The Impact of Prudence on Optimal Prevention Revisited*

Jingyuan Li
School of Management
Huazhong University of Science and Technology
Wuhan 430074, China
Email: jingyuanht@yahoo.com.cn

Georges Dionne
Canada Research Chair in Risk Management, HEC Montréal, CIRRELT, and CIRPÉE, Canada
Email: georges.dionne@hec.ca

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Abstract

This paper re-examines the link between absolute prudence and self-protection activities. We show that the level of effort chosen by an agent with positive and decreasing absolute prudence is larger than the optimal effort chosen by a risk-neutral agent if the degree of absolute prudence is less than a threshold that is utility-independent and empirically verifiable. We explain this threshold by a trade-off between the variation of the variance and the level of the third moment of the loss distribution. We also discuss our result in terms of skewness. Our contribution extends the model of Eeckhoudt and Gollier (2005).

Key words: Absolute prudence, Moments of the loss distribution, Self-protection, Variance, Skewness.

JEL classification: D61, D81

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1 Introduction

The optimality of self-protection activities was first examined by Ehrlich and Becker (1972). It is well known that increased risk aversion does not necessarily raise the optimal investment in prevention (see, e.g., Dionne and Eeckhoudt, 1985; Briys and Schlesinger, 1990; Briys et al., 1991). This negative result is still not well explained in the literature.

Recently, some papers studied the effect of prudence on optimal prevention. Jullien, et al. (1999) and Chiu (2000) show that prudence plays a role in the determination of thresholds for optimal prevention. However, their thresholds are utility-dependent, and thus vary from agent to agent. Eeckhoudt and Gollier (2005) propose a sufficient condition on the loss probability of the risk neutral agent to obtain the optimal effort chosen by a prudent (imprudent) agent to be smaller (larger) than the optimal effort chosen by a risk-neutral agent. Since their threshold probability is $\frac{1}{2}$, there is room to find a condition that would permit to obtain a larger level of effort by prudent agents when $p \leq \frac{1}{2}$.

We extend the analysis by linking differently optimal prevention and absolute prudence. We show that the level of effort chosen by an agent with positive and decreasing absolute prudence is larger than the optimal effort chosen by a risk-neutral agent if absolute prudence is less than a threshold that is utility-independent, or stays the same for all agents. This threshold is equal to the "marginal change in probability on variance per third moment of loss distribution." Intuitively, the level of effort chosen by a prudent agent is larger than the optimal effort chosen by a risk-neutral agent when the positive benefit, for a risk averse individual, of reducing the variance is larger than the utility cost of spending money on protection for a prudent agent who prefers to save money in such circumstance. Our contribution extends the model of Eeckhoudt and Gollier (2005) [1].

The article is organized as follows. Section 2 presents the model and main result. Section 3 explains the result in terms of loss distribution moments and skewness. Section 4 shows how the main result applies to HARA utility functions. Section 5 concludes the paper.

[1] Menegatti (2009) proves that, in a two-period framework, prudence has a positive effect on optimal prevention. Here we are limited to a single period model. Chiu (2005a) shows that, when protection activities are mean-preserving, degree of absolute prudence plays an important role in determining the optimal choice of self-protection. We do not consider the mean-preserving condition in this paper. Eeckhoudt et al. (2010) and Dachraoui et al. (2004) consider background risk as well.

2 The Model and Main Result

We consider an expected utility maximizer who is endowed with wealth w_0 and faces the risk of losing the amount L with probability $p(e)$; e is the amount of money invested in prevention and $p(e)$ is differentiable with respect to e. We assume that the utility function u on final wealth is increasing and differentiable. The decision problem for a risk-averse individual can be written as

$$e^* \in \arg\max_{e \geq 0} V(e) = p(e)u(w_0 - e - L) + (1 - p(e))u(w_0 - e). \tag{1}$$

We assume that V is concave in e (see Arnott, 1991, and Jullien et al., 1999, for analysis of the different conditions). The optimal preventive investment e_n for the risk-neutral agent, assuming an interior solution, is given by

$$-p'(e_n)L = 1. \tag{2}$$

Condition (2) states that the marginal cost must equal the marginal benefit. The effect of prevention is limited to the variation of expected loss for this decision maker.

Define $p_n = p(e_n)$ as probability of loss of the risk-neutral agent, and $w_n = w_0 - e_n$ as the agent's final wealth in the no-loss state. We have the following lemma.

Lemma 2.1 *(i) Risk-averse agents exert more effort than the risk-neutral agent if*

$$AP(w_n - y) \leq \frac{1 - 2p_n}{p_n} \frac{1}{y} \; for\ all\ y \in [0, L], \tag{3}$$

where $AP(x) = -\frac{u'''(x)}{u''(x)}$ *is the absolute prudence coefficient (Kimball, 1990).*

(ii)Risk-averse agents exert less effort than the risk-neutral agent if

$$AP(w_n - y) \geq \frac{1 - 2p_n}{p_n} \frac{1}{y} \; for\ all\ y \in [0, L]. \tag{4}$$

Proof See Appendix.

When $p_n \geq \frac{1}{2}$, $\frac{1-2p_n}{p_n}\frac{1}{y} \leq 0$, and $AP \geq \frac{1-2p_n}{p_n}\frac{1}{y}$ for all prudent agents. Lemma 2.1 states that prudent agents exert less effort than the risk-neutral agent. Dachraoui et al. (2004) showed that $p_n \leq \frac{1}{2}$ is a necessary condition for more mixed risk-averse agents to spend more effort. Lemma 2.1 is a complement of their result. If $p_n \leq \frac{1}{2}$, then $\frac{1-2p_n}{p_n}\frac{1}{y} \geq 0$, and $AP \leq \frac{1-2p_n}{p_n}\frac{1}{y}$ for all imprudent agents ($AP(w_n - y) < 0$). Lemma 2.1 indicates that imprudent agents exert more effort than the risk-neutral agent. Eeckhoudt and Gollier's result (2005, Corollary 1) is recovered.

Lemma 2.1 states that the level of effort chosen by a prudent agent is larger (less) than the optimal effort chosen by a risk-neutral agent if coefficient of absolute prudence is less (larger) than a threshold for all level of loss $y \leq L$. This threshold is utility-independent and stays the same for all agents. However, it depends on the y values in interval $[0, L]$. If we use the assumption of decreasing absolute prudence (DAP), then these coefficients of absolute prudence and thresholds depend only on loss L. In fact, part (i) of Lemma 2.1 implies the following proposition.

Proposition 2.2 *If $p_n < \frac{1}{2}$ and $AP(w_n - L) \leq \frac{1-2p_n}{p_n}\frac{1}{L}$, then risk-averse agents with DAP exert more effort than the risk-neutral agent.*

Proof Since

$$p_n < \frac{1}{2} \Rightarrow \frac{1-2p_n}{p_n}\frac{1}{L} \leq \frac{1-2p_n}{p_n}\frac{1}{y} \; for \; all \; y \in [0, L] \tag{5}$$

and

$$DAP \Rightarrow AP(w_n - y) \leq AP(w_n - L) \; for \; all \; y \in [0, L], \tag{6}$$

we have

$$p_n < \frac{1}{2}, \; DAP \; and \; AP(w_n - L) \leq \frac{1-2p_n}{p_n}\frac{1}{L} \tag{7}$$

$$\Rightarrow \quad AP(w_n - y) \leq \frac{1-2p_n}{p_n}\frac{1}{y} \; for \; all \; y \in [0, L]. \tag{8}$$

By combining (8) with part (i) of Lemma 2.1, we obtain the result. Q.E.D.

When $p_n \leq \frac{1}{2}$, Proposition 2.2 provides an upper bound on absolute prudence, $AP \leq \frac{1-2p_n}{p_n}\frac{1}{L}$, to obtain more effort by DAP agents than the risk-neutral agent. DAP was first defined by Kimball (1990). He showed that DAP is necessary and sufficient to guarantee that the effect of income risk on the marginal propensity to consume (or "precautionary premium") is decreasing in wealth. Since then, DAP has been associated to some other intuitive properties and there are a number of arguments in favor of this assumption in the literature (see, e.g. Eeckhoudt and Kimball (1991); Kimball (1993); Gollier (1996); and Gollier (2001)).

When $p_n < \frac{1}{2}$, we also have

$$\lim_{p_n \to 0} \frac{1-2p_n}{p_n}\frac{1}{L} = \infty \tag{9}$$

and

$$\lim_{L\to 0} \frac{1-2p_n}{p_n}\frac{1}{L} = \infty. \tag{10}$$

Hence, Proposition 2.2 suggests that, for small probability of loss ($p_n \to 0$), or small amount of loss ($L \to 0$), all decreasing prudent agents will exert more effort than the risk-neutral agent, which may appear to be a paradox. However there exist many applications where L is large and p_n is very low (catastrophe loss, environmental loss) and where L is small and p_n is quite high but less than $\frac{1}{2}$ (current life loss). In fact, there are very few risky situations where $p_n \geq \frac{1}{2}$. So our condition provides guidance for an empirical test. It can be verified with information on p_n, L and w for a particular utility function.

Before explaining our result in terms of second and third moments, we give another explanation for Proposition 2.2 in terms of relative prudence. We note that if $w_n - L > 0$, then

$$\begin{aligned}
& AP(w_n - L) \leq \frac{1-2p_n}{p_n}\frac{1}{L} && (11)\\
\Leftrightarrow\quad & -\frac{u'''(w_n - L)}{u''(w_n - L)} \leq \frac{1-2p_n}{p_n}\frac{1}{L} &&\\
\Leftrightarrow\quad & -(w_n - L)\frac{u'''(w_n - L)}{u''(w_n - L)} \leq \frac{1-2p_n}{p_n}\frac{w_n - L}{L} &&\\
\Leftrightarrow\quad & RP(w_n - L) \leq \frac{1-2p_n}{p_n}\frac{w_n - L}{L}, && (12)
\end{aligned}$$

where $RP(x) = -x\frac{u'''(x)}{u''(x)}$ is the coefficient of relative prudence. Some contributions in the literature suggest that the benchmark value for RP is 2 (see, e.g., Hadar and Seo, 1990; Choi et al., 2001; Gollier, 2001, pp. 60-61; White, 2008; Eeckhoudt et al. 2009, Wang and Li 2010; Chiu et al. 2010). Because

$$\frac{1-2p_n}{p_n}\frac{w_n - L}{L} \geq 2 \Leftrightarrow p_n \leq \frac{w_n - L}{2w_n}, \tag{13}$$

we get the following corollary from Proposition 2.2:

Corollary 2.3 *If $RP(w_n - L) \leq 2$ and $p_n \leq \frac{w_n - L}{2w_n}$, then risk-averse agents with DAP exert more effort than the risk-neutral agent.*[2]

3 An Explanation for the Threshold based on Moments

In this section, we show that a close examination of second and third moments of the loss distribution explains Proposition 2.2 and the cost-benefit analysis of prevention for a risk-averse

[2]Notice that $p_n \leq \frac{w_n - L}{2w_n} = \frac{1}{2} - \frac{L}{2w_n} < \frac{1}{2}$.

and prudent agent.

Define

$$\widetilde{Loss} = \begin{cases} L & with\ p_n \\ 0 & with\ 1 - p_n \end{cases}$$

as loss of the risk-neutral agent. The variance (or second central moment) of the loss is

$$Var(\widetilde{Loss}) = p_n(1 - p_n)L^2, \tag{14}$$

and its third moment is equal to

$$E(\widetilde{Loss}^3) = p_n L^3. \tag{15}$$

The marginal change in probability on variance is

$$\frac{dVar(\widetilde{Loss})}{dp_n} = (1 - 2p_n)L^2. \tag{16}$$

Hence the threshold can be rewritten as

$$\begin{aligned} \frac{1 - 2p_n}{p_n}\frac{1}{L} &= \frac{(1 - 2p_n)L^2}{p_n L^3} \\ &= \frac{Marginal\ change\ in\ probability\ on\ variance}{Third\ moment\ of\ loss}. \end{aligned} \tag{17}$$

Proposition 2.2 states that risk-averse agents with DAP exert more effort than the risk-neutral agent if AP is less than the "marginal change in probability on variance per third moment of loss distribution."[3]

Another way to see the result is to note that more self-protection is desirable when (38) in the Appendix is positive for all $y \in [0, L]$. Since

$$H''(y) \geq 0\ for\ all\ y \in [0, L] \Leftrightarrow AP(w_n - y) \leq \frac{1 - 2p_n}{p_n}\frac{1}{y}\ for\ all\ y \in [0, L] \tag{20}$$

[3]Since the third central moment of loss is

$$E(\widetilde{Loss} - E\widetilde{Loss})^3 = p_n(1 - p_n)(1 - 2p_n)L^3, \tag{18}$$

the threshold can also be rewritten as

$$\begin{aligned} \frac{1 - 2p_n}{p_n}\frac{1}{L} &= \frac{p_n(1 - p_n)(1 - 2p_n)L^3}{p_n(1 - p_n)L^2 p_n L}\frac{1}{L} \\ &= \frac{Third\ central\ moment\ of\ loss}{(Variance\ of\ loss)\ (Expected\ loss)}\frac{1}{L}. \end{aligned} \tag{19}$$

Hence, the threshold can also be interpreted as a trade-off among loss amount, expected loss, variance and third central moment.

and

$$DAP\ and\ H''(L) \geq 0 \Rightarrow AP(w_n - y) \leq \frac{1-2p_n}{p_n}\frac{1}{y}\ for\ all\ y \in [0, L], \tag{21}$$

then more self-protection is desirable when

$$H''(L) = (2p_n - 1)u''(w_n - L) - p_n L u'''(w_n - L) \tag{22}$$

is positive. (22) can be rewritten as

$$H''(L)L^2 = (2p_n - 1)L^2 u''(w_n - L) - p_n L^3 u'''(w_n - L). \tag{23}$$

We see from (23) that our sufficient condition includes the variation of the variance and the level of the third moment. The variation of the variance and the level of the third moment multiply $u''(w_n - L)$ and $u'''(w_n - L)$ respectively. Hence, when $p < \frac{1}{2}$, the cost-benefit of self-protection for a risk-averse and decreasing prudent agent is equal to a reduction in the variance, which is (most of the time) desirable for a risk-averse agent, less the utility cost of spending money for protection against an uncertain event, which is not desirable for a prudent agent who prefers to save money in such circumstance (Kimball, 1990).

This trade-off was suggested in a comment by Eeckhoudt and Gollier (2005):

> *When p_n is larger than $\frac{1}{2}$, the effect of risk aversion goes in the same direction as the effect of prudence to generate a smaller level of effort. In the more interesting case where p_n is less than $\frac{1}{2}$, these two effects go in opposite directions.*

We now interpret the result in terms of skewness. In the statistics literature, skewness is often proposed to measure downside risk. It is well known that an increase of skewness will imply an increase in downside risk only under specific conditions (Chiu, 2005b; Menezes et al., 1980). In our application, more self-protection yields a new distribution that is more skewed to the left. The skewness of $\widetilde{Loss}$ is defined as

$$S_{Loss} = \frac{E[\widetilde{Loss} - E(\widetilde{Loss})]^3}{[Var(\widetilde{Loss})]^{\frac{3}{2}}}. \tag{24}$$

Since

$$\begin{aligned} & E[\widetilde{Loss} - E(\widetilde{Loss})]^3 \qquad (25) \\ = \ & p_n(y - p_n L)^3 + (1 - p_n)(-p_n L)^3 = p_n(1 - p_n)(1 - 2p_n)L^3, \end{aligned}$$

we have

$$S_{Loss} = \frac{1-2p_n}{\sqrt{p_n(1-p_n)}}. \tag{26}$$

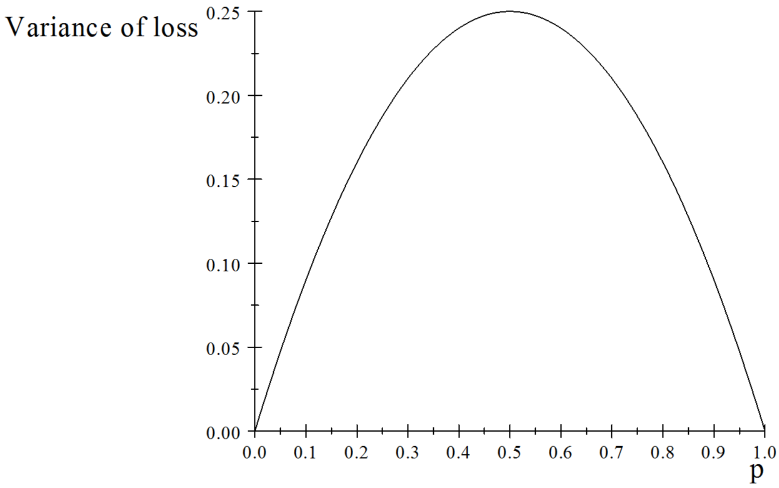

Figure 3.1 $Variance = p((1-p))L^2$ with $L = 1$

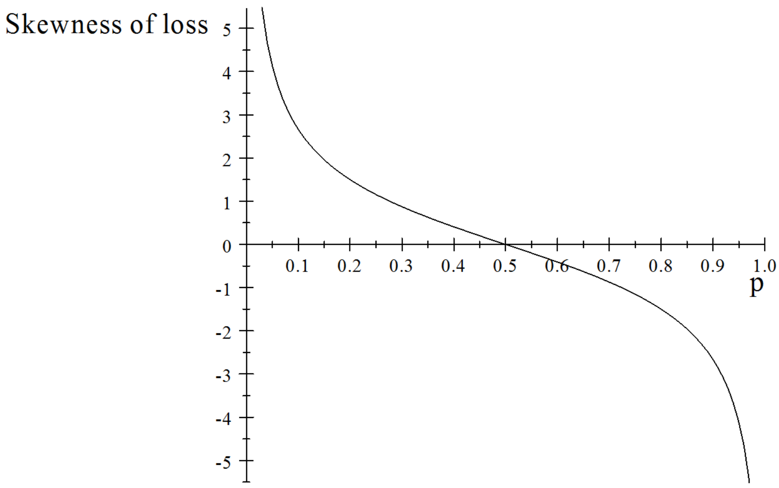

Figure 3.2 $Skewness = \frac{1-2p}{\sqrt{p(1-p)}}$

We observe that (26) is independent of L. Figures 3.1 and 3.2 illustrate the variance and skewness of loss distribution as a function of p. We observe that the variance first increases when $p < \frac{1}{2}$ and then decreases when p increases. The skewness always decreases when p increases but is positive when $p < \frac{1}{2}$ and negative otherwise.

When $p_n < \frac{1}{2}$, for the risk-averse and decreasing prudent agent, there is a trade-off between the variance and the skewness of the loss distribution. Spending more on self-protection (reducing p) decreases the variance of loss (see Figure 3.1), which is desirable. However, for the prudent agent, spending more on self-protection increases the positive skewness of loss (see Figure 3.2), which is undesirable in this application. Hence, when $p_n < \frac{1}{2}$, the cost-benefit analysis of preventive actions for a risk-averse and prudent agent depends on the trade-off between the decrease in the variance and the increase in the skewness. As shown by Chiu (2005b), prudence has an important role to play for characterizing this trade-off when both distributions have the same expected mean. Here we show that this is also the case even when self-protection changes the expected loss.

We propose a sufficient condition for more self-protection by a risk-averse and decreasing prudent agent in terms of the skewness of loss.

If $p_n < \frac{1}{2}$, then

$$S_{Loss} = \frac{1-2p_n}{\sqrt{p_n(1-p_n)}} < \frac{1-2p_n}{p_n}. \tag{27}$$

From Proposition 2.2, we obtain the following corollary.

Corollary 3.1 *Suppose $p_n < \frac{1}{2}$, risk-averse and decreasing prudent agents exert more effort than the risk-neutral agent if*

$$AP(w_n - L) \leq \frac{S_{Loss}}{L}. \tag{28}$$

Corollary 3.1 provides a short-cut sufficient condition for decreasing prudent agents to exert more effort than the risk-neutral agent: absolute prudence be less than skewness of loss per amount of loss.

4 Sufficient Conditions for HARA

In the economic literature, the class of harmonic absolute risk aversion (HARA) utility functions is particularly useful to derive analytical results. HARA utility functions take the following form:

$$u(x) = \zeta(\eta + \frac{x}{\gamma})^{1-\gamma}, \tag{29}$$

and the absolute prudence coefficient is equal to (see e.g., Gollier, 2001, p. 26)

$$AP(x) = \frac{\gamma+1}{\gamma}(\eta + \frac{x}{\gamma})^{-1}. \tag{30}$$

Hence Proposition 2.2 implies the following corollary.

Corollary 4.1 *Suppose DAP and HARA, risk-averse agents exert more effort than the risk-neutral agent if*

$$\frac{\gamma+1}{\gamma}(\eta + \frac{w_n - L}{\gamma})^{-1} \leq \frac{1-2p_n}{p_n}\frac{1}{L}. \tag{31}$$

The sufficient condition for some well known HARA utility functions is summarized in the following table.

Parameter	Utility	$AP(w_n - L)$	$AP(w_n - L) \leq \frac{1-2p_n}{p_n}\frac{1}{L}$
$\gamma = -1$	Quadratic	0	$p_n \leq \frac{1}{2}$
$\eta = 0$ and $\gamma = 1$	Logarithmic	$\frac{2}{w_n - L}$	$\frac{L}{w_n - L} \leq \frac{1-2p_n}{2p_n}$
$\eta = 0$ and $\gamma \neq 1$	Power	$\frac{\gamma+1}{w_n - L}$	$\frac{L}{w_n - L} \leq \frac{1-2p_n}{(1+\gamma)p_n}$
$\gamma \to \infty$	Negative exponential	$\frac{1}{\eta}$	$\frac{1}{\eta} \leq \frac{1-2p_n}{p_n}\frac{1}{L}$

Table 4.1: HARA utility functions

From Table 4.1, we observe that, for quadratic, logarithmic, power ($\gamma < -1$) and negative exponential ($\eta > 0$) functions , $p_n \leq \frac{1}{2}$ is a necessary condition for these sufficient conditions.

5 Conclusion

We have investigated the link between optimal prevention and prudence by providing a sufficient condition for risk-averse agents with DAP to exert more self-protection than a risk-neutral agent. We have formalized the intuition by using the second and third moment of the loss distribution. We have also interpreted our main result in terms of the skewness of the loss distribution.

6 Appendix

6.1 Proof of Lemma 2.1

Because V is concave, the optimal effort e^* for a risk-averse agent will be larger than e_n if and only if $V'(e_n)$ is positive:

$$V'(e_n) = -[p_n u'(w_n - L) + (1-p_n)u'(w_n)] - p'(e_n)[u(w_n) - u(w_n - L)] \geq 0. \tag{32}$$

Using condition (2), we see that $V'(e_n) \geq 0$ if and only if

$$\frac{u(w_n) - u(w_n - L)}{L} \geq p_n u'(w_n - L) + (1-p_n)u'(w_n) \tag{33}$$

or if and only if

$$u(w_n) - u(w_n - L) - L[p_n u'(w_n - L) + (1 - p_n)u'(w_n)] \geq 0. \tag{34}$$

Given L, we have fixed e_n and p_n (by (2)). Define

$$H(y) = u(w_n) - u(w_n - y) - y[p_n u'(w_n - y) + (1 - p_n)u'(w_n)],\ for\ y \in [0, L], \tag{35}$$

then

$$H(L) \geq 0 \Leftrightarrow V'(e_n) \geq 0. \tag{36}$$

We note that $H(0) = 0$ and

$$H'(y) = (1 - p_n)[u'(w_n - y) - u'(w_n)] + p_n y u''(w_n - y). \tag{37}$$

Moreover, (37) implies that $H'(0) = 0$ and

$$H''(y) = (2p_n - 1)u''(w_n - y) - p_n y u'''(w_n - y). \tag{38}$$

Since

$$\begin{aligned} & H'(0) = 0\ and\ H''(y) \geq 0 (\leq 0)\ for\ all\ y \in [0, L] \\ \Rightarrow\ & H'(y) \geq 0 (\leq 0)\ for\ all\ y \in [0, L] \end{aligned} \tag{39}$$

and

$$\begin{aligned} & H(0) = 0\ and\ H'(y) \geq 0 (\leq 0)\ for\ all\ y \in [0, L] \\ \Rightarrow\ & H(y) \geq 0 (\leq 0)\ for\ all\ y \in [0, L] \\ \Rightarrow\ & H(L) \geq 0 (\leq 0), \end{aligned} \tag{40}$$

we conclude that $H''(y) \geq 0 (\leq 0)$ for all $y \in [0, L]$ is a sufficient condition for $H(L) \geq 0 (\leq 0)$.

(i) Because

$$AP(w_n - y) \leq \frac{1 - 2p_n}{p_n} \frac{1}{y}\ for\ all\ y \in [0, L] \tag{41}$$

$$\begin{aligned} \Leftrightarrow\ & -\frac{u'''(w_n - y)}{u''(w_n - y)} \leq \frac{1 - 2p_n}{p_n} \frac{1}{y}\ for\ all\ y \in [0, L] \\ \Leftrightarrow\ & H''(y) \geq 0\ for\ all\ y \in [0, L], \end{aligned} \tag{42}$$

we obtain

$$\begin{aligned} & AP(w_n - y) \leq \frac{1 - 2p_n}{p_n} \frac{1}{y}\ for\ all\ y \in [0, L] \\ \Rightarrow\ & H(L) \geq 0 \\ \Leftrightarrow\ & V'(e_n) \geq 0. \end{aligned} \tag{43}$$

(ii) We can prove this assertion by the same approach used in (i). Q.E.D.

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