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# Reaching nirvana with a defaultable asset?

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## Notes

1. Cox and Huang ([1989](#)) require the global Lipschitz continuity of the diffusive coefficient for the risky asset-value process [see Conditions A and B at p. 46 in Cox and Huang ([1989](#))]. By contrast, the diffusive coefficient in our setting is

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6. There are parameter values that make the investor with  $(\phi > 1)$  take a net short position in the risky defaultable asset.
7. Similar investment-horizon effects have been found in the literature on dynamic portfolio choice with a risky non-defaultable asset characterized by a mean-reverting drift and a constant volatility [see, for example, Kojien et al. (2009)].
8. The functions  $U$  and  $V$  are conjugate if and only if  $(U(w) = \inf_{y > 0} (V(y) + wy))$  and  $(V(y) = \sup_{w > 0} (U(w) - wy))$ .
9. The superscript  $(\left( \cdot \right)^{\{DS\}})$  refers to the notations of Delbaen

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## 1.1 A.1 Proof of proposition [3.1](#)

The problem of utility maximization can be written as  $\max_{w \in \tilde{W}} \left( e^{\frac{1}{1-\phi} u(w)} \right)$  where  $u$  is defined as

$$u(w) = \sup_{\tilde{w} \in \tilde{W}} E[U(\tilde{w}_T)].$$

(A.1)

We apply to problem (A.1) the duality approach developed by Kramkov and Schachermayer (1999, 2003). To this aim, we observe that the utility function  $U$  satisfies Inada conditions [equation (2.4) in Kramkov and Schachermayer (1999)]. Let  $V$  denote the conjugate function<sup>8</sup> of  $U$ , that is  $V(y) = \frac{\phi}{1-\phi} y^{\frac{1-\phi}{\phi}}$  and define

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$$\frac{1}{\phi} = w \frac{\eta^{-\frac{1}{\phi}}}{E \left[ \eta^{-\frac{1-\phi}{\phi}} \right]}. \end{aligned} \$\$$$

The value function is then

$$\begin{aligned} J(w) &= \left( e^{rT} \right)^{1-\phi} E \left[ U(\tilde{W}^*) \right] = U(w e^{rT}) E \left[ \left( \frac{\eta^{-\frac{1}{\phi}}}{E \left[ \eta^{-\frac{1-\phi}{\phi}} \right]} \right)^{1-\phi} \right] \\ &= U(w e^{rT}) \left( E \left[ \eta^{-\frac{1-\phi}{\phi}} \right] \right)^{\phi} \\ &= U(w e^{rT}) \left( E \left[ \exp \left( \frac{1-\phi}{\phi} \int_0^T \sqrt{Y_t} dZ_t + \frac{1-\phi}{2\phi} \int_0^T Y_t dt \right) \right] \right)^{\phi} \\ &= U(w e^{rT}) F(T, y). \end{aligned} \$\$$$

(\square \)

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The random variable  $(L_{\{T\}})$  in (A.2) is the Radon–Nikodym density of a probability measure equivalent to  $(\mathbb{P})$ . In fact, Theorem<sup>9</sup> 2.3 in Delbaen and Shirakawa (2002) applied to  $(S^{\{DS\}}=Y, \rho^{\{DS\}}=0.5, r^{\{DS\}}=b>0, \sigma^{\{DS\}}=2\sqrt{c\phi}, \mu^{\{DS\}}=b+2a\sqrt{c\phi}),$  and  $(\theta^{\{DS\}}=a)$  implies that  $(\eta_{\{T\}}^{\{DS\}}=L_{\{T\}})$  is the Radon–Nikodym density of an equivalent probability measure  $(\hat{\mathbb{Q}})$  equivalent to  $(\mathbb{P}).$  Girsanov’s theorem implies then that

$$\begin{aligned} \hat{Z}_t &= Z_t - \int_0^t a \sqrt{Y_s} ds \\ \end{aligned}$$

(A.3)

is a  $(\hat{\mathbb{Q}})$ -Brownian motion. Thus,

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(A.6)

where  $G(t, y)$  is a  $(\mathcal{C}^{\{1,2\}})$  function to be determined in such a way that  $(G(0,y)=1)$  and  $M$  is a  $(\{\hat{\mathbb{Q}}\})$ -martingale. In particular, Eq. (A.6) implies for  $(t=0)$  that  $(M_0=G(T,y))$  and for  $(t=T)$

$$\begin{aligned} M_T &= \exp \left( \frac{a^2 + a}{2} \int_0^T Y_t dt \right) G(0, Y_T) = \exp \left( \frac{a^2 + a}{2} \int_0^T Y_t dt \right), \end{aligned}$$

since  $(G(0,\cdot)=1.)$  The martingality condition  $(M_0 = E^{\{\hat{\mathbb{Q}}\}}[M_T])$  yields then

$$G(T,y) = E^{\{\hat{\mathbb{Q}}\}} \left[ \exp \left( \frac{a^2 + a}{2} \int_0^T Y_t dt \right) \right]$$

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$$\begin{aligned} g(t) &= \frac{(a^2 + a)(e^{\sqrt{q}t} - 1)}{\sqrt{q} + b + e^{\sqrt{q}t}(\sqrt{q} - b)}. \end{aligned}$$

Since  $(M_t)$  has 0 drift in the Ito decomposition under  $(\hat{\mathbb{Q}})$ ,  $(M_t)$  is a  $(\hat{\mathbb{Q}})$  local martingale. To conclude that  $(M_t)$  is a martingale we define

$$\mathfrak{z}_t = \frac{M_t}{M_0},$$

which is a  $(\hat{\mathbb{Q}})$  local martingale as well, and show that  $(\mathfrak{z}_t)$  is a  $(\hat{\mathbb{Q}})$  martingale. To this aim, we first observe that process  $(\mathfrak{z}_t)$  is a stochastic exponential. In fact, Ito formula implies that

$$dM_t = e^{\frac{a^2 + a}{2} \int_0^t \dots}$$

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with

$$\begin{aligned} m_t &= \int_0^t 2\sqrt{c\phi} g(T-s)\sqrt{Y_s} d\hat{Z}_s. \end{aligned}$$

We apply Theorem 4.1 in Klebaner and Lipster ([2014](#)) to conclude that  $(\frac{z_t}{\sqrt{Y_t}})$  is a true martingale. In particular, with Klebaner and Lipster notations (4.2) at page 44

$$\begin{aligned} a_s(y) &= b_s(y) = 2\sqrt{c\phi} \sqrt{y} \quad \text{from (A.5)} \\ \sigma_s(y) &= 2\sqrt{c\phi} g(T-s)\sqrt{y} \quad \text{from our def. of } m_t, \end{aligned}$$

we get

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## 1.3 A.3 Proof of proposition [3.3](#)

In what follows, we will mainly work under the martingale measure  $(\mathbb{Q}, \mathbb{P})$  whose density with respect to  $(\mathbb{P})$  is  $(\eta)$  in Eq. ([2.3](#)). We denote with  $(Z_t^\mathbb{Q})$  the  $(\mathbb{Q})$ -Brownian motion

$$Z_t^\mathbb{Q} = Z_t + \int_0^t \sqrt{Y_s} ds.$$

(A.10)

Before proving the result, we first list some technical lemmas.

### Lemma A.1

Let  $(L^* = \frac{L_T}{\eta})$  where  $(L_T)$  is given by ([A.2](#)). Then

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$$\{\mathbb{Q}\}}\}\{\mathrm{d}\{\mathbb{P}\}}\}\}\{\frac{\mathrm{d}\{\mathbb{Q}\}}{\mathrm{d}\{\mathbb{P}\}}\}}=\frac{\mathrm{d}\{\hat{\mathbb{Q}}\}}{\mathrm{d}\{\mathbb{Q}\}}, \end{aligned}$$$$

and from the definitions of  $\eta$  in (2.3) and of  $L$  in (A.2) that

$$\begin{aligned} L_T^*&=\frac{L_T}{\eta}=\exp\left(a\int_0^T\sqrt{Y_s}\,\mathrm{d}Z_s-\frac{a^2}{2}\int_0^TY_s\mathrm{d}s+\int_0^T\sqrt{Y_s}\,\mathrm{d}Z_s+\frac{1}{2}\int_0^TY_s\mathrm{d}s\right)\\&=\exp\left(\left(a+1\right)\int_0^T\sqrt{Y_s}\,\mathrm{d}Z_s+\frac{1-a^2}{2}\int_0^TY_s\mathrm{d}s\right).\end{aligned}$$$$

From the definition of  $(Z_s^{\mathbb{Q}})$  in Eq. (A.10) we get

$$\begin{aligned} L_T^*&=\exp\left(\left(a+1\right)\int_0^T\sqrt{Y_s}\,\mathrm{d}Z_s^{\mathbb{Q}}-\sqrt{Y_s}\,\mathrm{d}s\right)\end{aligned}$$

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Let  $(M_t)$  be the  $(\hat{\mathbb{Q}})$ -martingale defined in (A.6), namely

$$M_t = e^{\frac{a^2 + a}{2} \int_0^t Y_s ds} e^{Y_t g(T-t)}.$$

Then we have

$$dM_t &= 2\sqrt{c\phi(Y_t)} M_t g(T-t) d\hat{Z}_t \\ &= 2\sqrt{c\phi(Y_t)} M_t g(T-t) \left( dZ_t^{\mathbb{Q}} - \frac{1}{\phi(Y_t)} dt \right)$$

(A.12)

where  $(\hat{Z}_t)$  is defined in (A.3) and  $(Z_t^{\mathbb{Q}})$  in Eq. (A.10).

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$$_{t}^{\ast}\}\{\sqrt{Y_{t}}\}dZ_{t}^{\mathbb{Q}}\}\end{aligned}\$$$

(A.13)

since  $(d\tilde{P}_t=\tilde{P}_t\sqrt{Y_t}\sigma _tdt+\tilde{P}_t\sigma _tdZ_t=\tilde{P}_t\frac{\xi }{\sqrt{Y_t}}dZ_t^{\mathbb{Q}})$  from (2.1) and (A.10).

Therefore, we look for the Ito representation of  $(\tilde{W}^{\ast }(t)=E^{\mathbb{Q}}[\tilde{W}^{\ast }|\mathcal{F}_t])$  to derive  $(\psi ^{\ast })$ . Denoting with  $(L_t=E\left[ L_T\Big | \mathcal{F}_t\right] )$  and  $(\eta _t=E\left[ \eta \Big | \mathcal{F}_t\right] )$ , we have

$$\begin{aligned} E^{\mathbb{Q}}\left[ \eta ^{-\frac{1}{\phi }}\Big | \mathcal{F}_t\right] &= \frac{E\left[ \eta ^{1-\frac{1}{\phi }}\Big | \right.} \end{aligned}$$

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