Borrowing Choice Set Discretization in a Deterministic Two Period Model

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Borrowing Constraint

In a standard incomplete market savings/borrowing model, households are able to borrow and save, with risk-free asset b and given interest rate r. $b < 0$ is borrowing, and $b > 0$ is saving.

- Savings is limited by the cash-on-hand available to households today.
- Borrowing is limited by households' minimum Wealth in future periods.

To model financial constraints, an exogenous or endogenous bound, $\overline{b} \leq 0$ with $\overline{b} \leq b$, is often imposed on borrowing that could be tighter than the (non-binding) naturally borrowing limit.

Financial deepening might come in the form of relaxing/decreasing $\overline{b}$ so that households can borrow to finance investments and consumption when they are low on cash today relative to the future.

Increasing the Borrowing Choice Set

$b \geq \overline{b}$ assumes that lenders impose a quantity bound, and a development banker's policy could shift $\overline{b}$ to the left or the right.

In reality, lenders can also choose what borrowing quantities/levels are available to households, and couple these with variations in borrowing rates r_b:

$$\textit{Borrow Choice Set}: \{\{\mathcal{b}_1, r_1\}, ..., \{\mathcal{b}_N, r_N\}\}$$

Improving borrowing condition--financial deepening--might not involve allowing for larger maximum borrowing quantity, but by increasing the number of borrowing options within the existing maximum bound.

Why Would Lenders Offer Only a Borrowing Choice Set

Why not allow households to choose their optimal borrowing level?

Empirically, some, perhaps many, development banks and microfinance lenders offer loans in discretized borrowing sets.

Even if more continuous borrowing ranges are allowed, it is common for development lenders to at least set the smallest level of borrowing. This is the simplest form of discretization. It happens in the opposite direction as the standard borrowing limit.

Perhaps from the perspective of operating a large-scale national development-oriented bank that has branches in rural areas, it is sometimes just administratively easier to deal with standardized loan sizes that are at least larger than a particular size.

Perhaps in places with credit-rating is more readily available, it is easier for banks to come up with a formula to determine the exact upper bound for borrowing. When credit cards are obtained in the US for example, any borrowing up to the credit-limit is allowed.

Two Period Model and Choice Set

Given the simplest two period borrowing problem, what is the optimal choice, and what is the choice when the choice set is B-discrete-constrained:

- Exogenous endowments in both periods: z_1, z_2
- One choice: b, borrow or save
- Assume for now all interest rates are the same

$$max_{b\in\mathscr{B}} \log\left(z_1 - b\right) + \beta \cdot \log\left(z_2 + (1+r)\cdot b\right)$$

where: $\mathscr{B} \in \left\{\left\{b_1^{\text{br}}, b_2^{\text{br}}, ..., b_N^{\text{br}}\right\} \cup \left\{b^{\text{save}} \mid b \geq 0\right\}\right\}$

Unconstrained Problem

In the following numerical example, the endowment is higher in the second period, giving households an incentive to borrow. To simplify things, the interest rate is the same for all levels of borrowing. First, I draw the budget line, indifference curve, endowment point, and the optimal unconstrained borrowing choice.

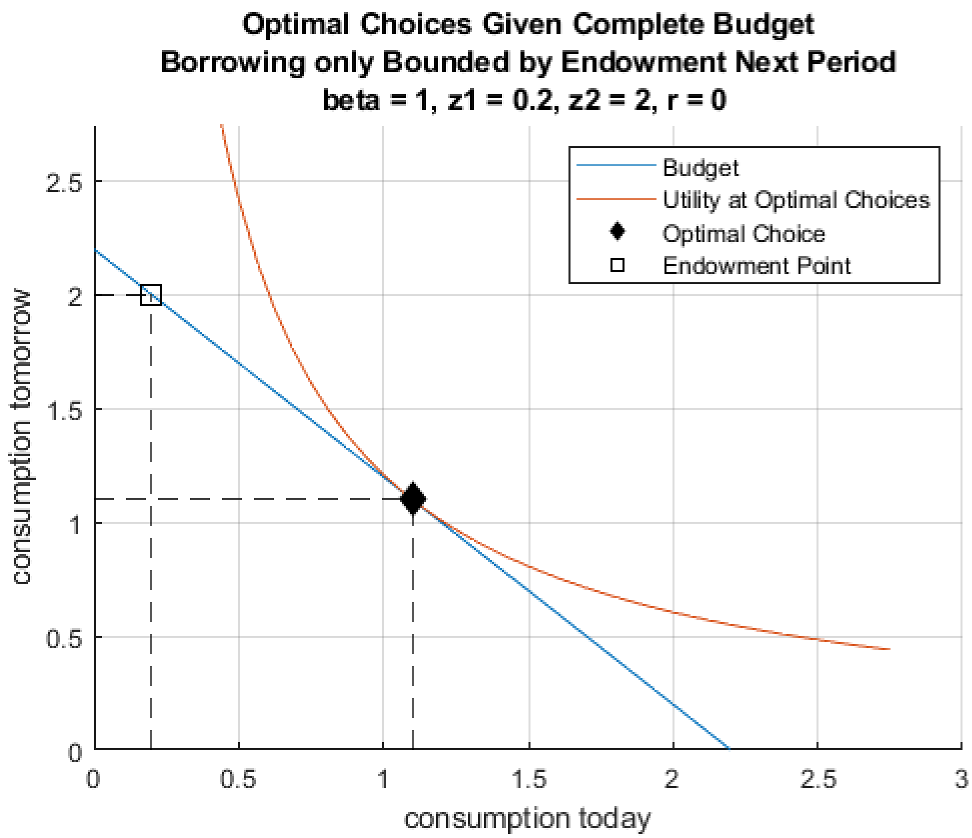
```
% Numbers
z1 = 0.2;
z2 = 2;
beta = 1;
r = 0;

% Symbols
syms b

% Utility
Utility = log(z1-b) + beta*log(z2+b*(1+r));
```

```
% Optimal Choice
b_opti = double(solve(diff(Utility, b)==0, b, 'Real', true));
c1_opti = z1 - b_opti;
c2_opti = z2 + b_opti*(1+r);

% Value (Utility at Optimal Choices)
U_at_b_opti = double(subs(Utility, {b}, {b_opti}));

% Results In Table
unconstrained_table=table(b_opti, c1_opti, c2_opti, U_at_b_opti)
```

unconstrained_table = 1×4 table

	b_opti	c1_opti	c2_opti	U_at_b_opti
1	-0.9000	1.1000	1.1000	0.1906

```
% Define Budget Line and Indifference Curve
syms c1
% The Budget Line
f_budget = z1*(1+r) + z2 - c1*(1+r);
% Indifference at V*
f_indiff = exp((U_at_b_opti-log(c1))/(beta));

% Graph
figure();
hold on;
% Main Lines
fplot(f_budget, [0, (z1 + z2/(1+r))*1.25]);
fplot(f_indiff, [0, (z1 + z2/(1+r))*1.25]);

% Endowment Point
scatter(c1_opti, c2_opti, 100, 'k', 'filled', 'd');
plot(linspace(0,c1_opti,10),ones(10,1) * c2_opti, 'k--', 'HandleVisibility','off');
plot(ones(10,1) * c1_opti, linspace(0,c2_opti,10), 'k--', 'HandleVisibility','off');

% Optimal Choices Point
scatter(z1, z2, 100, 'k', 's');
plot(linspace(0,z1,10),ones(10,1) * z2, 'k--', 'HandleVisibility','off');
plot(ones(10,1) * z1, linspace(0,z2,10), 'k--', 'HandleVisibility','off');

% Labeling
ylim([0, (z1 + z2/(1+r))*1.25])
title({['Optimal Choices Given Complete Budget'],...
       ['Borrowing only Bounded by Endowment Next Period'],...
       ['beta = ' num2str(beta) ', z1 = ' num2str(z1)...
        ', z2 = ' num2str(z2) ', r = ' num2str(r) ' ']})
xlabel('consumption today');
ylabel('consumption tomorrow');
legend({'Budget', 'Utility at Optimal Choices', 'Optimal Choice', 'Endowment Point'})
grid on;
```



Optimal Choices with Grid-Constrained Borrowing Choice Set

Now we solve for the grid-constrained problem. We don't have to worry about savings here because endowment is higher in the second period, so households naturally want to borrow.

- The borrowing grid is equi-distance and starts at 0
- Different households will be impacted by the same borrow grid differently depending on how much they need to borrow
- If the borrow grid points happen to be close to the unconstrained optimal choice, discretization has low costs

```
% There is a grid of b choices
b_grid_gap = 0.6;
% This is the max natural borrowing constraint
b_max_borrow = z2/(1+r);
% The is the choice Grid
b_grid = (-1)*(0:b_grid_gap:b_max_borrow);
% r_grid = zeros(size(b_grid)) + r;
r_slope = 0;
r_grid = zeros(size(b_grid)) + r;
% r_grid = r + 0:(r_slope):((length(b_grid)-1)*(r_slope));
% b_grid = [0 b_opti/2 b_opti*1.5];
c1_b_grid = z1 - b_grid;
c2_b_grid = z2 + b_grid.*(1+r_grid);
```

```
% Utility Along Choice Grid
Utility_Grid = log(z1-b_grid) + beta*log(z2+b_grid.*(1+r_grid));

% Optimal Choice
[val_og, max_idx] = max(Utility_Grid);
b_opti_grid_constrained = b_grid(max_idx);
r_og = r_grid(max_idx);
c1_opti_grid = z1 - b_opti_grid_constrained;
c2_opti_grid = z2 + b_opti_grid_constrained*(1+r);

% Results In Table
unconstrained_table
```

unconstrained_table = 1×4 table

	b_opti	c1_opti	c2_opti	U_at_b_opti
1	-0.9000	1.1000	1.1000	0.1906

```
constrained_table = table(b_opti_grid_constrained, c1_opti_grid, c2_opti_grid, val_og)
```

constrained_table = 1×4 table

	b_opti_grid...	c1_opti_grid	c2_opti_grid	val_og
1	-1.2000	1.4000	0.8000	0.1133

Expenditure Minimization to Calculate Wealth Loss due to Discretization

Given the optimal b-grid-constrained choice, we evaluate utility at the optimal point and can solve for the expenditure minimization problem given this b-grid-constrained optimal value.

The expenditure minimization problem search for the budget that is required if choices were unconstrained that would achieve the same level of optimal utility as the b-grid-constrained problem.

Comparing the actual budget and the budget from expenditure minimization, we can calculate the Wealth loss due to discretization.

```
% Solve a Expenditure Minimization Problem
% Under what budget would the value at constrained optimal bundle
% be value for unconstrained problem?
syms c1 c2 lambda
lagrangian = (c2 + (1+r_og)*c1 - lambda*( log(c1) + beta*log(c2) - val_og));
solu_min = solve(diff(lagrangian, c1)==0,...
                 diff(lagrangian, c2)==0,...
                 diff(lagrangian, lambda)==0,...
                 c1, c2, lambda, 'Real', true);
solu_min_c1 = double(solu_min.c1);
solu_min_c2 = double(solu_min.c2);
Wealth_grid = solu_min_c1*(1+r_og) + solu_min_c2;
Wealth_loss = 1- (Wealth_grid/(z1*(1+r_og) + z2));
Wealth_loss_percent = round(Wealth_loss*10000)/100;

% Show Table Results
```

```
unconstrained_table
```

unconstrained_table = 1×4 table

	b_opti	c1_opti	c2_opti	U_at_b_opti
1	-0.9000	1.1000	1.1000	0.1906

```
constrained_table
```

constrained_table = 1×4 table

	b_opti_grid...	c1_opti_grid	c2_opti_grid	val_og
1	-1.2000	1.4000	0.8000	0.1133

```
exp_min_table = table(solu_min_c1, solu_min_c2, Wealth_loss, Wealth_loss_percent)
```

exp_min_table = 1×4 table

	solu_min_c1	solu_min_c2	Wealth_loss	Wealth_loss...
1	1.0583	1.0583	0.0379	3.7900

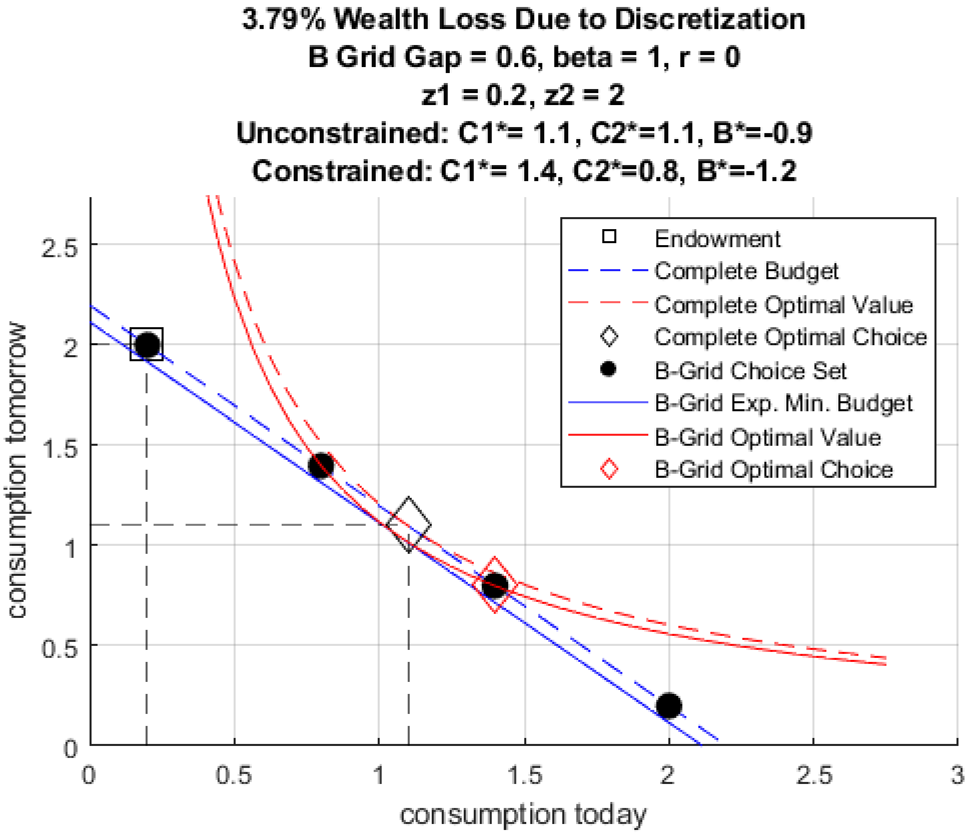
Graphical Results

Show results graphically. The Graph below will show these:

- **Endowment Point:** where z_1 and z_2 are
- **Unconstrained (complete budget) problem Budget**: Budget given interest rate, frontier when any borrowing and savings are allowed
- **Unconstrained (complete budget) problem Value**: Indifference curve for utility given the optimal unconstrained choice
- **B-Grid Choice Set**: Borrow Grid Constrained Choice Set
- **B-Grid Expenditure Minimizing Budget**: Given B-Grid optimal value, what is the budget from the expenditure minimization problem
- **B-Grid Optimal Value**: Given B-Grid optimal choice, what is the utility.
- **B-Grid Optimal Choice**: Optimal B-Constrained Choice

```
% For Graphing
syms c1
% The grid constrained value's unconstrained optimal budget line
f_budget_grid_constrained = solu_min_c1*(1+r_og) + solu_min_c2 - c1*(1+r_og);
% Indifference for grid constrained value
f_indiff_grid_constrained = exp((val_og-log(c1))/(beta));

% Graphing
figure();
hold on;

% Endowment Point
scatter(z1, z2, 250, 'k', 's');
plot(linspace(0,z1,10),ones(10,1) * z2, 'k--', 'HandleVisibility','off');
plot(ones(10,1) * z1, linspace(0,z2,10), 'k--', 'HandleVisibility','off');
```

```
% Unconstrained Lines now Dashed
fplot(f_budget, [0, (z1 + z2/(1+r))*1.25], 'b--');
fplot(f_indiff, [0, (z1 + z2/(1+r))*1.25], 'r--');

% Unconstrained Optimal Point
scatter(c1_opti, c2_opti, 250, 'k', 'd');
plot(linspace(0,c1_opti,10),ones(10,1) * c2_opti, 'k--', 'HandleVisibility','off');
plot(ones(10,1) * c1_opti, linspace(0,c2_opti,10), 'k--', 'HandleVisibility','off');

% Constrained Lines
scatter(c1_b_grid, c2_b_grid, 100, 'k', 'filled', 'c');
fplot(f_budget_grid_constrained, [0, (z1 + z2/(1+r))*1.25], 'b-');
fplot(f_indiff_grid_constrained, [0, (z1 + z2/(1+r))*1.25], 'r-');

% Constrained Optimal Choice
scatter(c1_opti_grid, c2_opti_grid, 250, 'r', 'd');

% Labeling
ylim([0, (z1 + z2/(1+r))*1.25])
title({[num2str(Wealth_loss_percent) '% Wealth Loss Due to Discretization'],...
       ['B Grid Gap = ' num2str(b_grid_gap)...
        ', beta = ' num2str(beta)...
        ', r = ' num2str(r)],...
       ['z1 = ' num2str(z1),...
        ', z2 = ' num2str(z2)],...
       ['Unconstrained: C1*= ' num2str(c1_opti)...
        ', C2*=' num2str(c2_opti)...
        ', B*=' num2str(b_opti)],...
       ['Constrained: C1*= ' num2str(c1_opti_grid)...
        ', C2*=' num2str(c2_opti_grid),...
        ', B*=' num2str(b_opti_grid_constrained)]});
xlabel('consumption today');
ylabel('consumption tomorrow');
legend({'Endowment',...
        'Complete Budget',...
        'Complete Optimal Value',...
        'Complete Optimal Choice',...
        'B-Grid Choice Set',...
        'B-Grid Exp. Min. Budget',...
        'B-Grid Optimal Value',...
        'B-Grid Optimal Choice'...
        })
grid on;
```



Grid Constrained Borrowing Choice Set at Four Wealth Levels

In these two period models, wealth is $z_1 \cdot (1+r) + z_2$. Generally, holding the ratio of z_1 and z_2 fixed, with the same borrowing grid-gap, higher wealth households will lose less Wealth due to discretization.

Intuitively, if the borrowing grid allows for borrowing 1, 2 and 3 units. Poorer households whose optimal borrowing quantity is 0.25 unit will suffer greater Wealth loss due to discretization than a household whose optimal borrowing quantity is 2.5. But the relationship is not monotonic, depending on wealth, it could be that your borrowing need at some point is exactly on the grid. (See chart below)

Using the same structure as above, now we do the exercise many times and graph results for four different wealth levels and compare Wealth losses due to discretization.

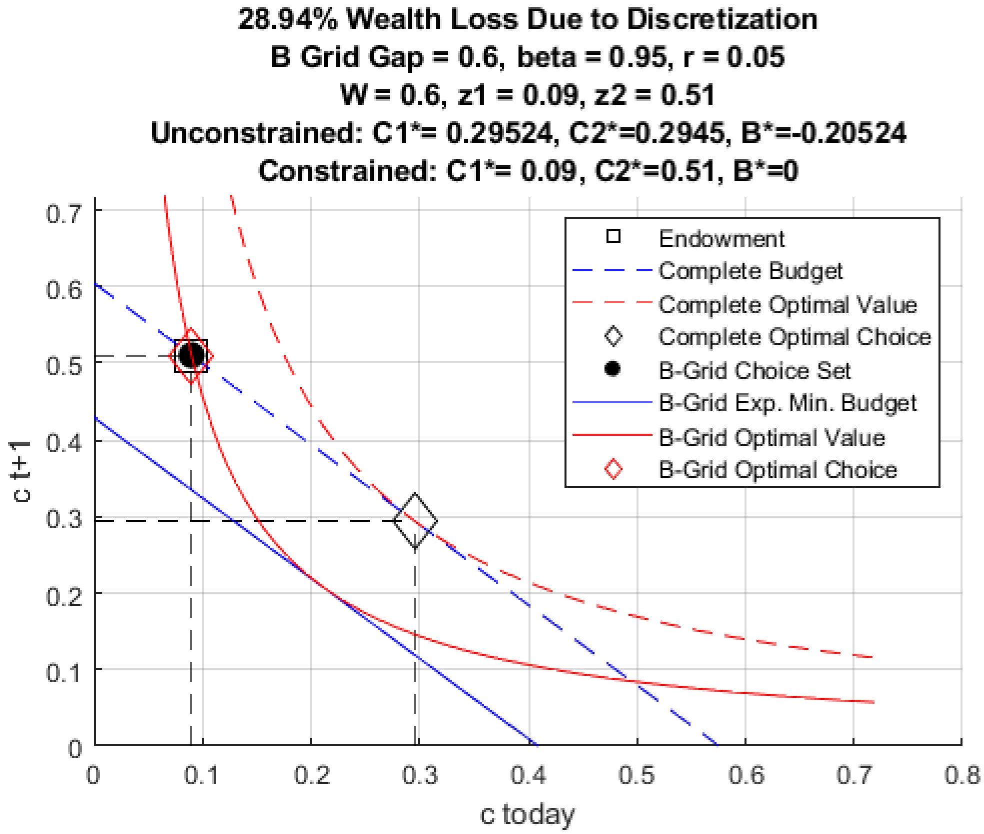
- Now I set $\beta = 0.95$, and also $r = 0.05$
- Borrow grid gap is still: 0.6
- Shift Overall Wealth level: $z_1 \cdot (1+r) + z_2$, from equal to the borrow grid gap to six times the borrow grid gap.

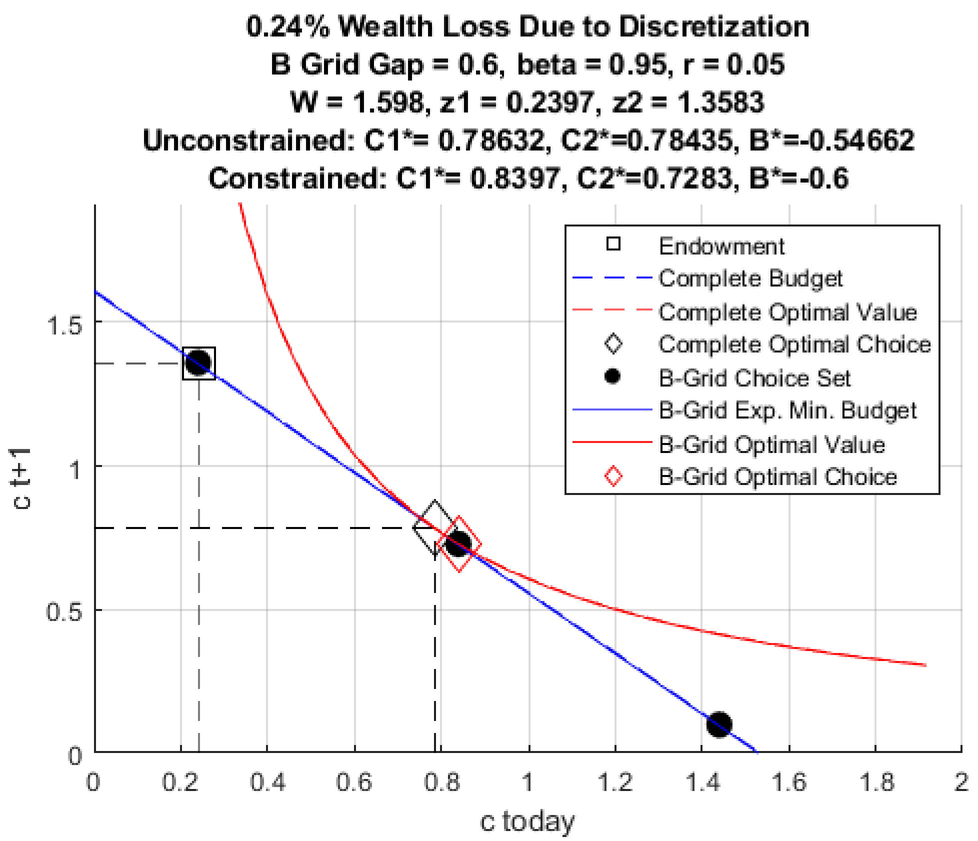
```
% There is a grid of b choices
b_grid_gap = 0.6;
beta = 0.95;
r = 0.05;
z1_share = 0.15;
z2_share = 1 - z1_share;
```

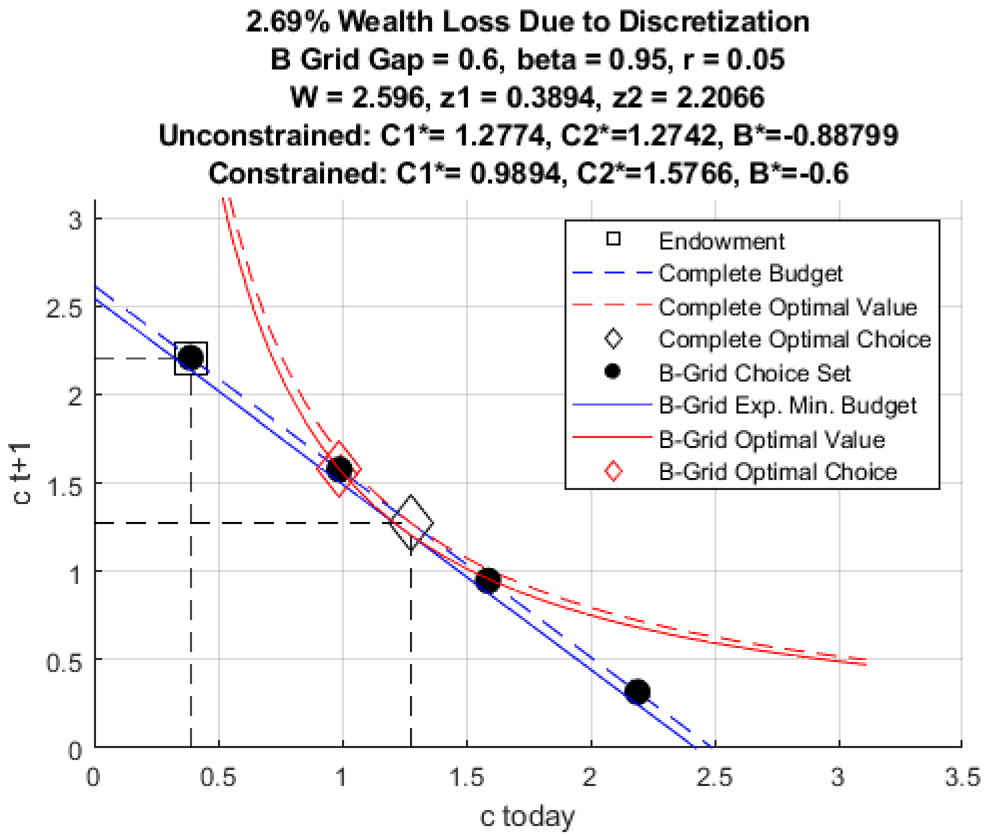
```
% Wealth Grid
wealth_grid_min = b_grid_gap;
wealth_grid_max = b_grid_gap*6;
wealth_grid_n = 500;
wealth_grid = linspace(wealth_grid_min, wealth_grid_max, wealth_grid_n);
wealth_grid_graph = [1 round(wealth_grid_n/3) round((wealth_grid_n)*2/3) wealth_grid_n];

% Store Wealth Loss Along Grid
Wealth_loss_percent_grid = zeros(size(wealth_grid));
% Store Wealth Loss Along Grid
opti_borrow_exct = zeros(size(wealth_grid));
opti_borrow_grid = zeros(size(wealth_grid));

% Graphing
for wealth_i=1:1:length(wealth_grid)

    % Numbers
    z1 = z1_share * wealth_grid(wealth_i);
    z2 = z2_share * wealth_grid(wealth_i);

    % Symbols
    syms b

    % Utility
    Utility = log(z1-b) + beta*log(z2+b*(1+r));

    % Optimal Choice
    b_opti = double(solve(diff(Utility, b)==0, b, 'Real', true));
    c1_opti = z1 - b_opti;
    c2_opti = z2 + b_opti*(1+r);

    % Value (Utility at Optimal Choices)
    U_at_b_opti = subs(Utility, {b}, {b_opti});

    % This is the max natural borrowing constraint
    b_max_borrow = z2/(1+r);
    % The is the choice Grid
    b_grid = (-1)*(0:b_grid_gap:b_max_borrow);
    % r_grid = zeros(size(b_grid)) + r;
    r_grid = zeros(size(b_grid)) + r;
    c1_b_grid = z1 - b_grid;
    c2_b_grid = z2 + b_grid.*(1+r_grid);

    % Utility Along Choice Grid
    Utility_Grid = log(z1-b_grid) + beta*log(z2+b_grid.*(1+r_grid));

    % Optimal Choice
    [val_og, max_idx] = max(Utility_Grid);
    b_opti_grid_constrained = b_grid(max_idx);
    r_og = r_grid(max_idx);
    c1_opti_grid = z1 - b_opti_grid_constrained;
    c2_opti_grid = z2 + b_opti_grid_constrained*(1+r);
```

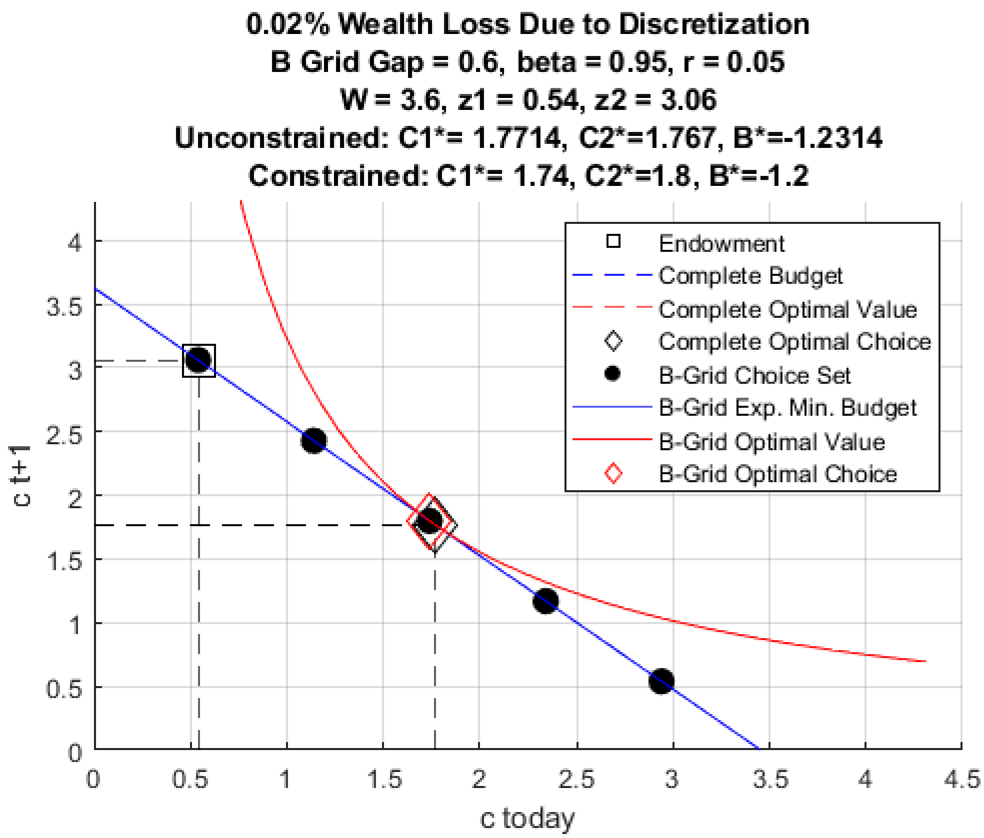
```
    % Solve a Expenditure Minimization Problem
    % Under what budget would the value at constrained optimal bundle
    % be value for unconstrained problem?
    syms c1 c2 lambda
    lagrangian = (c2 + (1+r_og)*c1 - lambda*( log(c1) + beta*log(c2) - val_og));
    solu_min = solve(diff(lagrangian, c1)==0,...
                     diff(lagrangian, c2)==0,...
                     diff(lagrangian, lambda)==0,...
                     c1, c2, lambda, 'Real', true);
    solu_min_c1 = double(solu_min.c1);
    solu_min_c2 = double(solu_min.c2);
    Wealth_grid = solu_min_c1*(1+r_og) + solu_min_c2;
    Wealth_loss = 1- (Wealth_grid/(z1*(1+r_og) + z2));
    Wealth_loss_percent = round(Wealth_loss*10000)/100;

    % Store Results
    Wealth_loss_percent_grid(wealth_i) = Wealth_loss_percent;
    opti_borrow_exct(wealth_i) = b_opti;
    opti_borrow_grid(wealth_i) = b_opti_grid_constrained;

    % Graph Budget and Indiff for a Subset
    if (ismember(wealth_i, wealth_grid_graph))

        % Subplotting
%         subplot(2,2,find(graph_grid==wealth_i));
        figure();
        hold on;

        % Define Budget Line and Indifference Curve
        syms c1
        % The Budget Line
        f_budget = z1*(1+r) + z2 - c1*(1+r);
        % Indifference at V*
        f_indiff = exp((U_at_b_opti-log(c1))/(beta));

        % The grid constrained value's unconstrained optimal budget line
        f_budget_grid_constrained = solu_min_c1*(1+r_og) + solu_min_c2 - c1*(1+r_og);
        % Indifference for grid constrained value
        f_indiff_grid_constrained = exp((val_og-log(c1))/(beta));

        % Endowment Point
        scatter(z1, z2, 250, 'k', 's');
        plot(linspace(0,z1,10),ones(10,1) * z2, 'k--', 'HandleVisibility','off');
        plot(ones(10,1) * z1, linspace(0,z2,10), 'k--', 'HandleVisibility','off');

        % Unconstrained Lines now Dashed
        fplot(f_budget, [0, (z1 + z2/(1+r))*1.25], 'b--');
        fplot(f_indiff, [0, (z1 + z2/(1+r))*1.25], 'r--');

        % Unconstrained Optimal Point
        scatter(c1_opti, c2_opti, 250, 'k', 'd');
        plot(linspace(0,c1_opti,10),ones(10,1) * c2_opti, 'k--', 'HandleVisibility','off');
        plot(ones(10,1) * c1_opti, linspace(0,c2_opti,10), 'k--', 'HandleVisibility','off');
```

```
        % Constrained Lines
        scatter(c1_b_grid, c2_b_grid, 100, 'k', 'filled', 'c');
        fplot(f_budget_grid_constrained, [0, (z1 + z2/(1+r))*1.25], 'b-');
        fplot(f_indiff_grid_constrained, [0, (z1 + z2/(1+r))*1.25], 'r-');

        % Constrained Optimal Choice
        scatter(c1_opti_grid, c2_opti_grid, 250, 'r', 'd');

        % Y and X lim
        ylim([0, (z1 + z2/(1+r))*1.25])

        % Labeling
        title({[num2str(Wealth_loss_percent) '% Wealth Loss Due to Discretization'],...
               ['B Grid Gap = ' num2str(b_grid_gap)...
                ', beta = ' num2str(beta)...
                ', r = ' num2str(r)],...
               ['W = ' num2str(wealth_grid(wealth_i))...
                ', z1 = ' num2str(z1),...
                ', z2 = ' num2str(z2)],...
               ['Unconstrained: C1*= ' num2str(c1_opti)...
                ', C2*=' num2str(c2_opti)...
                ', B*=' num2str(b_opti)],...
               ['Constrained: C1*= ' num2str(c1_opti_grid)...
                ', C2*=' num2str(c2_opti_grid),...
                ', B*=' num2str(b_opti_grid_constrained)]});
        xlabel('consumption today');
        ylabel('consumption tomorrow');
        legend({'Endowment',...
                'Complete Budget',...
                'Complete Optimal Value',...
                'Complete Optimal Choice',...
                'B-Grid Choice Set',...
                'B-Grid Exp. Min. Budget',...
                'B-Grid Optimal Value',...
                'B-Grid Optimal Choice'...
                });
        xlabel('c today');
        ylabel('c t+1');
        grid on;
    end
end
```


28.94% Wealth Loss Due to Discretization
B Grid Gap = 0.6, beta = 0.95, r = 0.05
W = 0.6, z1 = 0.09, z2 = 0.51
Unconstrained: C1*= 0.29524, C2*=0.2945, B*=-0.20524
Constrained: C1*= 0.09, C2*=0.51, B*=0
Endowment
Complete Budget
Complete Optimal Value
Complete Optimal Choice
B-Grid Choice Set
B-Grid Exp. Min. Budget
B-Grid Optimal Value
B-Grid Optimal Choice
c t+1
c today
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8


0.24% Wealth Loss Due to Discretization
B Grid Gap = 0.6, beta = 0.95, r = 0.05
W = 1.598, z1 = 0.2397, z2 = 1.3583
Unconstrained: C1*= 0.78632, C2*=0.78435, B*=-0.54662
Constrained: C1*= 0.8397, C2*=0.7283, B*=-0.6
Endowment
Complete Budget
Complete Optimal Value
Complete Optimal Choice
B-Grid Choice Set
B-Grid Exp. Min. Budget
B-Grid Optimal Value
B-Grid Optimal Choice
c t+1
c today
0
0.5
1
1.5
0.2
0.4
0.6
0.8
1.2
1.4
1.6
1.8
2

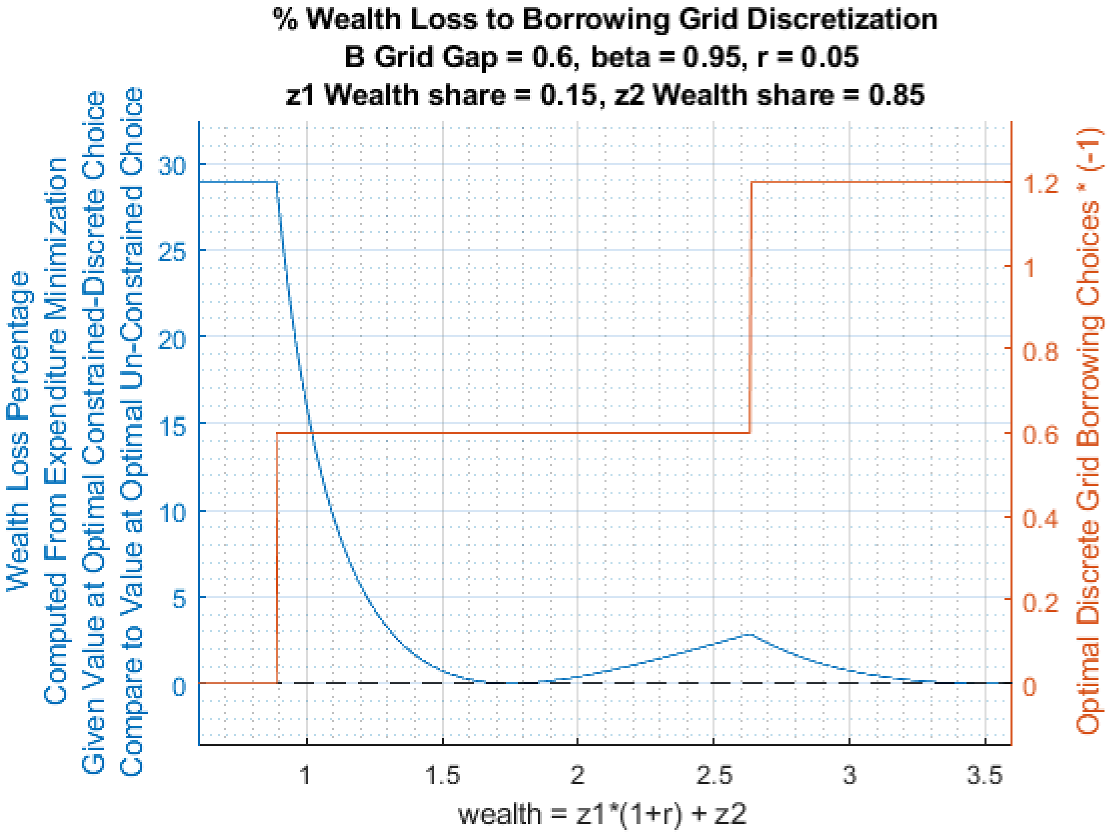




Shifting Wealth and Wealth Loss Due to Discretization

Plot also based on stored results, given the parameters here, variations in Wealth loss along the total 2 period wealth grid. Now I set $\beta = 0.95$, and also $r = 0.05$. It is important to note that the standard borrowing constraint does not pick up the welfare/Wealth loss due to discretization. If in reality, the formal borrowing choice set is limited, or at least have a minimum borrowing requirement, this leads potentially to very significant welfare/Wealth loss to households with low levels of optimal borrowing needs.

```
figure();
hold on;

% Left Axis Wealth Loss
yyaxis left
line(wealth_grid, Wealth_loss_percent_grid);
plot(wealth_grid, ones(size(wealth_grid)) * 0, 'k--');
ylim([-(max(Wealth_loss_percent_grid))/8 max(Wealth_loss_percent_grid)*9/8]);
xlim([wealth_grid_min wealth_grid_max]);

title({['% Wealth Loss to Borrowing Grid Discretization'],...
       ['B Grid Gap = ' num2str(b_grid_gap) ...
        ', beta = ' num2str(beta) ', r = ' num2str(r) ' '],...
       ['z1 Wealth share = ' num2str(z1_share) ...
        ', z2 Wealth share = ' num2str(z2_share)]})
xlabel('wealth = z1*(1+r) + z2 ');
ylabel({['Wealth Loss Percentage'],...
        ['Computed From Expenditure Minimization'],...
        ['Given Value at Optimal Constrained-Discrete Choice'],...
        ['Compare to Value at Optimal Un-Constrained Choice']});
grid on;
grid minor;

% Right Axis Optimal Choices
yyaxis right
line(wealth_grid, (-1)*opti_borrow_grid);
ylim([-(-1*min(opti_borrow_grid))/8 (-1*(min(opti_borrow_grid)+min(opti_borrow_grid)/8))]);
xlim([wealth_grid_min wealth_grid_max]);
ylabel({['Optimal Discrete Grid Borrowing Choices * (-1)']});
```


% Wealth Loss to Borrowing Grid Discretization
B Grid Gap = 0.6, beta = 0.95, r = 0.05
z1 Wealth share = 0.15, z2 Wealth share = 0.85
Wealth Loss Percentage
Computed From Expenditure Minimization
Given Value at Optimal Constrained-Discrete Choice
Compare to Value at Optimal Un-Constrained Choice
Optimal Discrete Grid Borrowing Choices * (-1)
wealth = z1*(1+r) + z2
0
5
10
15
20
25
30
0
0.2
0.4
0.6
0.8
1
1.2
1
1.5
2
2.5
3
3.5