinvestigating numerous former studies, Field (2003, 2006) emphasizes that the productivity growth rates in terms both of total productivity and of multifactor productivity in the 1930s are the highest throughout the 20th century in the United States. Following Field's research, Alexopoulos (2006) creates and uses new indicators to measure US productivity growth in the 20th century, and verifies Field's findings. In addition, she shows that the productivity slowdown was not a factor in the sharp decline in output during the Great Depressions although massive innovation activities after 1933 were major factors in the US economic recovery from the Depression. Shared by various researchers such as Mensch (1979), Kleinknecht (1987), and Mowery and Rosenberg (2000) is the view affirmed here that accelerated technological advances contributed to the rapid recovery. Although it is not our main purpose, the model in this paper gives a theoretical explanation for the scenario proposed by Alexopoulos and others.

The rest of our paper is organized as follows. Section 2 sets up the model and characterizes an within-period equilibrium. Section 3 investigates the macroeconomic factors (especially asset prices) influencing technology adoption. Finally, section 4 provides some concluding remarks.

2 The model

2.1 The environment

Consider an economy consisting of continuum of firms, each of which has one particular vintage technology for production. In the economy, the level of frontier technology ω_t grows at the constant rate $\gamma(>0)$, thus $\omega_t = \omega_0(1+\gamma)^t$. [2] Hence newly-entering firms have the latest (therefore, the most productive) technology of the period. Once the firms introduce their technologies, their technology levels (therefore, their productivity) are not influenced by future technological changes. Thus, as the level of innovative technology rises, technologies that have been embodied into existing capital become old and less productives. [3] Economy-wide productivity can increase only through the introduction of new technologies into production. [4]

The economy has one final good and two productive resources (asset and labor). The productive resources are used for the production of goods, and the asset does not depreciate over time ensuring a fixed amounts of supply $\bar{A}$. The final good produced by firms fully depreciates within a period.

[2]This model does not consider endogenous technological progress. Our objective is not to explain technological progress in a economic system but rather to investigate the macroeconomic factors influencing technology adoption.

[3]Bahk and Gort (1993), Power (1998), and Jensen et al. (2001) investigate the relationship between the volume of output or labor productivity and the ages of firms, and conclude that the productivity of young firm is higher than that of the old ones.

[4]We do not consider the case in which the firms replace old technologies with latest ones. We can exclude such a case by assuming that the replacements would incur enormous outlays. Cooley et al. (1997) and Zou (2006) study a vintage model in which firms can invest not only new vintage technology, but also existing one.

2.2 Introduction of new technologies

Each period new firms appear with the latest technology ω_t, and each production requires $\hat{A}$ units of asset and one unit of labor as productive resources. The new firms try to set up their businesses by introducing the newest technology. However, since they have no initial endowment, they must raise funds to purchase the needed productive resources. In addition, a set up cost $\omega_t\phi$ is needed when they introduce the newest technology into the production process. The ϕ is distributed between 0 and $\hat{\phi}$, following the cumulative distribution function $F(\phi)$, which implies that the firms with low ϕ have potentially high abilities. Since these costs are supplied by a financial intermediary requiring an expected rate of return $R(> 1)$ which is exogenously given, [5] the newly-entering firms can raise funds by making a one-period' financial contract with the intermediary. The firms that have succeeded in setting up their bussinesses produce $\theta_t\omega_t$ units of final goods using their technologies. Here θ_t represents an aggregate productivity shock that includes monetary, fiscal and other various factors. We take the random variable θ to be i.i.d. with a mean $\bar{\theta}$.

Each of newly-entering firms must satisfy the following condition to set up a business in Period t,

$$\bar{\theta}\omega_t + P^E_{t+1}\hat{A} \geq R(P_t\hat{A} + W_t(\omega_t) + \omega_t\phi), \tag{1}$$

where P_t, P^E_{t+1}, W_t and $\bar{\theta}$ denote asset prices, expected asset prices, a wage rate, and an expected aggregate productivity in Period t. [6] Here we assume that the wage rate W_t grows with the firm's technological progress. The left-hand side (LHS) of the equation represents expected profits obtained from undertaking productions while the right-hand side (RHS) represents the debts with interest, i.e., Eq.(1) is the lender's incentive constraint. [7] Letting $\bar{\phi}_t \left(\equiv 1/\omega_t \left\{[\bar{\theta}\omega_t + P^E_{t+1}\hat{A}]/R - P_t\hat{A} - W_t(\omega_t)\right\}\right)$ be the maximum level of ϕ that satisfies Eq.(1). The new firms with $\phi \leq \bar{\phi}_t(W_t(\omega_t), P_t, P^E_{t+1})$ succeed in introducing the newest technology. Hence the aggregate asset demand in Period t is obtained as follows:

$$D_t = \hat{A}\int_0^{\bar{\phi}_t(W_t(\omega_t),P_t,P^E_{t+1})} dF(\phi). \tag{2}$$

From the properties of $\bar{\phi}_t$, it is clear that D_t is decreasing in asset P_t and $W_t(\omega_t)$, and increasing in P^E_{t+1}. The new firms that set up production in Period t produce $\theta_{t+1}\omega_t$ units of the final good in

[5] Hence the economy is considered a small open economy.

[6] We can also express Eq.(1) in terms of the NPV role as follows:

$$NPV_t \equiv \frac{\bar{\theta}\omega_t + P^E_{t+1}\hat{A}}{R} - (W_t + P_t\hat{A} + \omega_t\phi) > 0.$$

If the $NPV \geq 0$, new firms can raise funds and start up their businesses in Period t.

[7] Here we assume that the final good price is a numeraire.

Period $t+1$, and then, repay their debt. Firms that have to liquidate their assets to pay off their debt are forced to retire from the market and release their assets to declare bankruptcy. The firms with $\phi \leq \tilde{\phi}_{t+1}(W_t(\omega_t), P_t, \theta_{t+1})$ can pay their debt off without liquidating their own assets, where $\tilde{\phi}_{t+1}$ is the maximum level which satisfies the expression $\theta_{t+1}\omega_t \geq R(P_t\hat{A} + W_t(\omega_t) + \omega_t\phi)$. The profits of firms are distributed among the firms' owners. To stay in business, they must raise funds to purchase one unit of labor through contracts with the intermediary in succeeding periods. [8] At Period $t+1$, since new firms with the most advanced technologies will have appeared in the economy, the technologies that were introduced into the production processes in Period t become relatively obsolete compared with the newer ones available in Period $t+1$. [9]

The newly-entering firms from Period t with $\tilde{\phi}_{t+1} < \phi \leq \bar{\phi}_t$ are forced to retire from production and hence scrap their technologies in Period $t+1$. Therefore, in Period $t+1$, the aggregate assets liquidated by newly-entering firms from Period t, $S_{t+1}^{\text{New}_t}$, are as follows:

$$S_{t+1}^{\text{New}_t} = \hat{A} \int_{\tilde{\phi}_{t+1}(W_t(\omega_t), P_t, \theta_{t+1})}^{\bar{\phi}_t(W_t(\omega_t), P_t, P_{t+1}^E)} dF(\phi). \tag{3}$$

Figure.1 shows the time line of such firms' behavior.

《Insert Figure. 1》

2.3 Scrapping old technologies

In this subsection we consider the scraipping of old vintage technologies. Let us denote $\underline{v}_t$ and $\omega_{\underline{v}_t}$ as the oldest vintage technology in use and its technological level (productivity) in Period t. Also, G_v represents the number of firms that have introduced technologies into productions in Period $v(< t)$. We assume that G_v is in between $G_{\underline{v}_{t-1}}$ and G_{t-1} in Period t. Here $\underline{v}_{t-1}$ represents the oldest vintage technology in use in Period $t-1$. Therefore the number of firms in production in Period t is expressed by $\sum_{v=\underline{v}_{t-1}}^{t-1} G_v$. [10] Since the assets in the model are assumed to be exogenously given such as real estate, they do not become available to the potential entrants without the retirements of the incumbent firms.

[8] Since the firms already have $\hat{A}$ units of assets not which depreciate over time, they do not need to buy assets again. Since the sets up cost is needed only when technologies are introduced into production processes, the firms that continue their businesses must raise funds for only the wage payments.

[9] In our model, we assume that the firms can not replace old technologies with new ones if they introduce their technologies into the production processes once. Therefore the productivity of the firms have early started their businesses relatively lowers compared with new firms' ones. If we, however, consider effects of learning, old firms can have relatively high productivity than new firms' ones. Salvanes and Tveteras (2004) empirically show that there is both a learning effect and a vintage capital effect using data from a panel of Norwegian manufacturing plants, and the former effect dominates the early years in the life of a plant and the latter effect dominates the later years.

[10] Firms who realize their productions in Period t are those that started up their businesses in Period $t-1$.

The firms in production in Period $t-1$ (old firms) produce outputs and cleare up their debt in Period t. If the old firms don't have high enough ω_v to satisfy the following constraint, then they have to sell their assets to pay off their debt, thus being forced to exit from the market, [11]

$$\omega \geq \frac{RW_{t-1}(\omega_{t-1})}{\theta_t} \equiv \omega_{v_t^P}(W_{t-1}(\omega_{t-1}), \theta_t). \tag{4}$$

The lowest level of productivity of technology $\omega_{v_t^P}$ (therefore the oldest vintage technology v_t^P) to pay off debt without liquidating assets (therefore avoiding bankruptcy) is obtained from Eq.(4). Since the firms with $\omega < \omega_{v_t^P}$ go bankrupt, the technologies with vintages $v < v_t^P$ are scrapped. However, the firms with $\omega \geq \omega_{v_t^P}$ can pay off their debt without selling their assets and thus avoid exiting from the market. The firms with $\omega \geq \omega_{v_t^P}$ distribute the profits among their owners and then try to raise funds for wage payments in Period t to continue in business. For this, each firm is required to have ω which satisfies the following constraint,

$$\omega \geq \frac{RW_t(\omega_t) - P_{t+1}^E \hat{A}}{\bar{\theta}} \equiv \omega_{v_t^R}(W_t(\omega_t), P_{t+1}^E). \tag{5}$$

Eq.(5) is derived by rewriting $\bar{\theta}\omega + P_{t+1}^E \hat{A} \geq RW_t(\omega_t)$. From the above expression, the lowest level of productivity of technology $\omega_{v_t^R}$ (therefore the oldest vintage technology v_t^R) that is required in order to raise funds in Period t is obtained.

The assets liqudated by the old firms in Period t depend on which constraint is in effect, $\omega_{v_t^P} > \omega_{v_t^R}$ or $\omega_{v_t^P} \leq \omega_{v_t^R}$ (that is, $v_t^P > v_t^R$ or $v_t^P \leq v_t^R$). The effective constraint is determined by Eqs.(4) and (5).

If $\omega_{v_t^P} > \omega_{v_t^R}$ is in effect, no firms go bantrupt due to failure in financing the wage payments because Eq.(5) is not bound. Hence the oldest vintage technology in use in Period t is determined by v_t^P obtained from Eq.(4), namely $\underline{v}_t = v_t^P$. As a result, the assets supplied by the old firms are written as follows;

$$S_t^{P,\mathrm{Old}_t} = \hat{A} \sum_{v=\underline{v}_{t-1}}^{v_t^P(W_{t-1}(\omega_{t-1}),\theta_t)} G_v. \tag{6}$$

The oldest vintage technology still in use in Period t is determined by v_t^R obtained from Eq.(5), i.e., $\underline{v}_t = v_t^R$, when $v_t^P \leq v_t^R$ is in effect. As a result, the assets supplied by the old firms are obtained as follows,

$$S_t^{R,\mathrm{Old}_t} = \hat{A} \sum_{v=\underline{v}_{t-1}}^{v_t^R(W_t(\omega_t),P_{t+1}^E)} G_v. \tag{7}$$

In that case, however, the firms with $\underline{v}_{t-1} \leq v < v_t^P$ retire from the market when they clear up their debts, while those with $v_t^P \leq v < v_t^R$ go bankrupt due to their failure to raise funds needed to pay wages.

[11] This constraint is obtained by rewriting $\theta_t\omega \geq RW_{t-1}$.

Hence the aggregate assets supplied in Period t are obtained as follows,

$$S_t = \begin{cases} S_t^P = S_t^{\mathrm{New}_{t-1}}(W_{t-1}(\omega_{t-1}), P_{t-1}, P_t^E, \theta_t) + S_t^{P,\mathrm{Old}_t}(W_{t-1}(\omega_{t-1}), \theta_t) & (when\ v_t^P > v_t^R) \\ S_t^R = S_t^{\mathrm{New}_{t-1}}(W_{t-1}(\omega_{t-1}), P_{t-1}, P_t^E, \theta_t) + S_t^{R,\mathrm{Old}_t}(W_t(\omega_t), P_{t+1}^E) & (when\ v_t^P \leq v_t^R). \end{cases} \quad (8)$$

The first terms of the RHS ($S_t^{\mathrm{New}_{t-1}}$) represent the assets liquidated in Period t by the firms that had newly set up their businesses in Period $t-1$, while the second terms (S_t^{P,Old_t} and S_t^{R,Old_t}) are the assets supplied by the old firms in Period t. [12] In what follows, we consider which constraint is more likely depending on the economic situation characterized by the level of θ_t.

2.4 Within-period equilibrium

In this subsection let us characterize an within-period equilibrium of the asset market. First the assets are demanded by the firms attempting to introduce the newest technology into production processes in Period t. The aggregate demand $D_t(W_t(\omega_t), P_t, P_{t+1}^E)$ is obtained from Eq.(2), which is decreasing in P_t and W_t, and increasing in P_{t+1}^E.

The assets are supplied by the firms that have to liquidate their assets to pay off their debts or those unable to raise funds for the wage payments, while the aggregate asset supply depends on which constraint is in effect $\omega_{v_t^P} > \omega_{v_t^R}$ or $\omega_{v_t^P} \leq \omega_{v_t^R}$.

Suppose that aggregate productivity, θ_t declines sharply. $\omega_{v_t^P}$ obtained from Eq.(4) also rises sharply, and then $v_t^P > v_t^R$ is more likely to be satisfied than $v_t^P \leq v_t^R$. Hence the aggregate asset supply function in Period t becomes S_t^P in Eq.(8). In contrast, $\omega_{v_t^P}$ obtained from Eq.(4) declines when θ_t rises. In that case $v_t^P \leq v_t^R$ is more likely to hold than $v_t^P > v_t^R$, and hence the asset supply function is expressed by S_t^R obtained from Eq.(8). In both cases, the asset supply curves do not depend on P_t, and hence becomes vertical. This property makes our following analyses and results clearer. [13]

2.5 Technological progress, technology adoption and productivity growth

Despite the fact that $\underline{v}_t$ is determined by either v_t^P or v_t^R (the oldest vintage technology in use in Period t), the asset supply function S_t depends on wages (W_{t-1} and W_t). The wage rate rises with technological advances, and $\underline{v}_t$ increases with wage rate over time. Therefore the old vintage technologies are scrapped gradually over time, and the assets which have been used by the firms with scrapped technologies are

[12] Here old firms are those that succeeded in continuing to do their business in Period $t-1$.

[13] If we consider the case that expected asset prices depend on the present asset prices or the case that firms choose to interrupt their productions and sell their assets athough they can continue their businesses, we can get the upward-sloping asset supply curve. In both cases, however, the main results of the paper remain unchanged.

returned to the asset market. As a result, the adoption of new technologies takes place in the economy. Hence the economy-wide productivity (the output) also increases over time.

Suppose that $\underline{v}_{t-1}$ is given, and $\underline{v}_t(> \underline{v}_{t-1})$ is determined in Period t. Since the vintage technologies with $\underline{v}_{t-1} \leq v < \underline{v}_t$ are scrapped, $\hat{A} \sum_{v=\underline{v}_{t-1}}^{\underline{v}_t} G_v$ units of asset become available for potetial entrants. Thanks to this new technology adoption, the economy-wide productivity $\bar{\omega}$ increases as follows,

$$\Delta\bar{\omega}_t = \sum_{v=\underline{v}_{t-1}}^{\underline{v}_t} \{(\omega_t - \omega_v)G_v\}. \tag{9}$$

Now if we assume that the aggegate productivity θ_t is constant at the average level $\bar{\theta}$ over the periods, a rise in economy-wide productivity thanks to the new technology adoption increases the output from Period t to $t+1$ by the following amounts,

$$\Delta Y_t = \bar{\theta} \sum_{v=\underline{v}_{t-1}}^{\underline{v}_t} \{(\omega_t - \omega_v)G_v\}. \tag{10}$$

Since $\omega_t > \omega_v$ holds for all $t > v$, $\Delta\bar{\omega}_t$ is always positive if $\underline{v}_t > \underline{v}_{t-1}$. The larger the difference between $\underline{v}_t$ and $\underline{v}_{t-1}$, the soarer the scrapping of old vintage technologies and the adoption of new technologies take place. As a result, a rise in economy-wide productivity (the output) increases even further.

However when $\underline{v}_t \leq \underline{v}_{t-1}$ is satisfied for some reason, the adoption of new technology does not take place because old technologies are not scrapped nor are productive resources (assets) released for the asset market. Therefore, neither economy-wide productivity nor output would increase. Figure 2 shows a mechanism of scrapping old technologies and introducing new ones when we assume that G_v's' are given by a constant value of $\bar{G}$ for all $v(< t)$.

《Insert Figure 2》

In the economy, an increase in economy-wide productivity rises only through scrapping old vitage technologies and introducing new ones. In this sense, technology adoption is an essential element for productivity growth. In what follows we will analyze the macroeconomic factors (especially asset prices) influencing technology adoption.

3 Asset prices and technology adoption

The analysis in the previous section has shown that the asset supply function S_t depends on which constraint is in effect, $\omega_{v_t^P} > \omega_{v_t^R}$ (that is, $v_t^P > v_t^R$) or $\omega_{v_t^P} \leq \omega_{v_t^R}$ (that is, $v_t^P \leq v_t^R$). Let us consider which constraint is more likely depending on the economic situation characterized by the level of θ (in booms or recessions), and then investigate the macroeconomic factors (especially asset prices) influencing the technology adoption for each case.

3.1 Technology adoptions during recessions

First, suppose a recession takes place, and aggregate productivity θ_t falls shaply in Period t. The outputs $\theta_t \omega$ decrease sharply. Hence $\omega_{v_t^P}$ obtained from (4) increases and therefore the vintage technology v_t^P also increases, so that the condition $v_t^P > v_t^R$ is more likely than the other. The oldest vintage technology in use in Period t is determined by v_t^P, that is $\underline{v}_t = v_t^P$, as is shown in Figure 3(a).

《Insert Figures 3(a) and 3(b)》

The sharp increase in $\omega_{v_t^P}$ caused by a decline in θ_t makes even the firms with vintage technologies that are not old liquidate their assets to clear off their debt. Therefore the number of firms that exit from the market increases, and the economy experiences a serious recession. Consequently, many resources flow into the asset market, and the asset supply curve then shifts to the right as shown in Figure 3(b). Hence the asset prices in Period t decline.

The fall in the asset prices in turn encourages potential entrants to enter the market, and hence a massive adoption of new technologies takes place in the recession. Then the economy-wide productivity growth soars, which can be a driving force for the economy to recover from the resession. Here one can arrive at the following proposition. [14]

Proposition 1 In recessions, many firms with relatively old technologies go bankrupt and many resources that have been held by those firms are released to the asset market, which lowers asset prices. As a result, the new firms become able to set up their businesses, and a massive adoption of new technologies takes place.

However, if the economic agents become pessimistic during a reccession, they will expect the future asset prices P_{t+1}^E to decline sharply and then $\omega_{v_t^P}$ to increase more significantly. In this case $\omega_{v_t^P} \leq \omega_{v_t^R}$ may occur, although $\omega_{v_t^P}$ increases by the decline in θ_t as shown in Figure 4(a) and 4(b).

《Insert Figures 4(a) and 4(b)》

[14] Here we assume that expected future asset prices remain unchanged. Even if the expected asset prices rise, Eq.(4) is still in effect, and the Proposition 1 holds.

Since Eq.(5) is in effect, the decline in expected asset prices P_{t+1}^E becomes important in affecting the aggregate asset supply. A decline in P_{t+1}^E makes evaluations of the old firms' assets decline, hence it is difficult for the old firms to raise funds for wage payments. As the bankrupticies of the old firms multiply, the supply of the asset increases, triggering an upward shift in the supply curve, as is shown in Figure 4(b).

In contrast, a fall in P_{t+1}^E decreases the asset demand by the new firms (a downward shift of asset demand curve in Figure 4(b)). The shifts of supply and demand curves cause a sharp decline in asset prices, enabling the new firms to set up their businesses easily. The adoption of new technology also grows more active, and the productivity growth is largely enhanced. The following proposition can be obtained.

Proposition 2 A decrease in expected future asset prices in a recessions leads to a sharp decline in the current asset prices, and hence the adoption of new technologies becomes active. As a result, the productivity growth is largely enhanced.

The above propositions are similar to "the cleasing effect of recessions" in Caballero and Hammour (1994) conclude that old machines are scrapped massively in recessions. The cleasing effect of recessions is supported by such empirical studies as one by Gali and Hammour (1991).

3.2 Technology adoptions during booms

Next consider that a boom occurs and the aggregate productivity θ_t rises sharply. In such a case, $\omega_{v_t^P}$ obtained from Eq.(4) declines sharply and hence the condition $\omega_{v_t^P} \leq \omega_{v_t^R}$, that is $v_t^P \leq v_t^R$, holds more likely than the other. Figure 5(a) shows this situation.

《Insert Figures 5(a) and 5(b)》

In this case, Eq.(5) becomes effective and then the expected asset prices come to affect the aggregate asset supply, and therefore technology adoption.

If a sharp rise in the asset prices is not expected, $v_t^P \leq v_t^R$ is maintained, and the leftward shift of the supply curve is correspondingly small as shown in Figure 5(b). In this case, since the number of the firms that go bankrupt declines, the number of the potential entrants that enter the market also decreases. Therefore the introduction of new technologies is deterred, and the economy-wide productivity growth slows down.

In contrast, if a sharp rise in asset prices is expected, the v_t^R may decrease and fall lower than v_t^P, although v_t^P decreases by an increase in θ_t as is shown in Figure 6(a).

《Insert Figures 6(a) and 6(b)》

In this case, even the firms with older vintage technologies become able to raise funds because the lenders can collect debt by liquidating the firms' assets, even if the profits of the firms are small. Thus a rise in expected asset prices facilitates the finances of the old firms. Hence, many old firms survive and many productive resources are then locked in the production with old vintage technologies. This shifts the asset supply curve to the left. The rise in expected asset prices also raises the firms' expected profits (which is evident from Eq.(2)) and causes the aggegate asset demand of newly-entering firms to increase. The asset demand curve, then, shifts to the right, as shown in Figure 6(b). The sharp rise in current asset prices caused by the shifts in supply and demand curves prevents new firms from entering the market, so that the adoption of new technology slows markedly. The following proposition can be obtained.

Proposition 3 With future asset prices expected to rise during boom periods, the assets demanded by new firms increase while old firms do not go bankrupt and so do not release their productive resources. As a result, the asset prices increase sharply, which make it difficult for newly arrived firms to set up their businesses. The introduction of new technologies is deterred, thus lowering productivity growth.

Since asset prices generally move procyclically, Propositions 1, 2 and 3 are complementary to each others. Those three propositions clearly explain why technology adoption is countercyclical, so that a recession forces the firms to default, which in turn increases the resources released from the production with old technologies. Hence, asset prices decline, which facilitates new firms to set up businesses. Hence, massive adoption of new technologies takes place in the economy. In contrast, a boom helps the incumbent firms with low profitability to survive, which in turn makes sure that productive resources remain locked in the production with old technologies. Consequently, asset prices rise and technology adoption is detered, confirming that asset prices play a crucial role in adopting new technologies.

The countercyclical movements of technology adoption are confirmed by the empirical study of Gittleman et al. (2006) that estimate the age structure of capital based upon a vintage model. Furthermore, their result is also consistent with historical events. For example, the fact that productivity growth rates were high in the 1930s or Great Depression is empirically verified by Solow (1957), Kendrick (1961), Gordon (2000) and Field (2003, 2006). Alexopoulos (2006) also shows that massive innovation activities after 1933 were the main factors in helping the US economy to recover from the Depression. Although it is outside the scope of our enquiry, the model in this paper provides a theorical explanation to confirm her story.

In addition, our results make it clear that loans based on collaterals exert a negative effect on the economy. Eq.(5) shows that secured loans lower $\omega_{\hat{v}_t}$ which helped the incubment firms with low productivities to survive. Such an effect becomes stronger, especially in a period with high expected future asset prices, so that both scrapping old technologies and introducing advanced ones are detered. Hence, the following proposition is obtained.

Proposition 4 Lending based upon collaterals helps unprofitable firms to survive and deters the adoption of new technologies. That effect is enhanced when the intermediaries expect the future asset prices to increase.

A similar view is expressed by Nishmura et al. (2005) insist that the reason why firms with relatively low productivity could survive in an industry is due to the support given by financial intermediaries.

4 Conclusions

Having been motivated by the empirical facts, this paper has analyzed the relationship between technology adoption and macroeconomic conditions such as slumps and booms based upon a vintage model. As a result, it was shown that the scrapping of old machines is accelerated, and much new capital equipment with leading technologies is introduced during slumps. These phenomena have been analyzed by various researchers and have become known as "the cleansing effect of recessions" (Caballero and Hammour, 1994).

However, this paper has pointed out a different channel that leads to the same goal. In this sense, among various propositions put forward in this paper, the following may be considered as our main contributions.

1) Asset prices play a key role in the determination to scrap old machines and introduce new ones. Higher prices help firms with old and unprofitable technologies to survive. As a result, some productive resources and structures are locked in the old technologies. This low availability of resources make it difficult for potential entrants to break into markets with frontier technologies. The opposite mechanism is in effect in that the introduction of new technologies is accelerated during slumps with low asset prices.

2)Lending based upon collaterals enable unprofitable firms to survive, hence delaying the adoption of new technology. This effect is enhanced when, as expected, asset prices rise, slowing down the introduction of new technoligies. In contrast, a decrease in lending during slumps fosters the abandonment of old equipment and accelerates the introduction of new technologies. This in turn increases the productivity of the economy as a whole and facilitates its recovery from recessions.

References

[1] Alexpoulos, M. (2006). "Believe it or not! The 1930s Was a Technologically Progressive Decade" Mimeo, University of Toronto.

[2] Bahk, B. and M. Gort (1993). "Decomposing Learning by Doing in New Plants" *Journal of Political Economy* 101 :561-583.

[3] Caballero, J. and M, Hammour (1994). "The Cleansing Effect of Recessions" *American Economic Review* 84(5):1350-1368.

[4] Clark, P (1979). "Issues in the Analysis of Capital Formation and Productivity Growth" *American Economic Review* 79(1):14-31.

[5] Cooley, T.F., J. Greenwood, and M. Yorukoglu (1997). "The Replacement Problem" *Journal of Monetary Economics* 40:457-499.

[6] De Long, J, B. (1990). "Liquidation Cycles: Old-Fashioned Real Business Cycle Theory and the Great Depression" *NBER Working Paper* No. 3546.

[7] Field, A. (2003). "The Most Technologically Progressive Decade of the Century" *American Economic Review* 93(4):1399-1413.

[8] Field, A. (2006). "The Technological Change and U.S. Economic Growth during the Interwar Years" *Journal of Economic Histry* 66(1):203-236.

[9] Gali, J, and M. Hammour (1991). "Long-Run Effects of Business Cycles" Mimeo, Columbia University.

[10] Gittleman, M., R. Raa, and E. Wolff (2006). "The Vintage Effect in TFP-growth: An Analysis of the Age Structure of Capital" *Structural Change and Economic Dynamics* 17 :307-328.

[11] Gordon, R (2000). "Interpreting the "One Big Wave" in U.S. Long-Term Productivity Growth" *NBER Working Paper* No. 7752.

[12] Jensen, J., R. H. McGuckin, and K. J. Stiroh (2001). "The Impact of Vintage and Survival on Productivity: Evidence from Cohorts of U.S. Manufacturing Plants" *Review of Economics and Statistics* 83 :323-332.

[13] Johansen, L (1959). "Substitution versus Fixed Production Coefficients in the Theory of Economic Growth: A Synthesis" *Econometrica* 27(2):157-176.

[14] Jorgenson, D (1966). "The Embodiment Hypothesis" *Journal of Political Economy* 74(Feb):1-17.

[15] Kendrick, J (1961). Productivity Trends in the United States. Princeton, NJ: Princeton University Press.

[16] Kleinknecht, A. (1987). *Innovation Patterns in Crisis and Prosperity: Schumpeter's Long Cycle Reconsidered.* New York: St. Maytine's Press.

[17] Menche, G. (1979). *Stalemate in Technology: Innovations Overcome the Depression* Cambridge, MA:Ballinger.

[18] R. Minetti (2007). "Bank Capital, Firm Liquidity, and Project Quality", *Journal of Monetary Economics.*

[19] Mowery, D., and N. Rosenberg (2000). "Twentieth Century Technological Change". *In The Cambridge Economic History of the United States,* ed. Stanley Engerman and Robert Gallman, 803-926. Cambridge University Press.

[20] Nishimura, K. G., T. Nakajima, and K. Kiyota (2005). "Does the Natural Selection Mechanism Still Work in Severe Recessions? Examination of Japanese Economy in the 1990s" *Journal of Economic Behavior and Organization* 58 :53-78.

[21] Ohanian, L. (2001). "Why Did Productivity Fall So Much During the Great Depression?" *American Economic Review* 91(2):34-38.

[22] Power, L. (1998). "The Missing Link: Technology, Investment and Productivity" *Review of Economic and Statistics* 80:300-313.

[23] Salvanes, K.G., and R. Tveteras (2004). "Plant Exit, Vintage Capital and The Business Cycle" *The Journal of Industrial Economics* 52(2):255-276.

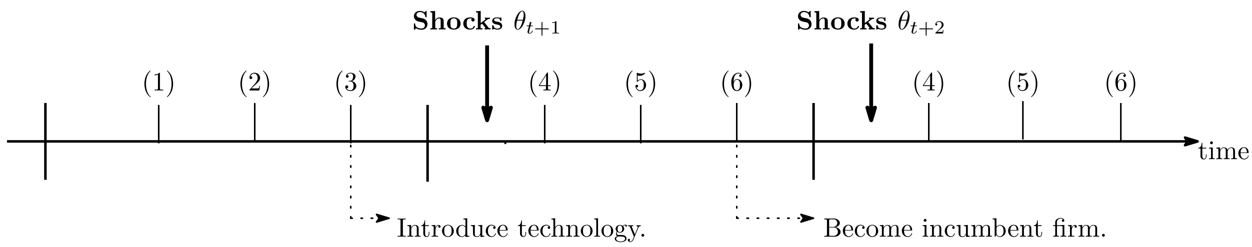
[24] Solow, R. (1957). "Technical Change and the Aggregate Production Function" *Review of Economics and Statistics* 39(3):312-320.

[25] Solow, R. (1960). "Investment and Technological Progress" in K.J. Arrow, S Karlin, and P. Suppes, eds., *Mathematical Methods in the Social Sciences.* Stanford, CA: Stanford University Press, pp.89-104.

[26] Wolff, E. (1991). "Capital Formation and Productivity Convergence over the Long-term" *American Economic Review* 81(3):565-579.

[27] Wolff, E. (1996). “The Productivity Slowdown: the Culprit at Last” *American Economic Review* 86(5):1239-1252.

[28] Zou, B. (2006). “Vintage Technology, Optimal Investment and Technology Adoption” *Economic Modelling* 23:515-533.



(1)Potential entrants appear with latest technology.
(2)Potential firms raise funds using a one-period contract with a financial intermediary.
(3)Potencial firms introduce their technologies and input productive resources.
(4)Output realised, and firms clear their debt from previous periods.
(5)Firms distribute the profits among their owners.
(6)Incumbent firms rise funds for wage payments and continue their businesses.

Figure 1: Timeline of Events

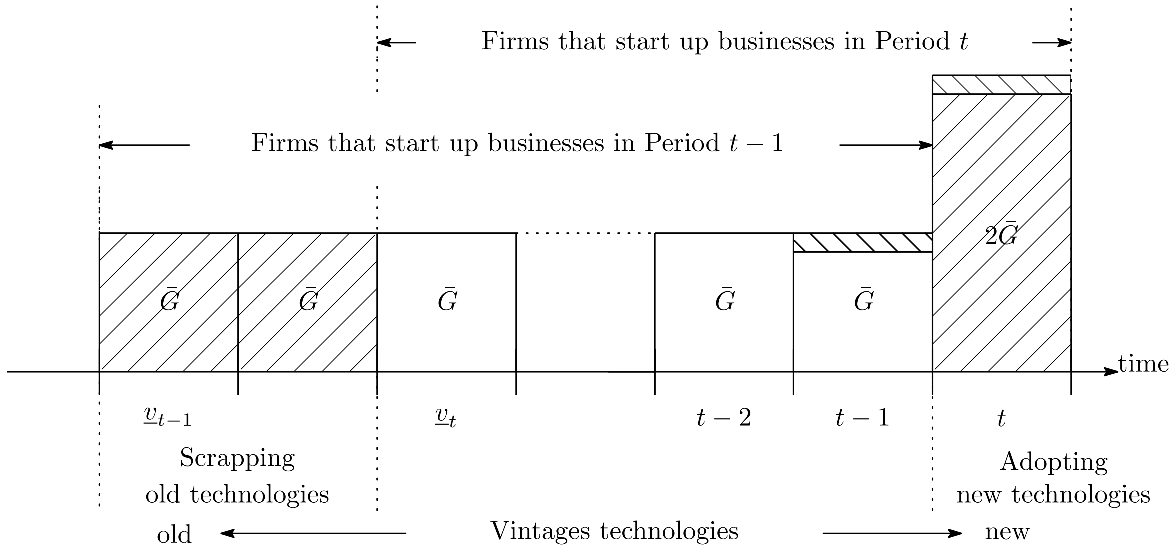


Figure 2: Scrapping old technologies and introducing new ones.

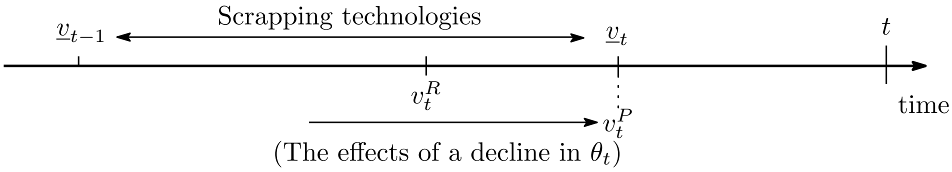


Figure 3(a): Scrapping old technologies.

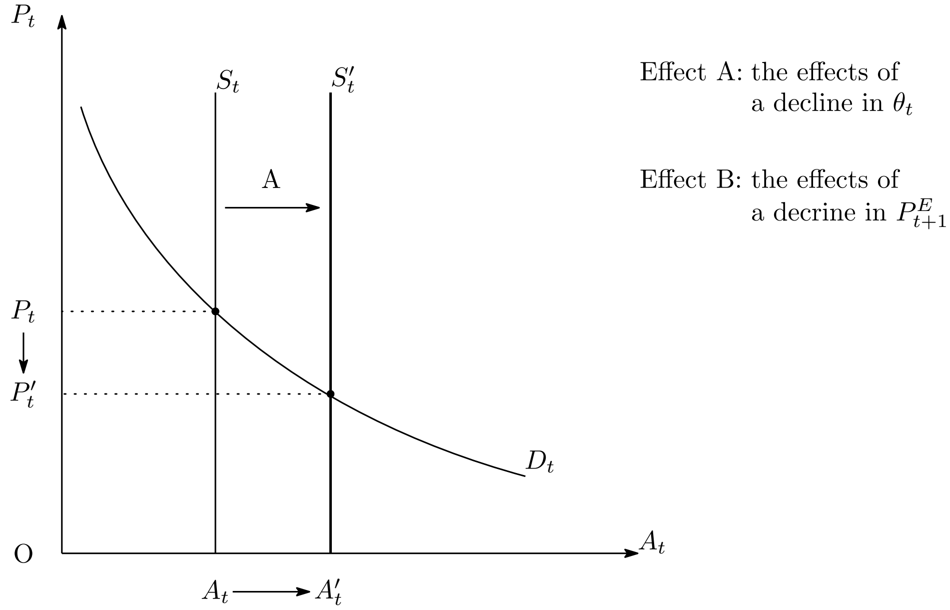


Figure 3(b): Released assets and asset prices.

Figure 3: Asset prices and technology adoptions during recessions.

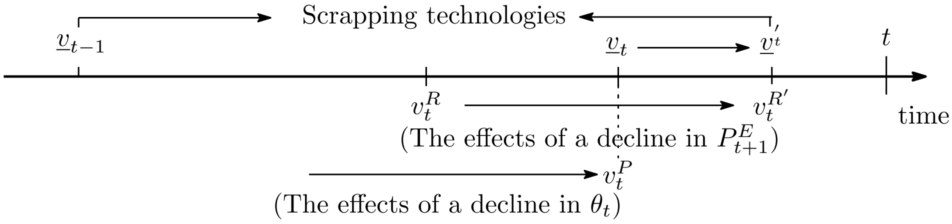


Figure 4(a): Scrapping old technologies.

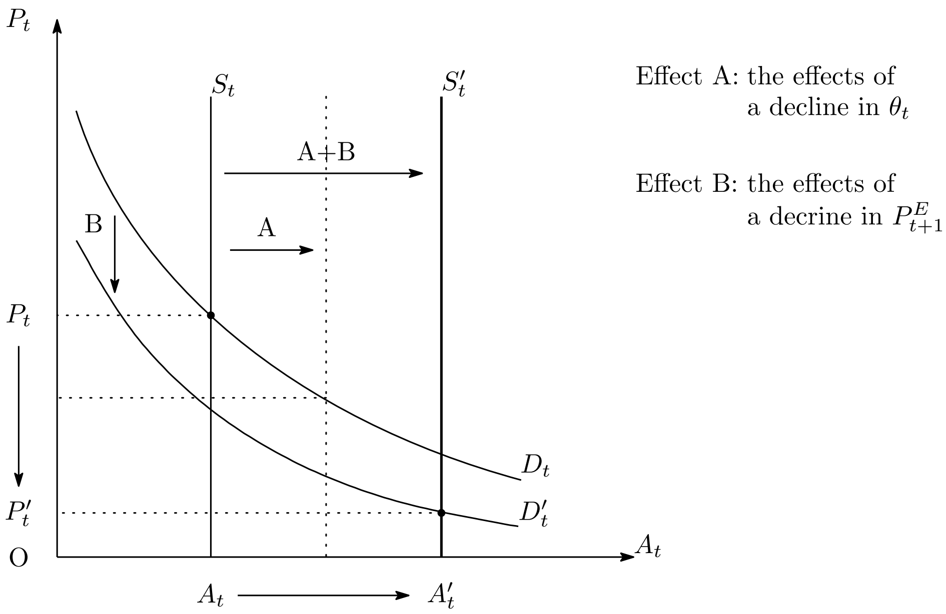


Figure 4(b): Released assets and asset prices.

Figure 4: Asset prices and technology adoptions during recessions with a decline in expected asset prices.

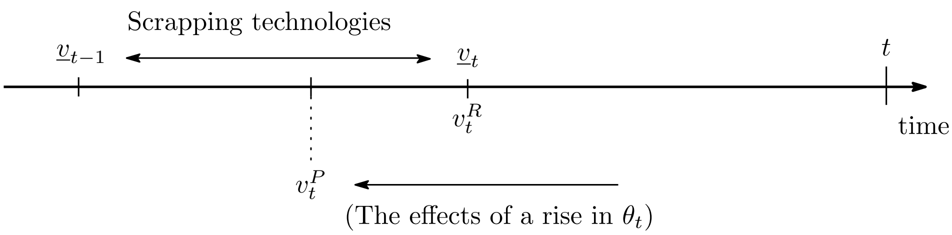


Figure 5(a): Scrapping old technologies.

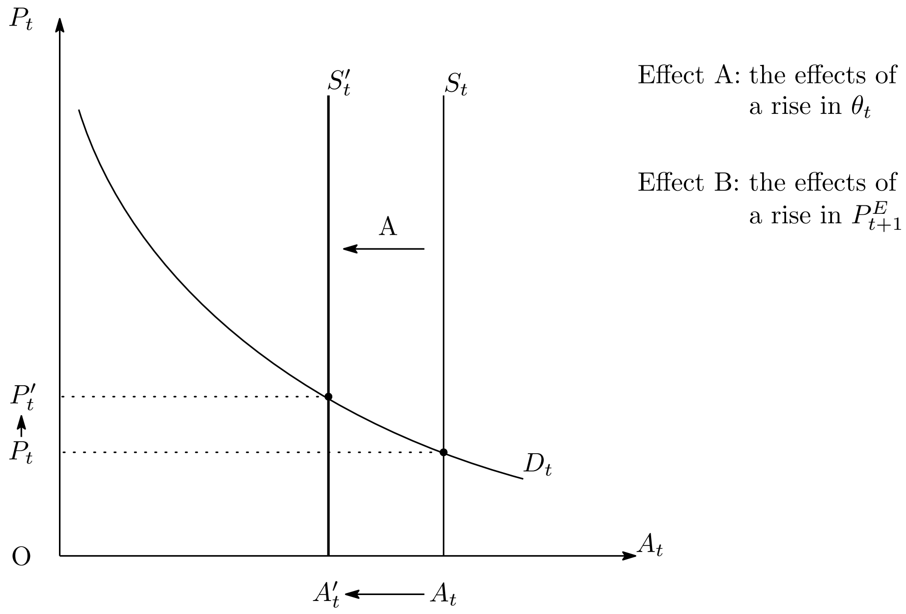


Figure 5(b): Released assets and asset prices.

Figure 5: Asset prices and technology adoptions during booms.

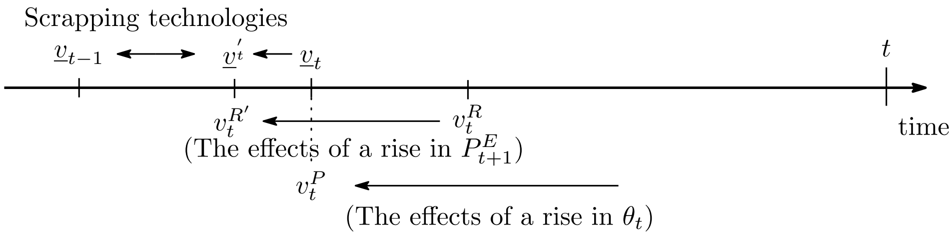


Figure 6(a): Scrapping old technologies.

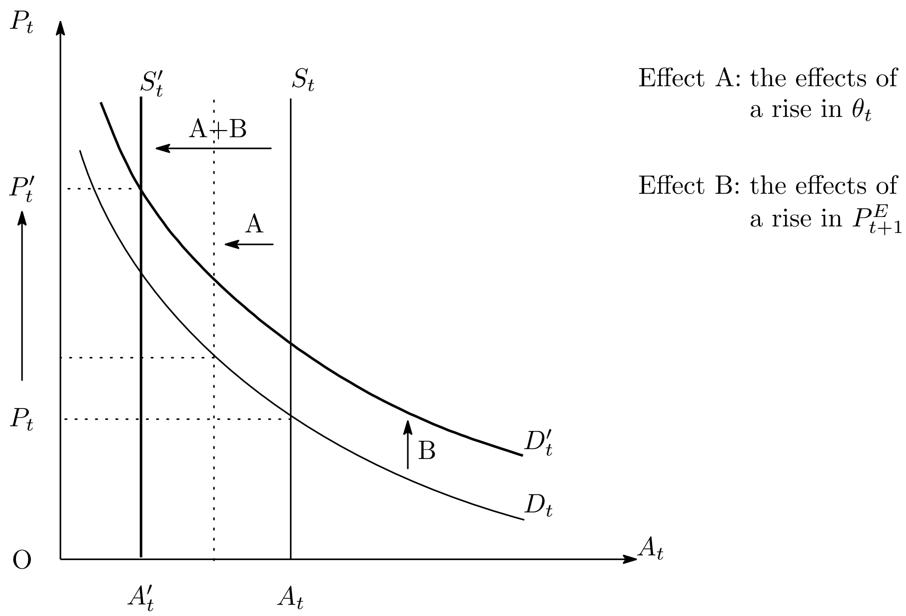


Figure 6(b): Released assets and asset prices.

Figure 6: Asset prices and technology adoptions during booms with a rise in expected asset prices.