Capital, Turnover, and Payback Time
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Ec. 100B, Macro-economics, Professor Gaffney

Class notes, January 21, 1981

Capital, Turnover, and Payback Time

1. What is Capital? A simple working definition is, Capital is the sum of goods that have been produced but not yet used up. There is an interval of time between the input of labor (and other prime factors) and the final delivery of service to consumers. During this interval the production must be "financed". This means that an investor or capitalist must "carry"the capital by advancing money to workers, lenders of money, landlords, sellers of raw material and utilities, tax-collectors and others, thus financing the product until he recovers his advances from sales.

Almost all output goes through a period of being "capital". There is little direct consuming of products as they are produced, simultaneously. Direct services like haircuts are an exception, although even they last a while (some people make them last for years), and during this interval they are called "human capital" because incorporated in a human body.

During the interval between production and consumption, capital is said to be "ripening". (Another common metaphor is to say it is "in the pipeline.") The analogy is to food production. Seeds are capital, which slowly ripen into harvests. Maybe 20% of all capital fits this pattern. We will call it "growing" capital, things like crops, livestock, cheese, liquor, and timber. With a little use of statistical probability, we can apply the model to inventories and to deposits of minerals, both of which have value added to them while they are held.

Some other capital, like trucks and houses, delivers service as the capital wears out. When United Parcel comes to your door, it is delivering to you (and you pay for) a little piece of the truck along with the package. In case of the truck, you may ask how it is "ripening" when it is wearing out? Think of it as being annular, that is composed of concentric rings, like a tree or an onion. The outer ring represents the currently usable service flow. Each year (or other period) one outer ring is used up and wears off, exposing the next one for use. This next one is what has now "ripened" into a higher value. Sounds strange? This is exactly the way mathematicians, appraisers and valuation engineers view trucks and houses when they place a value on them. Thus a house value is the sum of several annual "rings" of service, each one of which is appreciating or ripening as it moves forward in time to the year when it will actually give service. But the sum of these appreciating rings depreciates, why? Because each year there is one less of them; and each succeeding one is smaller.*

Capitalists create income when they advance capital to hired factors like workers. This is "investment". Investing consists of two stages or parts: paying money; and delivering the goods to back up the money. Here we collapse these two stages into one (for a while.) The capitalist simply grubstakes the worker by advancing ripe goods to the worker, while the worker makes unripe goods for the capitalist.

*These rings really do appreciate. The 50th year of life built into a house adds only a little to cost today compared to its value in the 50th year, as a rule. Another $1,000 today might add a year's service worth $7,000 then in constant dollars.

3. Capitalists can advance capital to workers each time it comes back to them in sales. They constantly "recycle" it this way. This is the circulation of capital. The flow of payrolls thus depends on the quantity of capital times the number of times it is recycled each year. The latter is called "Turnover." Volume (a synonym for flow) equals capital times turnover. This formula is familiar to all merchants.

4. Let's take a simple introductory case. "Broilers" (poultry raised for meat) take about 13 weeks from the chick to the slaughter. That is ¼ of a year.

P = Payback Period = ¼ year
T = Turnover = 4/year = 1/P
V = Volume/year = 4K = TK (where K = Capital)
V/K = Flow/Fund ratio = T = 4
K/V = Fund/Flow ratio = P = ¼ . (Often called the Capital/Output ratio.)

The last two ratios are obvious, yet so easy to forget, so let's repeat. The flow/fund ratio is the same as turnover. Turnover is the reciprocal of the payback period. The capital/output ratio is the same as the payback period. Let's just lean on that last one. The capital/output ratio is the same as the payback period. This says that the longer is the payback period, the more capital it takes to produce a given output (and to employ a given number of workers.) This is an idea to conjure with. To make capital soak up the unemployed, we need to reduce payback times. This increases the valence of capital for labor.

5. Alas for simplicity, the simple case leaves out some important factors. It does not account for the regular flow of current inputs (called "running costs", or "operation and maintenance") into the ripening stock as value is added from chick to broiler. There are running costs of feed, shelter, waste removal, health care, management, etc. This changes the payback period average. For example, the feed investment of week 12 is recovered in just one week, not 13. To handle this, we need a more complex accounting. Fortunately, the needed mathematics has all been worked out for us long since.

Besides the visible running costs there are invisible ones, notably the regular plowback of interest on unrecovered capital. When capital is not recovered in sales, interest on the capital is still figured, but it becomes part of the value of the capital itself. Then in the next period we have to figure interest both on the original capital, and the accrued interest. This is what compound interest is all about.

You can see that this might get a little heavy. But don't despair, that means you are about to learn some worthwhile techniques, skills that will not depreciate until you do and will stand you in good stead. As your dentist says, it only hurts a little and it will sharpen your bite.

Some are prone to declare "impossible" anything that strikes them as difficult. This is true not only of unwilling students, but of the neo-classical Micro-economists. But we will see that it is possible, and more interesting than difficult.

One approach, which we follow here, is to model a "normalized" or staggered operation. The idea is that you start one cohort of chicks each week, and sell one cohort each week, thus evening out the flow of your sales. This is called a "going concern" model.

Each week there will be sales; and there will be a constant amount of capital on hand. The ratio of capital to sales, or K/V, is the payback time. A formal proof of this would be interesting, and at some stage necessary, but here we content ourselves with saying we have already shown it for the simple case, and assume it applies to the general case.

I assume you know the formula for compound interest. If we invest \$1 at the beginning of week #1, it will grow to a value of $(1 + i)$ raised to the 13th power at the end of week#13, (where i is the rate of interest per period, in this case per week.)

Say it costs \$1 to start each cohort of broilers. Say that running costs are zero (we'll put them in later.) Using \$1 for startup costs doesn't say that's what they really are, nor is it unrealistic, it just puts everything on a per-dollar basis.

To justify tying up the capital for 13 weeks, sales from each cohort must be:

$$V = (1 + i)^{13} \tag{1}$$

Aggregating the capital is the only hard part. We'll do it at the end of each week. For cohort #1, the value is now $(1 + i)$; for cohort #2, it is $(1 + i)^2$; for #3, $(1 + i)^3$; and so on to #13, $(1 + i)^{13}$. This is the sum of a geometric progression, and a standard formula in the mathematics of finance.

$$K = \sum_{h=1}^{13} (1 + i)^h = \frac{(1+i)^{13} - 1}{i} \tag{2}$$

More generally we can replace 13 by n:

$$K = \sum_{1}^{n} (1 + i)^n = \frac{(1+i)^n - 1}{i} \tag{3}$$

Now divide K by V

$$K/V = \frac{1 - (1+i)^{-n}}{i} \tag{4}$$

Table 1 gives values of K/V for different values of n & i.

Table I: Values of $K/v = \frac{1-(1+i)^{-n}}{i}$

i (%) →	.5	1	2	3	4	5	6	7	8	9	10	20
n												
1	1.00	.99	.98			.95					.91	.83
2												
3												
4												
5	4.93	4.85	4.71			4.33					3.79	2.99
10	9.73	9.47	8.98			7.72					6.14	4.19
15	14.42	13.87	12.85			10.38					7.61	4.68
20	18.79	18.05	16.35			12.46					8.51	4.87
30	27.79	25.81	22.40			15.37					9.43	4.98
40						17.16						
50						18.20						
60						18.93						
70						19.34						
80						19.60						
90		59.16				19.75						5.00

I have nailed down the corners of the table. You can get the feel of it from this. Average payback times are shorter than the full carcass life (n), especially at higher i. Remember that one input where period of investment is averaged in is the input of capital plowed back each period when interest accrues but is not recovered in sales.

Next, let's add the factor of running costs (c). Startup costs were $1. Let running costs be 10¢ or $.10. These will add to both sales and capital. Sales must be higher in order to pay back the running costs, plus interest on these costs during their respective individual periods of investment.

$$\text{added sales} = c\,\frac{(1+i)^n - 1}{i} \qquad (5)$$

$$\text{added capital} = c\left[\frac{(1+i)^1 - 1}{i} + \frac{(1+i)^2 - 1}{i} + \cdots + \frac{(1+i)^n - 1}{i}\right] = \frac{c}{i}\left[\sum_1^n (1+i)^n - n\right]$$

$$= \frac{c}{i}\left[\frac{(1+i)^n - 1}{i} - n\right] \qquad (6)$$

$$\frac{\text{added K}}{\text{added V}} = \frac{1}{i} - \frac{n}{(1+i)^n - 1} \qquad (7)$$

For the full picture now we should add the new K to the original, and the new sales to the original, and take the ratio. But that gets heavy, so let's get the feel of things by first tabulating (7). (7) is the value of K/V when startup costs are zero:

Table 2: Values of $\frac{\Delta K}{\Delta V} = \frac{1}{i} - \frac{n}{(1+i)^n - 1}$

i (90) →											
n											
1											
2	.50			.49					.48		
3	.99			.97					.94		
4	1.49			1.44					1.38		
5	3.96			1.90					1.81		
10	4.42			4.10					3.73		
15	6.81			6.10					5.28		
20	9.17			7.90					6.51		
30	13.76			10.97					8.18		
40	18.18			13.38					9.10		
50	22.47			15.24					9.57		
75	32.38			18.02					9.94		
100	41.34			19.23					9.99		

Again, the skeleton of the table is enough to give us a feel for it. Payback periods are shorter than carcass lives, especially at high interest rates and long carcass lives.

Last, let's do a model for depreciating capital: a house, machine, fixture, or industrial plant. Each unit yields us \$1/year, so sales per year are \$n.

$$K = \sum_{y=0}^{n} \left[\frac{1-(1+i)^{-(n-y)}}{i} \right] \qquad (8)$$

$$= \frac{1}{i}\left[n - (1+i)^{-n} \sum_{0}^{n} \{(1+i)^{y}\} \right] = \frac{1}{i}\left[n - \frac{1-(1+i)^{-n}}{i} \right]$$

$$K/S = \frac{1}{i}\left[1 - \frac{1-(1+i)^{-n}}{in} \right] \qquad (9)$$

These values are in Table 3.

You are not required to master the mathematics above. The idea is to show you the basic method for finding payback periods, and to give you a feel for what they are like, in actual numbers. By an extension of these methods we can find average periods for any asset. By measuring the nation's capital, dividing by output, we know the nation's payback period.

Table 3: Values for $\frac{K}{V} = \frac{1}{i}\left[1 - \frac{1-(1+i)^{-n}}{i\,n}\right]$

n \ i →	½	1	3	4	5	6	7	8	9	10
1										
2	1.49	1.48			1.41					1.32
3	1.98	1.97			1.85					1.71
4	2.48	2.45			2.27					2.08
5	2.97	2.93			2.68					2.42
6										
7										
8										
9										
10	5.39	5.29			4.56					3.86
11										
12										
13										
14										
15										
16										
17										
18										
19										
20	10.13	9.77			7.54					6.23
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