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Katsukai Teraseawa

Optimal Replacement of Consumer Durables
1. Replacement Theory

The problem of determining the optimal procedure for the replacement of a machine, which is exposed to wear and tear and ultimately ceases to function, is a common occurrence in many industries. This chapter provides a framework for analyzing such situations, with a focus on the economic implications of replacement decisions.

The replacement of a machine is a critical decision, as it affects the overall efficiency and profitability of an organization. The optimal replacement policy aims to minimize the total cost associated with the machine's operation, taking into account the costs of replacement and the benefits of new technology.

In this chapter, we will explore different models and approaches to replacement theory, with a particular emphasis on the deterministic and stochastic frameworks. The deterministic approach assumes that all parameters are known with certainty, while the stochastic approach acknowledges the inherent uncertainties in real-world situations.

The chapter begins with an introduction to the basic concepts of replacement theory, followed by a detailed discussion of the deterministic model. We then move on to the stochastic model, which incorporates uncertainties in the form of random variables. Finally, we will conclude with a section on practical applications and case studies, illustrating how these theoretical concepts can be applied to real-world problems.
of the last machine in the chain. Substituting this into (3) yields (1), which

\[ L'(1) = \int L'(t) \, dt \]

condition is \( \frac{d}{dt} x \), \( t \to x \). The economic index 

\[ I'(t) = \int_{t}^{0} \left( \int_{s}^{0} L'(s) \, ds \right) \, dt \]

\[ \frac{d}{dt} x \]

assuming the second order condition is satisfied, the maximization

\[ \max_{x} \int_{0}^{x} \left( \int_{s}^{0} L'(s) \, ds \right) \, dx \]

Here the subscript \( k \) = 1, 2, \ldots, \( n \), indicates the number of links in the chain.

\[ \{ \int_{0}^{T} \left[ \int_{t}^{0} \left( \int_{s}^{0} L'(s) \, ds \right) \, dt \right] \, dx + \int_{0}^{T} \left[ \int_{s}^{0} L'(s) \, ds \right] \, dx \} + \int_{0}^{T} \left[ \int_{s}^{0} L'(s) \, ds \right] \, dx = 0 \]

function.

\[ \{ \int_{0}^{T} \left( \int_{s}^{0} L'(s) \, ds \right) \, dx \} + \int_{0}^{T} \left( \int_{s}^{0} L'(s) \, ds \right) \, dx = 0 \]
have the same optimal life (\(T\)). Substituting (11) into (10) we obtain

\[ (C + S)x = \int_0^T (1)(S)dx \]  

(11)

and the minimizing condition

\[ C - \int_0^T (1)(S) + S + \int_0^T \frac{d}{dT} (1)(S) dx \int_0^T = 0 \]  

(10)

Thus it is clear in the infinite chain case that each machine in the chain will

\[ \therefore \int_0^T (1)(S) = 0 \]  

(7)

For the work of \(T\), Taylor’s [10] later simplified and retained by H. Horikawa

\[ C - \int_0^T (1)(S) = 0 \]  

(6)

Substituting (5) into (6) and (4) we obtain

\[ \int_0^T (1)(S) = - \int_0^T (1)(x) \]  

(5)

different in general.

due to the nature of infinity. Thus we are to minimize the expression of the chain of machines. Then the infinite "goodwill" of each period must be the same

\[ \int_0^T (1)(S) \]  

(4)

This is the expression's portion extends over an infinite.

\[ \int_0^T (1)(S) \]  

(3)
By differentiating the term below with respect to $\mu$, then the optimal length of each machining $\mu_i$ can be obtained.

Optimal number of machinings $\mu$ is chosen if

$$\left\{ \begin{array}{ll}
\text{max} & \int_0^\infty \left[ \sum_{i=1}^\infty \frac{1 + f_{\mu i} \mu}{1 + f_{\mu i} \mu} + \mu \right] + \frac{\mu}{1 + f_{\mu i} \mu} d\mu = 0 \\
\text{subject to} & \mu \geq (\lambda \mu) \\
\text{boundary condition} & \mu > (\lambda \mu)
\end{array} \right. \tag{21}$$

Then set $Y = \frac{1}{\mu}$, then $X = \frac{1}{\mu}$, and set $Y = \frac{1}{\mu}$, then the optimal horizon $T_Y$ can be obtained.

Therefore an optimal number of replacements $m^\ast$ is chosen if

$$\left\{ \begin{array}{ll}
\text{max} & \int_0^\infty \left[ \sum_{i=1}^\infty \frac{1 + f_{\mu i} \mu}{1 + f_{\mu i} \mu} + \mu \right] + \frac{\mu}{1 + f_{\mu i} \mu} d\mu = 0 \\
\text{subject to} & \mu \geq (\lambda \mu) \\
\text{boundary condition} & \mu > (\lambda \mu)
\end{array} \right. \tag{21}$$

Thus

$$\frac{d}{d\mu} \int_0^\infty \left[ \sum_{i=1}^\infty \frac{1 + f_{\mu i} \mu}{1 + f_{\mu i} \mu} + \mu \right] + \frac{\mu}{1 + f_{\mu i} \mu} d\mu = 0$$

Under the optimal condition, the condition is satisfied.

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Under the optimal condition, the condition is satisfied.
changes are taken into account, similar to the above. The above example extends to the

where

\[
\{ c - S + \sum_{i=1}^{n} \frac{v_i - 1}{v_i} \} \frac{1}{v_i} + \{ 0 \} \{ 1, 0 \} = (Q)Q \tag{12}
\]

and the cost of new machine does not depend upon the chronological year.

For example, assume the company has the following parameters:

- \( c \) = cost of old machine on sale at time 1
- \( v \) = scrap value of machine at age 1 at time 1
- \( f \) = discount factor at age t
- \( q \) = annual repair cost of machine at age 1 at time 1
- \( p \) = stands for the policy to keep the present machine
- \( k \) = stands for the policy to replace the present machine

Then we have the following expression:

\[
\{ c - S + \sum_{i=1}^{n} \frac{v_i - 1}{v_i} \} \frac{1}{v_i} + \{ 0 \} \{ 1, 0 \} = (Q)Q \tag{13}
\]

Solving for \( (Q)Q \) for replacement, we obtain

\[
(1) c + (0)Q + c - S = \tag{14}
\]

\[
(1) Q + (1)Q = (1)Q
\]

\[
(1) Q + (0)Q = (0)
\]

These are the functional equations for \( (Q)Q \) of the new machine. Thus, the functional equation for \( (Q)Q \) is

\[
(1) c + (0)Q + c - S = \tag{15}
\]

\[
(1) Q + (1)Q = (1)Q
\]

\[
(1) Q + (0)Q = (0)
\]

is derived.

If \( (Q)Q \) is optimal, then purchase a new one, thus the following system of equations:

\[
(1) c + (0)Q + c - S = \tag{16}
\]

\[
(1) Q + (1)Q = (1)Q
\]

\[
(1) Q + (0)Q = (0)
\]

is optimal. Policy will have the form:

- keep a new machine until \( (Q)Q \) becomes negative.
- replace the old machine at the present time.
\[
\text{The discounted present value of utility is given by:}
\]
\[
\begin{align*}
\sum_{t=1}^{T+1} \frac{1}{(1+r)^t} & = 1 \\
\text{where} & \\
1 - \frac{1}{(1+r)^T} & = \frac{1}{r}
\end{align*}
\]
\[ (x_{0}) \text{H} \] 

or given \( t \) 

\[ 0 \leq \sum_{i=1}^{t} (x_{i} + 1) \quad \triangleq \quad (x_{0}) \text{H} - \sum_{i=1}^{t} (x_{i} + 1) = \Delta_{i} \] 

(7.4.1) 

\[ \text{Profit of the new house at time } \Delta \] 

\[ \Delta_{i} = \sum_{i=1}^{t} (x_{i} + 1) \] 

(7.4.1) 

Thus, given the initial stock of \( S_{0} \) and the total \( D \), we can express \( (d)_{0} \text{H} \) as follows: 

\[ (d)_{0} \text{H} = \sum_{i=1}^{t} (x_{i} + 1) + S_{0} \] 

(7.4.1) 

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\[ (d)_{0} \text{H} = \sum_{i=1}^{t} (x_{i} + 1) + S_{0} \] 

(7.4.1)
The first order condition is given by
\[ 0 \geq J_{W} \quad \text{for} \quad 0 > \psi (\phi) \text{ at } \phi = 0 \quad \text{or} \quad \phi > J_{W} \]
where

\[ \sum_{t=1}^{\infty} \left( \frac{1}{\lambda_{t}^{3}} \right) \left( \frac{\Delta \lambda_{t}}{\lambda_{t}} \right) = \sum_{t=1}^{\infty} \left( \frac{1}{\lambda_{t}^{3}} \right) \left( \frac{\Delta \lambda_{t}}{\lambda_{t}} \right) \]

and the differential equation holds for all \( \lambda_{t} > 0 \).

For \( \theta > 0 \), assume \( S = S_{0} > 0 \) implies

Proposition 1

The optimal consumption sequence

\[ \begin{align*}
& \frac{1}{\lambda_{t}^{3}} \left( \frac{\Delta \lambda_{t}}{\lambda_{t}} \right) = \frac{\alpha_{t}}{\gamma_{t}^{3}} \\
& \text{and both}
\end{align*} \]

for \( \alpha_{t} \geq \frac{1}{\gamma_{t}^{3}} \), \( \theta = \frac{\alpha_{t}}{\gamma_{t}^{3}} \), respectively.

The optimal consumption sequence

\[ \begin{align*}
& 0 \geq \frac{1}{\gamma_{t}^{3}} \\
& \text{and both}
\end{align*} \]

for all \( \lambda_{t} > 0 \), respectively.

The optimal consumption sequence

\[ \begin{align*}
& 0 \geq \frac{1}{\gamma_{t}^{3}} \\
& \text{and both}
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for \( \lambda_{t} > 0 \), respectively.

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The optimal consumption sequence

\[ \begin{align*}
& 0 = \frac{1}{\gamma_{t}^{3}} \\
& \text{and both}
\end{align*} \]

for \( \lambda_{t} > 0 \), respectively.
then \( P > 1 \) implies \( \frac{dP}{MP} > 0 \)

\[
0 < \frac{1}{\lambda \delta} \quad \text{(5)}
\]

\[
\left\lfloor \frac{1}{\delta} \right\rfloor \leq \frac{dP}{MP} \quad \text{(6)}
\]

\[
0 < \left( \frac{dP}{MP} \right)_{A} = \left( \frac{dP}{MP} \right)_{M} \quad \text{(7)}
\]

In general, it is not possible to find the directional change of the optimal

negative effect on the utility. However, by having some additional

the replacement time in which direction would have both a positive and

replacement time (8) + the point of new house changes. The change of

\[\frac{dP}{MP} > 0. \quad \text{(7.11)}\]

Then, \( \frac{dP}{MP} > 0. \) implies \( \frac{dP}{MP} > 0. \) for given \( \theta \) assume \( \theta^2 \)

Consequently

Q.E.D.

we have \( \frac{dP}{MP} > 0. \)

By the result above \( \frac{dP}{MP} > 0. \) with respect to \( P \) to obtain

\[
0 > \frac{dP}{MP} \quad \text{(7.11)}
\]

To show \( \frac{dP}{MP} > 0. \) we obtain the following two propositions with opposite restrictions on the nature of the utility function and the end conditions.

Proposition 2-1

Q.E.D.

However, \( \frac{dP}{MP} > 0. \) and \( 0 > \frac{dP}{MP} \)

Thus, \( \frac{dP}{MP} > 0. \) implies \( \frac{dP}{MP} > 0. \) and hence the following differentials of the time of replacement associated with different prices of a house are the same and positive and the stock of different prices of a house are the same and positive and the stock of

Assume \( \lambda = 0 \) and \( \frac{dP}{MP} \)

\[
\text{However, } 0 > \frac{dP}{MP}
\]

Proposition 2-1

Q.E.D.
Thus we obtain

(1) Area in $\mathbb{R}^2$

\[ q + (d)_a + \cdots + (d)_a = t \]

(2) By assumption (g), which implies that

\[ 1 + (d)_a + \cdots + (d)_a \leq t \]

(3) Area in $\mathbb{R}^2$

\[ q + 1 + (d)_a + \cdots + (d)_a = t \]

(4) Area in $\mathbb{R}^2$

\[ q + 1 + (d)_a + \cdots + (d)_a = t \]

where $q$ is any arbitrary positive integer such that the inequality above is satisfied.

Assume $t \geq \frac{1}{2}$.

\[ [\frac{2}{d}, \frac{2}{d}]^p_a \leq [\frac{1}{d}, (d)_a]^p_a \]

At time $t$, we obtain

\[ A(t) \subset [\frac{1}{d}, (d)_a]^p_a \]
\( \frac{\partial p}{\partial p} < \frac{2p}{3p} \quad (1) \)

\( I' \ldots I = 1 \quad 0 < \frac{\partial p}{\partial p} \quad (1) \)

Proposition 3.

**Proof.** Similar to Proposition 2-1, we conclude 1 instead of Proposition 1.

\( (d)_{s} \geq (d)_{s} \quad (1) \)

then implies \( I' \ldots I = 1 \quad 0 > \frac{\partial p}{\partial p} \quad (5) \)

\( \left[ \frac{2p}{3p} - I + (d)_{s} \right] < \left[ \frac{2p}{3p} - I + q \right] \quad (6) \)

\( n = \frac{p}{n} \quad (3) \)

\( 0 = \frac{\partial p}{\partial p} \quad (3) \)

Thus, it is clear that the optimal consumption in the first period agrees as

\( I = 1 \quad I' \ldots I = 1 \quad 0 < \frac{\partial p}{\partial p} \quad (1) \)

\( \frac{\partial p}{\partial p} > \ldots > \frac{\partial p}{\partial p} \quad (1) \)

Differentiate (1.15) above with respect to \( x \) to obtain

\( \frac{\partial p}{\partial p} > \ldots > \frac{\partial p}{\partial p} \quad (1) \)

We conclude 1 instead of Proposition 2-1.

Thus, we conclude the effect of change in the rate of interest.
The equation (1.1.9) above, we have

\[ 0 > \frac{\frac{\partial p}{\partial \phi}}{\frac{\partial p}{\partial \phi}} \]

And

\[ 0 \geq \frac{\frac{\partial p}{\partial \phi}}{\frac{\partial p}{\partial \phi}} \]

Thus we have

\[ 0 \geq \frac{\frac{\partial p}{\partial \phi}}{\frac{\partial p}{\partial \phi}} \]

\[ \left( \frac{\pi + 1}{1} \right) \left( \frac{\pi + 1}{1} \right) \Lambda (1 - 1) + \left( \frac{\pi + 1}{1} \right) \frac{\partial p}{\partial \phi} \Lambda = \frac{\frac{\partial p}{\partial \phi}}{\frac{\partial p}{\partial \phi}} \Lambda (1.1.9) \]

Proposition:

\[ 0 > \frac{\frac{\partial p}{\partial \phi}}{\frac{\partial p}{\partial \phi}} \]

\[ \left( \frac{\pi + 1}{1} \right) \left( \frac{\pi + 1}{1} \right) \Lambda (1 - 1) + \left( \frac{\pi + 1}{1} \right) \frac{\partial p}{\partial \phi} \Lambda = \frac{\frac{\partial p}{\partial \phi}}{\frac{\partial p}{\partial \phi}} \Lambda (1.1.9) \]

Differentiation (1.1.9)

\[ 0 > \frac{\frac{\partial p}{\partial \phi}}{\frac{\partial p}{\partial \phi}} \]

To show

\[ 0 > \frac{\frac{\partial p}{\partial \phi}}{\frac{\partial p}{\partial \phi}} \]

(1.1.9)

(1)
\[ \begin{bmatrix}
    a & 0 & \cdots & 0 \\
    b & a & \cdots & 0 \\
    \vdots & \vdots & \ddots & \vdots \\
    c & d & \cdots & a
\end{bmatrix}
\]

The determinant of the upper left triangle of the matrix is given by:

\[ \det(A) = \prod_{j=1}^{n} (a_{i,j} - c_{i,j}) \]

where

\[ A_{ij} = a_{i,j} - c_{i,j} \]

The expression for the determinant of the matrix is:

\[ \prod_{j=1}^{n} (a_{i,j} - c_{i,j}) = \prod_{j=1}^{n} (a - c) \]

where

\[ A_{ij} = a - c \]

The equation of the line is:

\[ y = mx + b \]

where

\[ m = \frac{\text{slope}}{\text{run}} \]

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and replacement timing. We note that the delayed optimal timing
concepts pressuring value of utility with respect to the consumption time path.

We formulate a model in which the consumer maximizes the dis-


4. Conclusion Remarks

Q. E. D.

\[ \mathcal{C}_2 \gg \mathcal{I}_2 \text{ for } \mathcal{Z}_2 \gg \mathcal{I}_2 \]

Thus by the comparator of assumption (7) we must have

\[ 0 < \frac{\partial \mathcal{Q}}{\partial \mathcal{P}} (\mathcal{Z} - \mathcal{I}) = \frac{\partial \mathcal{Q}}{\partial \mathcal{P}} \]

(2.7.1)

Then by the differential equation, with respect to $\mathcal{Z}_2$ we have

\[ 0 < \frac{\partial \mathcal{P}}{\partial \mathcal{Q}} \text{ which implies } \mathcal{Z}_2 \gg \mathcal{I}_2 \]

where

\[ (\mathcal{Z}_2) \frac{\partial \mathcal{P}}{\partial \mathcal{Q}} = \mathcal{P} \]

(2.7.2)

Thus

\[ \mathcal{Q} = \mathcal{P} \]

(2.7.3)

Moreover, 

\[ \mathcal{I}_2 \gg \mathcal{I}_2 \]

then

\[ \mathcal{I}_2 \gg \mathcal{I}_2 \]

(2.7.4)

Assume $\mathcal{I}_2 \gg \mathcal{I}_2$ be such that (1) holds.

Proposition 5

Reference, 7.1, 9, 10...

Recalling the equivalence between the integral can and the re-

\[ \mathcal{Q} = \mathcal{P} \]

(2.7.5)

Recalling the equivalence (1.20)-(6) we note the equality

\[ \mathcal{P} \]

(2.7.6)

Thus

\[ \mathcal{Q} \]

(2.7.7)

\[ \mathcal{P} \]

(2.7.8)

\[ \mathcal{Q} \]

(2.7.9)

\[ \mathcal{P} \]

(2.7.10)

\[ \mathcal{Q} \]

(2.7.11)

\[ \mathcal{P} \]

(2.7.12)

\[ \mathcal{Q} \]

(2.7.13)

\[ \mathcal{P} \]

(2.7.14)

\[ \mathcal{Q} \]

(2.7.15)

\[ \mathcal{P} \]

(2.7.16)

\[ \mathcal{Q} \]

(2.7.17)

\[ \mathcal{P} \]

(2.7.18)

\[ \mathcal{Q} \]

(2.7.19)

\[ \mathcal{P} \]

(2.7.20)

\[ \mathcal{Q} \]

(2.7.21)

\[ \mathcal{P} \]

(2.7.22)

\[ \mathcal{Q} \]

(2.7.23)

\[ \mathcal{P} \]

(2.7.24)

\[ \mathcal{Q} \]

(2.7.25)

\[ \mathcal{P} \]

(2.7.26)

\[ \mathcal{Q} \]

(2.7.27)

\[ \mathcal{P} \]

(2.7.28)

\[ \mathcal{Q} \]

(2.7.29)

\[ \mathcal{P} \]

(2.7.30)

\[ \mathcal{Q} \]

(2.7.31)

\[ \mathcal{P} \]

(2.7.32)

\[ \mathcal{Q} \]
will yield partial results in the study of consumer durables.

The author followed past literature studying consumption's optimal number
of durable goods and its changes. The model can be easily generalized
to handle n-replacement (n > 0). However, only Proposition I and
replaced by the assumption of the optimal number
of replacement takes place exactly once, the model can be easily generalized

The conclusion of the analysis here is confined to the situation where
durable goods. Effects, after counterattack. The empirical position must all be taken into

study of consumer durables.

The author followed past literature studying consumption's optimal number
of durable goods and its changes. The model can be easily generalized
to handle n-replacement (n > 0). However, only Proposition I and
replaced by the assumption of the optimal number
of replacement takes place exactly once, the model can be easily generalized

The conclusion of the analysis here is confined to the situation where

12. We would only consider the case where 

\[ a \leq 1, \quad b > 0, \quad c \in (0, a) \cup (a, b) \].

This is possible by

Substitution of the above into (1) yields (2) yields (3):

\[
\frac{1}{x} \int_{x}^{\infty} (d\phi - d) = (d)
\]

Thus (2) can be expressed by the following:

\[
0 = \sum_{i=1}^{n+1} (d) \int_{x}^{\infty} (d\phi - d) = \sum_{i=1}^{n+1} (d)
\]

where (d) is the optimal value of the quantity in the fixed

15. It is shown that \( T \) is the optimal value of the quantity in the

16. In particular if \( T = 1 \), then it can be shown that \( T \) is the optimal value of the quantity in the

17. If \( T \) is the optimal value of the quantity in the

18. Note the equation (13) can be written as

\[
(\mathcal{O} - S + \pi) \int_{0}^{\infty} \frac{d\phi - d}{x} = (d)
\]

19. If the consumer owns a house completely then \( T \) and the initial out

20. We assume that the date \( (1 + g) \) is the consumer completes the

21. We have the following:

1. \( x \geq 1 \)

2. \( x > 1 \)

Thus given these possible cases we have the equation (13) where

\[
\int_{0}^{\infty} \frac{d\phi - d}{x} = 0
\]

11. Rewriting the equation (13) we have

\[
\int_{0}^{\infty} \frac{d\phi - d}{x} = 0
\]