The Envelope Theorem and the Euler Equation

This handout shows how the Envelope theorem is used to derive the consumption Euler equation in a multiperiod optimization problem with geometric discounting and intertemporally separable utility.

The consumer’s goal from the perspective of date $t$ is to

$$\max_{c_{t+1}} \sum_{n=0}^{T-t} \beta^n u(c_{t+n})$$

subject to the dynamic budget constraint

$$m_{t+1} = (m_t - c_t)R + y_{t+1}. \quad (2)$$

The problem can be written in Bellman equation form as

$$v_t(m_t) = \max_{\{c_t\}} u(c_t) + \beta v_{t+1}((m_t - c_t)R + y_{t+1}). \quad (3)$$

The first order condition for (3) can be written as

$$0 = u'(c_t) + \beta \left( \frac{dm_{t+1}}{dc_t} \right) v_{t+1}'(m_{t+1})$$

and we can define a function $c_t(m)$ that returns the $c_t$ that solves the max problem for any given $m_t$. That is, for $c_t = c_t(m_t)$ the first order condition (5) will hold so that

$$u'(c_t(m_t)) - R\beta v_{t+1}'((m_t - c_t(m_t))R + y_{t+1}) = 0. \quad (6)$$

Now define a function

$$v_t(m_t, c_t) = u(c_t) + \beta v_{t+1}((m_t - c_t)R + y_{t+1}) \quad (7)$$

with partial derivatives

$$\nabla_c v_t(m_t, c_t) \equiv \left( \frac{\partial v_t}{\partial c_t} \right) = u'(c_t) - R\beta v_{t+1}'((m_t - c_t)R + y_{t+1}) \quad (8)$$

$$\nabla_m v_t(m_t, c_t) \equiv \left( \frac{\partial v_t}{\partial m_t} \right) = R\beta v_{t+1}'(m_{t+1}) \quad (9)$$

and note that by definition

$$v_t(m_t) = \nabla_c v_t(m_t, c_t(m_t)). \quad (10)$$
The Chain Rule of differentiation tells us that
\[ v_t'(m_t) \equiv v_t^m(m_t) \equiv \left( \frac{d v_t}{d m_t} \right) = v_t^m(m_t, c_t(m_t)) + \left( \frac{\partial c_t(m_t)}{\partial m_t} \right) v_t'(m_t, c_t(m_t)). \] (11)

Here’s the key insight: The assumption that consumers are optimizing means that we will always be evaluating the value function and its derivatives at a \( c_t \) that satisfies the first-order optimality condition (6).\(^1\) Thus we have from (8) that
\[ v_t^c(m_t, c_t(m_t)) = u'(c_t(m_t)) - R \beta v_{t+1}^c((m_t - c_t(m_t))R + y_{t+1}) \] (12)
\[ = 0. \] (13)

This means that the second term in (11) is always equal to zero, so from (9) we obtain
\[ v_t'(m_t) = R \beta v_{t+1}^c(m_{t+1}). \] (14)

Now notice that the RHS’s of (5) and (14) are identical, so we can equate the left hand sides,
\[ v_t'(m_t) = u'(c_t) \] (15)
and since a corresponding equation will hold in period \( t + 1 \) we can rewrite (14) as
\[ u'(c_t) = R \beta u'(c_{t+1}). \] (16)

The general principle can be condensed into a rule of thumb by realizing that the Envelope theorem will always imply that the total derivative of a value function with respect to any choice variable must be equal to zero for optimizing consumers (because the first order condition holds). Thus we could have obtained the result immediately by treating \( c_t \) as though it were a constant (that is, treating the problem as though \( c_t'(m_t) = 0 \)) and taking the derivative of Bellman’s equation with respect to \( m_t \) directly. This leads immediately to the key result:
\[ v_t(m_t) = u(c(m_t)) + \beta v_{t+1}((m_t - c_t(m_t))R + y_{t+1}) \] (17)
\[ v_t'(m_t) = \beta R v_{t+1}'(m_{t+1}). \] (18)

\(^1\)Unless there is some constraint that prevents the consumer from choosing this optimum - like a liquidity constraint.
Figure 1  Illustration of the Envelope Theorem at Alternative Values of $m$