

# Exercises chapter 6

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## Exercise 6.2

We have the following contractual information:

```
T <- 10      #length of contract
x <- 60      #age of insured
D <- 20000   #disability pension while disabeld
B <- 50000   #death benefit
r <- 0.05    #intensity rate
```

Where our state space is  $S = \{*, \diamond, \dagger\}$ , we have the following policy-functions:

$$a_{\diamond}(t) = \begin{cases} 0, & t < 0 \\ Dt, & t \in [0, T) \\ DT, & t \geq T \end{cases} \quad a_{*\dagger}(t) = \begin{cases} B, & t \in [0, T) \\ 0, & else \end{cases}$$

Since we for now do not care about the premiums in the policy-functions, we get

$$\dot{a}_*(t) = 0$$

and

$$\dot{a}_{\diamond}(t) = D\mathbb{1}_{[0, T)}(t)$$

We can set up thieles differential equations:

$$\begin{aligned} \frac{d}{dt}V_*^+(t) &= r(t)V_*(t) - \mu_{*\diamond}^x(t)[V_{\diamond}^+(t) - V_*^+(t)] - \mu_{*\dagger}^x(t)[B\mathbb{1}_{[0, T)}(t) - V_*^+(t)] \\ \frac{d}{dt}V_{\diamond}^+(t) &= r(t)V_{\diamond}(t) - D\mathbb{1}_{[0, T)}(t) - \mu_{*\diamond}^x(t)[V_*^+(t) - V_{\diamond}^+(t)] + \mu_{\diamond\dagger}^x(t)V_{\diamond}^+(t) \end{aligned}$$

With finial conditions:  $V_*^+(T) = V_{\diamond}^+(T) = 0$

In order to solve this numerically, we partition up  $[0, T]$  in times  $t_i = t_0 + ih$ , with  $0 = t_0 < \dots < t_n = T$ .

We also iterate backwards, giving us:

$$\frac{V_*^+(t_i) - V_*^+(t_{i-1})}{h} = rV_*(t_i) - \mu_{*\diamond}^x(t_i)[V_{\diamond}^+(t_i) - V_*^+(t_i)] - \mu_{*\dagger}^x(t_i)[B - V_*^+(t_i)]$$

We then solve for  $V_*(t_{i-1})$ , giving us:

$$V_*^+(t_{i-1}) = V_*^+(t_i) - h [rV_*^+(t_i) - \mu_{*\dagger}^x(t_i)[V_{\diamond}^+(t_i) - V_*^+(t_i)] - \mu_{*\dagger}^x(t_i)[B - V_*(t_i)]]$$

We do the same for  $V_{\diamond}^+(t_{i-1})$ :

$$V_{\diamond}^+(t_{i-1}) = V_{\diamond}^+(t_i) - h [rV_{\diamond}^+(t_i) - D\mathbb{1}_{[0, T)}(t) - \mu_{*\diamond}^x(t_i)[V_*^+(t_i) - V_{\diamond}^+(t_i)] + \mu_{\diamond\dagger}^x(t_i)V_{\diamond}^+(t_i)]$$

```
#states 0:alive, 1:disabled, 2:dead
```

```
mu01 <- function(u){
  a1 <- 4*10^{-4}
  b1 <- 3.4674*10^{-6}
  c1 <- 0.138755
  return(a1 + b1*exp(c1*u))
}
```

```
mu02 <- function(u){
  a2 <- 5*10^{-4}
  b2 <- 7.5858*10^{-5}
  c2 <- 0.087498
  return(a2 + b2*exp(c2*u))
}
```

```
mu12 <- function(u){
  return(mu02(u))
}
```

```
mu10 <- function(u){
  return(0.1*mu01(u))
}
```

```
#a.e. derivative of a_{\diamond}(t)
```

```
dis_dot <- function(t){
  if(t >= 0 && t<T){ return(D) }
  if(t >= T){ return(0) }
}
```

```
#PV of policy V0 and V1
```

```
h <- 1/12
N <- T/h
```

```
PV_act <- PV_dis <- rep(0,N+1)
```

```
PV_act[N+1] <- PV_dis[N+1] <- 0 #by construction of contract
```

```
for(i in N:1){
  PV_act[i] <- PV_act[i+1] - h*(r*PV_act[i+1]
    - mu01(x+(i+1)*h)*(PV_dis[i+1]-PV_act[i+1])
    - mu02(x+(i+1)*h)*(B-PV_act[i+1])
  )

  PV_dis[i] <- PV_dis[i+1] - h*(r*PV_dis[i+1]- dis_dot((i+1)*h)
    - mu10(x+(i+1)*h)*(PV_act[i+1]-PV_dis[i+1])
    + mu12(x+(i+1)*h)*PV_dis[i+1]
  )
}
```

And from this we can find the one-time premium  $\pi_0 = V_*^+(0)$ :

```
pi0 <- PV_act[1]
pi0
```

```
## [1] 20608.17
```

We were asked to find the yearly premium  $\pi$ , we then use the method, where we create an artificial policy, where one pays a premium of NOK 1 during  $[0, T)$ , i.e this is the only contribution of interest, thus:

$$a_*^{Prem=1}(t) = \begin{cases} 0, & t < 0 \\ -t, & t \in [0, T) \\ -T, & t \geq T \end{cases} \implies \dot{a}_*^{Prem=1}(t) = -1\mathbb{1}_{[0, T)}(t)$$

$$a_\diamond^{Prem=1}(t) = 0, \forall t \implies \dot{a}_\diamond^{Prem=1}(t) = 0$$

$$a_{*\dagger}^{Prem=1}(t) = 0$$

We can now set up the new thieles equations:

$$\frac{d}{dt}V_*^+(t, A^{Prem=1}) = rV_*^+(t) - \dot{a}_*(t) - \mu_{*\diamond}^x(t)[V_\diamond^+(t) - V_*^+(t)] + \mu_{*\dagger}^x(t)V_*^+(t)$$

$$\frac{d}{dt}V_\diamond^+(t, A^{Prem=1}) = rV_\diamond^+(t) - \mu_{*\diamond}^x(t)[V_*^+(t) - V_\diamond^+(t)] + \mu_{\diamond\dagger}^x(t)V_\diamond^+(t)$$

And again solve for  $V_*^+(t_{i-1})$  and  $V_\diamond^+(t_{i-1})$ :

$$V_*^+(t_{i-1}) = V_*^+(t_i) - h \left[ rV_*^+(t_i) - \dot{a}_*(t_i) - \mu_{*\diamond}^x(t_i)[V_\diamond^+(t_i) - V_*^+(t_i)] + \mu_{*\dagger}^x(t_i)V_*^+(t_i) \right]$$

$$V_\diamond^+(t_{i-1}) = V_\diamond^+(t_i) - h \left[ rV_\diamond^+(t_i) - \mu_{*\diamond}^x(t_i)[V_*^+(t_i) - V_\diamond^+(t_i)] + \mu_{\diamond\dagger}^x(t_i)V_\diamond^+(t_i) \right]$$

```
#a.e derivative a_{*}:
a_dot_prem1 <- function(t){
  if(t >= 0 && t < T){ return(-1) }
  if(t >= T){ return(0) }
}

PV_prem1_act <- PV_prem1_dis <- rep(0, N+1)
PV_prem1_act[N+1] <- PV_prem1_dis[N+1] <- 0 #follows from contract

for(i in N:1){
  PV_prem1_act[i] <- PV_prem1_act[i+1] - h*(r*PV_prem1_act[i+1] - a_dot_prem1((i+1)*h)
    - mu01(x+(i+1)*h)*(PV_prem1_dis[i+1]-PV_prem1_act[i+1])
    + mu02(x+(i+1)*h)*(PV_prem1_act[i+1])
  )

  PV_prem1_dis[i] <- PV_prem1_dis[i+1] - h*(r*PV_prem1_dis[i+1]
    - mu10(x+(i+1)*h)*(PV_prem1_act[i+1]-PV_prem1_dis[i+1])
    + mu12(x+(i+1)*h)*PV_prem1_dis[i+1]
  )
}
PV_prem1_act[1]

## [1] -6.453883
```

We will now use the equivalence principle, which tells us:

$$\begin{aligned}\pi V_*^+(0, A^{Prem=1}) + V_*^+(0) &= 0 \\ \Downarrow \\ \pi &= -\frac{V_*(0)}{V_*^+(0, A^{Prem=1})}\end{aligned}$$

This gives us:

```
pi0
```

```
## [1] 20608.17
```

```
yearly_premium <- (-1)*pi0/PV_prem1_act[1]  
yearly_premium
```

```
## [1] 3193.142
```