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Roundaboutness is Not a Mysterious Concept: A Financial Application to Capital Theory

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Roundaboutness is Not a Mysterious Concept: A Financial Application to Capital Theory

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Abstract *We apply the EVA terminology to the concepts of roundaboutness and average period of production in capital theory. By doing this we show that these terms have a clear and well understood financial interpretation. A financial application to capital theory helps to clarify obscure and controversial economic terms.*

1. Introduction

The distinctive aspect of Austrian business-cycle theory is the effect that monetary policy can have on the allocation of capital goods. The Austrian theory of the business cycle makes use of Wicksell's natural interest rate analysis and of Böhm-Bawerk's capital theory. According to this business-cycle theory, the structure of production is altered when the monetary authority changes the level of interest rates. Succinctly, a monetary policy that reduces interest rates, increases the 'average period of production', or the degree of 'roundaboutness,' of the 'structure of production,' that is out of sync with consumer preferences, thus creating unsustainable imbalances in that structure. The increase in 'roundaboutness,' followed by its reduction when the monetary authority revises interest rates upward, is what constitutes the boom and bust in this business-cycle theory. The appeal and credibility of this theory has been limited by its use of concepts that are hard to define and operationalize.

Most contemporary empirical studies of the Austrian business-cycle theory focus on the effects produced by monetary policy on the structure of production as presented in the Hayekian triangle, and as embedded in Garrison's (2001)

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model (Lester & Wolff, 2013; Luther & Cohen, 2014; Mulligan, 2002, 2013; Powell, 2002; Young, 2005).[1] This approach falls short, however, because it has to observe the constraints and simplifications of this model in order to do the empirical research.

In this paper we offer an alternative way of thinking about ‘roundaboutness’ or ‘average period of production’ that has not received the attention it deserves. We use the Economic Value Added (EVA) literature to reframe roundaboutness and interest rate sensitivity into financial terminology (Ehrbar, 1998; Koller et al., 1990; Stern et al., 2003; Young & O’Byrne, 2000).[2] As we explain later, an advantage of the EVA literature is that offers a variable for invested (financial) capital, which is at the center of the concept of roundaboutness.

This paper contributes in two ways to the contemporary literature on this subject. First, it argues that notions of ‘duration’ (as commonly used in the financial literature) offer a more straightforward interpretation of ‘roundaboutness’ or ‘average period of production’ than the one represented in the Hayekian triangle. Even though the concept of duration is well known and its application may seem trivial at first sight, trivial concepts can have non-trivial applications. The connection between ‘roundaboutness’ and duration has not, to the best of our knowledge, been made explicit.

Second, it offers a connection between the EVA literature (mostly commonly applied in the field of corporate finance) and economics that remains largely unexplored. As far we can tell, J.C. Cachanosky (1999) and N. Cachanosky (in press) are the only studies offering a direct connection between the EVA literature and Austrian business-cycle theory.[3] Duration and related concepts have wide applications to issues in corporate finance and investments. We thus offer a new application to a different context, the context of money-macroeconomic policy. The complications that inhere in the notion of ‘roundaboutness’ at the center of the Austrian theory, and the renewed interest in this theory since the 2008 crisis, makes this new application a value-adding endeavor, one well-suited to illustrating how a financial framing can clarify some difficult concepts in capital theory.

In Section 2 we discuss the concept of ‘roundaboutness’ and its representation in the Hayekian triangle. In Section 3, the core of the paper, we introduce the financial interpretation of ‘average period of production’ and ‘roundaboutness’ making use of the EVA literature. We argue that these terms are not mysterious and do not contain the irresolvable difficulties that characterize the ‘average period of production’ approach. Rather they provide a straightforward value-based

[1]Some scholars offer a case study approach (Callahan & Garrison, 2003; Powell, 2002; Ravier & Lewin, 2012; Salerno, 2012). Other econometric studies focus on macroeconomic aggregates rather than in the ‘structure of production’ or Hayekian triangle (Bismans & Mougeot, 2009; Keeler, 2001; Mulligan, 2006). This approach is inadequate in the sense that such aggregation can also be interpreted as empirical evidence of rival business cycle theories. As such, the empirical evidence does not provide distinctive support for the Austrian theory.

[2]*EVA* is a registered trademark of Stern Stewart & Co.

[3]Cwik (2008) offers a corporate financial approach to the Mises–Hayek theory but does not rely on the *EVA* literature.

interpretation and can be applied to understand real world phenomena such as business cycles along the lines of Wicksell's theory. Section 4 concludes.

2. Roundaboutness

Roundaboutness is associated with (1) a higher average period of production and (2) a more capital-intensive method of production. It refers to a method of production that requires more 'time' but which is compensated for by higher productivity. The higher productivity results from the use of more (complex) capital goods, hence the notion of more 'roundabout' as more 'capital intensive' methods of production. It is possible to go from one point in a city to the opposite side by the shortest route, a road that goes through the middle of the city, or by taking the turnpike that requires going through a longer route because it borders the city. However, because the turnpike allows faster driving it is possible to reach the opposite side of the city more quickly than by taking the shortest route. The turnpike is a more roundabout, but more productive, way to go from one side of the city to the opposite side.[4] It is important to distinguish between the time that it takes to produce the good or service (crossing the city) and the time it takes to set-up the method of production. Once the turnpike is built, it is then faster to go from one point to the opposite side of the city, but it takes more time and funding to build the turnpike than it takes to build a road that goes through the middle of the city.

This idea comes originally from Menger (1871), and was expanded by Böhm-Bawerk (1884). In an attempt to encapsulate the relationship between time used in production and capital intensity, Böhm-Bawerk proposed the idea of measuring production time in a construct called the 'average period of production,' which can be written as follows.

$$\Gamma = \frac{\sum_{t=0}^{n}(n-t)l_t}{\sum_{t=0}^{n} l_t} = n - \frac{\sum_{t=0}^{n} t \cdot l_t}{N} \tag{1}$$

where Γ is the average period of production for a production process lasting n calendar periods; t, going from 0 to n, is an index of each sub-period; l_t is the amount of labor expended in sub-period t and $N = \sum_{t=0}^{n} l_t$ is the unweighted labor sum (the total amount of labor-time expended). Thus, Γ is a weighted average that measures the time on average that a unit of labor l is 'locked up' in the production process. The weights $(n-t)$ are the distances from final output. Γ depends positively on n, the calendar length of the project, and on the relation of the time pattern of labor applied (the points in time t at which labor inputs occur) to the total amount of labor invested N.[5] In this way Böhm-Bawerk hoped to have solved the problem of measuring roundaboutness.

[4]With a similar argument, the Turnpike Theorem argues that sometimes it is better to grow slowly for a while in order to ultimately grow faster—just like it is often worth taking the turnpike (highway/tollway) even though it may be a longer distance, because you get there more quickly.

[5]This formulation was the source of an enormous amount of subsequent controversy over a long period of time. Although arguably a deviation of the essential 'Mengerian' vision that characterized

In the special case where there is an even flow of inputs so that the same amount of labor-time, l_0, is applied in each period, $\sum_{t=0}^{n}(n-t)l_t = (1/2)n \cdot (n+1)l_0$ and $\sum_{t=0}^{n} l_t = n \cdot l_0$ and therefore $\Gamma = n/2 + 1/2$ or simply $n/2$ (when n is large enough so that the $\frac{1}{2}$ can be ignored, or when Γ is expressed in continuous time where it is absent). So, when inputs occur at the same rate over time, each unit is 'locked-up' on average for half the length of the production period. It is this idea that is reflected in Hayek's later use of a triangle (for which the average period is found half-way along the base of the triangle) to represent the idea of roundaboutness.

Hayek (1931, 1941) thus uses a triangle to capture, in a simple manner, the idea of roundabout methods of production. The triangle depicts a production process divided into different stages where the output of each stage is sold as the input to the next one. Mining, for instance, precedes refining, which in turn precedes manufacturing, which is followed by distributing and then retailing as the final stage of production before reaching the consumer (Figure 1). As production moves forward from one stage of production to another stage of production, the vertical axis captures the accumulation of the value added of each stage.

Time makes its appearance on the horizontal axis. As production takes place, intermediate goods move from the early or first stages of production (mining) to the later stages of production (retailing.) It is *how much capital is invested in each stage* and *what particular methods of production* are chosen that defines the 'structure of production.' Yet, as Garrison (2001, p. 49) points out, the horizontal line does not measure units of time, but rather a combination of the market value of resources and time. Two dollars of resources used for three years in a production process amounts to one dollar worth of resources used for six years (six dollar-years) of production time. It is the amount of dollars and how long they are locked up that constitutes the degree of roundaboutness. It may take one year to produce either the turnpike or the street that crosses the city, but the highway is still more roundabout because it requires a larger amount of capital (input-time). The ambiguity of the term and the difficulty of defining the 'average period of production' plus the graphical representation of the Hayekian triangle invite confusion and the appearance of paradoxes such as technology reswitching and capital reversing.[6]

Böhm-Bawerk's understanding of capital, it became the focus of much attention and the source of many developments involving the notion of capital, including neoclassical production and growth theory. See Lewin (1999, pp. 63–78).

[6]For discussion on the terminological ambiguities in the initial development of capital theory see Lewin (1999, pp. 63–73). For accounts of the related capital controversies see Cohen & Harcourt (2003), Cohen (2008), Felipe & McCombie (2014), Felipe & Fisher (2003), Kirzner (2010), Machlup (1935) and Yeager (1976). Among the many problems with the idea of 'average period of production' is that it is a conception of production occurring in a static environment in which technology is applied by identifiable, measurable resources over time to produce identifiable products in a known and unchanging manner with clearly identifiable starting and ending points. As such, it can be viewed as an unambiguous measure of the 'size' of the production process, in terms of 'resource-time-taken' or 'quantity of capital' that can be viewed looking forward or looking backward. This equilibrium construct, in which all values are known and revealed, allows for a fallacious 'cost of production' interpretation of the value of capital (of which the labor-theory of value is one

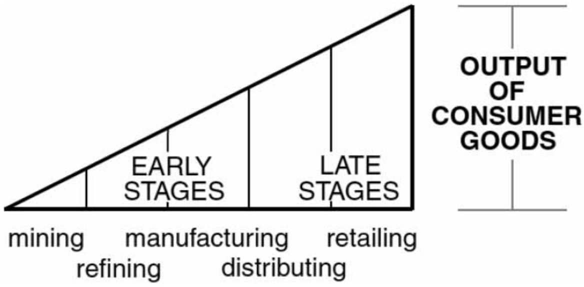

Figure 1. Hayekian triangle. Source: Garrison (2001, p. 47)

It is, however, very intuitive and useful as an expository device. The number of stages of production that can be sustained by the market depends on the time preference of consumers. For instance, a reduction in time-preference increases the supply of loanable funds and reduces the interest rate in the market, other things being constant. This increase in savings allows for extending the triangle by augmenting the financial capital needed to add stages of production. Namely, an increase in savings allows for the financing of a more capital-intensive structure of production. The interest rate, then, is (1) the slope of the Hayekian triangle and (2) the opportunity cost or minimum value added required by each stage of production to be profitable.

The Hayekian triangle offers a simplification of capital theory in order to emphasize particular features such as the effects of market interest rates on how long production takes in the economy. But this simplification imposes important challenges for empirical research based on the Hayekian triangle approach. The notion of stages of production is a mental construct. It enables one to study the production structure in the economy. It is not an objective demarcation that can be observed in the market. For the same objective reality, the Hayekian triangle in Figure 1 could depict a different number of separations between the different stages of production, and could also show more or fewer stages of production than five. In other words, empirical research inspired by the Hayekian triangle calls for a subjective judgment on how to separate and order the stages of production. Plausible assumptions might be available in a simple world, but the complexity of the real-world market economy makes this a non-trivial problem. The problems that arise from this are significant. For instance, the same economic activity can appear in different stages; electricity can be used to power early stages of production and also be a consumer service for households. This requires a decision on how to weight the participation of each industry at the different stages. It can also be the case that different stages of production sell their inputs to each other, making it unclear what the order should be—a phenomenon known as 'looping.' The car industry can

example). Moving from a quantitative physical input conception to a forward looking value conception, such as is implied by the use of the concept of *duration* to be discussed below, allows us to avoid these serious drawbacks with the original conception of roundaboutness.

sell vehicles to the steel industry, and the steel industry sells steel to the car industry. In addition, it is possible that an industry moves from early (late) stages of production to late (early) stages of production in time or as a result of the monetary policy being studied.[7] Finally, it is also possible that stages of production can grow not only vertically (increase the value added) but also horizontally (increase in the dollar-time). Luther & Cohen (2013) argue that this effect can significantly change how empirical results can be interpreted and produce misleading conclusions.

In addition, the wording of 'average period of production' plus the graphical representation of the Hayekian triangle may bias the interpretation of 'roundaboutness' as a backward-looking concept rather than a forward-looking investment decision.[8] It is how monetary policy affects forward-looking marginal investment decisions that should be the focus of attention.

Most of the contemporary empirical research on the Austrian business-cycle theory follows the Hayekian triangle. This work locates different industries in different stages of production of what would be the Hayekian triangle of the economy (Lester & Wolff, 2013; Luther & Cohen, 2014; Mulligan, 2002; Powell, 2002; Young, 2005). The Austrian business-cycle theory is then empirically tested against this classification according to the effects described in Garrison's model. According to this model, during an expansionary monetary policy the early and later stages of production should grow vertically with respect to the medium stages of production. This is because, for this theory, such a policy expands both *C* and *I* at the same time. The reduction in interest rates increases investment (in early stages of production) and also increases consumption by reducing the supply of savings. As discussed above, this approach confronts serious problems that undermine the strength and persuasiveness of the empirical results.

A few scholars take a different approach. Instead of locating industrial data in different stages of production, Young (2012) estimates the size (roundaboutness) of what would be the triangle of different industries. Young, however, does not make a reference to interest rate sensitivity and focuses on the behavior of the 'aggregate roundaboutness' rather than on 'stages of production.' Cachanosky (2014) separates economic activities at the industrial level into three groups with different degrees of roundaboutness for two Latin American countries with different exchange rate regimes and finds that in both countries the output of the more roundabout industries are more sensitive to changes in the U. Federal Reserve Funds rate than the output of less roundabout activities. This is a similar approach to the one taken by Robbins's ([1934] 1971) study of the Great Depression.[9] We turn now to an exposition of roundaboutness in terms of Macaulay duration.

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[7]Young (2012) finds empirical evidence that suggests that this effect was present during the 2002–2007 period.
[8]See the discussion in Kirzner (2010) and Lewin (1999, pp. 102–105).
[9]Cachanosky & Salter (2013) and Koppl (2002) also talk about interest rate sensitive sectors rather than stages of production.

3. Roundaboutness as Macaulay Duration

3.1. FCF, EVA and Macaulay's Duration

To further clarify the meaning of roundaboutness we use the EVA literature. As will become clear later, the degree of roundaboutness is a combination of time and invested capital. The EVA literature allows us to capture in one representation both dimensions and to see how these affect the interest rate sensitivity associated with more roundabout methods of production, either because there is more time involved or because there is more capital invested.

In finance, valuation can be summarized as the present value of future (expected) cash flows. In the case of bonds, the present value of the bond is the discounted future cash-flows that the issuer promises to pay. In the case of a firm and investment projects, this is referred to as 'free cash flows' (FCF.) Succinctly, FCF is the net operating profit after taxes (NOPAT) minus net investments (NI); FCF = NOPAT − NI. The value of a firm, then, is the free cash flow that investors receive after investments.

EVA is an algebraic rearrangement of the FCF approach. Let the return on invested capital (ROIC) be the ratio of NOPAT over invested capital, ROIC = NOPAT/K; and EVA be the invested capital (K) times the difference between the ROIC and the opportunity cost of capital (c), EVA = (ROIC − c)K. It is a measure designed to determine for the shareholders how much value is being added by their investment over what they might have earned in the next best alternative. This calculation aims to show the difference between the market value of a company and the capital contributed by investors (both bondholders and shareholders). In other words, it is the sum of all capital claims held against the company plus the market value of debt and equity.[10]

Let the value of a firm or project, V, be the present value of future FCFs. Then, V can be written in terms of EVA as follows:[11]

$$V = \sum_{t=0}^{\infty} \frac{\mathrm{FCF}_t}{(1+c)^t} \tag{2}$$

$$V = K_0 + \sum_{t=1}^{\infty} \frac{(\mathrm{ROIC}_t - c)K_{t-1}}{(1+c)^t} = K_0 + \sum_{t=1}^{\infty} \frac{\mathrm{EVA}_t}{(1+c)^t} \tag{3}$$

The value of the firm is depicted as the initial investment of the shareholders plus (the present) value added, which is calculated as the sum of the excess return over market on starting value in any period for each period. The value of initial capital features only to report the increase (or decrease) in value over time, the economic value added (EVA). Although intended as a financial consulting tool,

[10]More information can be found in Ehrbar (1998), Stern et al. (2003), and Young & O'Byrne (2000).
[11]See the Appendix A for a step-by-step derivation.

it is useful here as a way of investigating the influence of the different components of any project, specifically K, T and D (to be discussed below), on the interest sensitivity of value of the project. The expected market value added (MVA) of the firm is, then, $\text{MVA} = V - K_0$:

$$\text{MVA} = \sum_{t=1}^{T} \frac{(\text{ROIC}_t - c) \cdot K_{t-1}}{(1+c)^t} = \sum_{t=1}^{T} \frac{\text{EVA}_t}{(1+c)^t} \tag{4}$$

Note that the MVA representation captures the desired characteristics of capital theory; (1) it is forward looking, (2) it focuses on the length of the EVA cash flow, and (3) it captures 'capital size' in K. An interpretation of 'average period of production' or 'roundaboutness' can be given a straightforward financial interpretation as the Macaulay duration (D) of the project, where

$$D = \frac{\sum_{t=1}^{T} (\text{EVA}_t \cdot t)/(1+c)^t}{\sum_{t=1}^{T} \text{EVA}_t/(1+c)^t} = \frac{\sum_{t=1}^{T} (\text{EVA}_t \cdot t)/(1+c)^t}{\text{MVA}} \tag{5}$$

D has the interpretation 'the amount of time on average for which one expects to have to wait to earn a dollar from the project.' It is in units of time, constructed as the weighted average of each unit of time, where the weights are the importance of the present value of EVAs in the project as a whole.[12] It might be argued that to be able to calculate D, coupons and a maturity date, as in a bond, are necessary, and that these are absent in investment projects. While there is some truth to this, it is no less true that as long as there are cash-flows, D can be calculated. The fact that an investment project faces less certain cash-flows does not mean that the concept of D does not apply or become meaningless.

This interpretation keeps the spirit of the concept but does away with the problems that arise in the traditional Hayek–Böhm-Bawerk approach discussed above. The latter was a vain attempt to approximate a purely physical measure of 'time taken' or 'quantity of capital invested,' for example as the amount of homogeneous labor-time applied. By contrast, the Macaulay duration is a forward-looking value construct. From the producer's point of view, the weighted average time until the future EVA cash flows are received is the average period of production of the project. Because D weights the periods by the present-value of each period, this measure captures the dollar-time dimension mentioned above and thus avoids any necessity to directly measure physical quantities. Recalling the earlier discussion of Böhm-Bawerk's 'average period of production' formula as depicting the average amount of time for which a unit of labor-time is 'locked-up' in the production process, D, by contrast, depicts the average amount of time for which one dollar is 'locked-up' in the production process. As long as we are talking about the appraised value of a forward-looking investment no ambiguity or incommensurability of units attaches to this formulation. A

[12]The Fisher–Weil duration allows for a term structure of discount rates (a zero coupon curve). Although this is a more precise calculation than the Macaulay duration, the idea on the latter is precise enough for the purpose of this paper.

dollar is a dollar, whereas, a unit of labor-time is fraught with conceptual problems.

It should be noted that the MVA of a project is not a measure of its roundaboutness, D. The time pattern of earnings, of the EVAs, can produce differences in numerous ways in D for projects that appear to last the same time. For example, two projects that have a different time horizon and the same value of K can only have the same MVA if the longer project has lower EVA cash flows. For simplicity let us assume that the values of K and ROIC (and thus EVA) of each project are the same for each period t and that both projects have the same constant c for all t; then,

$$\mathrm{MVA}_{\mathrm{HR}} = \sum_{t=1}^{T_{\mathrm{HR}}} \frac{\mathrm{EVA}_{t,\mathrm{HR}}}{(1+c)^t} \tag{6}$$

$$\mathrm{MVA}_{\mathrm{LR}} = \sum_{t=1}^{T_{\mathrm{LR}}} \frac{\mathrm{EVA}_{t,\mathrm{LR}}}{(1+c)^t} \tag{7}$$

where subscripts HR and LR denote high-roundabout and low-roundabout respectively. If $\mathrm{MVA}_{\mathrm{HR}} = \mathrm{MVA}_{\mathrm{LR}} = \mathrm{MVA}$, with the same pattern of discount rates, and $T_{HR} > T_{LR}$, then $EVA_{HR} < EVA_{LR}$. This gives the HR project a higher D than the LR project. Therefore two projects with the same capital-size, as defined by K, can have a different D. It follows that $D_{\mathrm{HR}} > D_{\mathrm{LR}}$ [13]; that is:

$$\frac{\sum_{t=1}^{T_{HR}} (\mathrm{EVA}_{t,\mathrm{HR}} \cdot t)/(1+c)^t}{MVA} > \frac{\sum_{t=1}^{T_{\mathrm{LR}}} (\mathrm{EVA}_{t,\mathrm{LR}} \cdot t)/(1+c)^t}{\mathrm{MVA}} \tag{8}$$

3.2. Duration, APP and Roundaboutness

The concept of duration was discovered by Frederick Macaulay, and published in 1938. Although closely associated with the famous and prolific business cycle theorist Wesley Mitchell at the newly-founded NBER, Macaulay was not an economist and he worked mainly in actuarial science. It is not well known however, that John Hicks (1939) in his influential *Value and Capital*, independently discovered Macaulay's duration. What is perhaps more noteworthy is that Hicks makes this discovery in the context of trying to reformulate Böhm-Bawerk's APP in a more satisfactory manner.

Hicks realizes that the APP cannot be measured in physical terms—in terms of physical resource inputs per time unit to give a resource-time magnitude as Böhm-Bawerk had attempted to do. Yet Hicks much admired the work of the Austrians and sought in *Value and Capital* to clarify and rehabilitate the APP as a defensible and revealing value construct rather than a physical one. In doing so he provided a much richer concept than that of either Macaulay or Böhm-Bawerk.

[13]For a simple proof see the Appendix B.

Hicks's formulation (1939, p. 186) proceeds as follows: the capital-value (CV) of any stream of T payments (cash flows) is given by

$$\mathrm{CV}(T) = \sum_{t=0}^{T} \frac{\mathrm{CF}_t}{(1+c_t)^t} = \sum_{t=0}^{T} f_t \mathrm{CF}_t \tag{9}$$

where the $\mathrm{CF_t}$ are the expected future income payments, cash flows, and the f_t are the discount ratios, $1/(1 + c_t)^t$, c_t being the appropriate t-period discount rate. Hicks calls f_t the discount *ratio*, we may refer to it as the discount *factor*. We may calculate the elasticity of this CV with respect to the f_t as

$$E_{\mathrm{CV},f_t} = \frac{E(\mathrm{CV}(T))}{E(f_t)} = \frac{1}{\mathrm{CV}(T)}[f_1\mathrm{CF}_1 \cdot 1 + f_2\mathrm{CF}_2 \cdot 2 + \cdots + f_T\mathrm{CF}_T \cdot T] \tag{10}$$

or

$$E_{\mathrm{CV},f_t} = \frac{\sum_{t=1}^{T} f_t \mathrm{CF}_t \cdot t}{\mathrm{CV}(T)} \tag{11}$$

where E is the elasticity (or *d log*) operator. This follows from the rule that the elasticity of a sum is the weighted average of the elasticities of its parts. E_{CV,f_t} turns out to have a number of interesting interpretations.

First, and obviously, E_{CV,f_t} provides a measure of the sensitivity of the value of the project (investment) to changes in the rate of discount, or (inversely) in the discount factor.[14] So, if the discount rate is affected by market interest rates (most particularly rates targeted by monetary policy) the relative valuations of the components of the productive capital-structure will be unevenly affected by monetary policy. Those components of existing production processes that have a higher E_{CV,f_t} will be relatively more affected—for example, a fall in the discount rate (perhaps provoked by a fall in the Federal Funds Rate) will produce a rise in the value of high-E_{CV,f_t} projects relative to those with lower ones.

But, secondly,

> when we look at the form of this elasticity we see that it may be very properly described as the *Average Period* of the stream [of payments]; for it is the *average length of time for which the various payments are deferred from the present, when the times of deferment are weighted by the discounted values of the payments.* (Hicks 1939, p 186, emphasis in original; see also pp. 218–22)

This, in a nutshell, is a reformulated APP in terms of the time-values of the inputs. It is a measure of the average 'duration' of value in the project. A fall in the discount rate will raise its value and a rise will reduce it.[15] The APP correctly understood is the discount-factor elasticity of capital value. And it is identical to the

[14]In principle, different discount rates could be used for different future values. The usual case is to use a single discount rate for all future values so that $f_t = f_1 = f_2 = \ldots = f_n$. For any configuration of rates there is a constant f_t equivalent (yielding the same total present value). We use this in the text.
[15]For a proof see Hicks (1939, pp. 220–222).

concept discovered by Macaulay, known as Macaulay's duration, in 1938, discussed above.

3.3. Wicksell Effects and Modified Duration

The value of a combination of heterogeneous capital goods is the present value of their future cash flows from their employment in production. This means that the prices of capital goods vary inversely with the discount rate. According to Wicksell, there is a natural rate of interest that equilibrates the supply of and demand for loanable funds under full employment.[16] The natural rate of interest depends on the time preference of economic agents. In a competitive market in equilibrium there are no economic profits, therefore ROIC $= c$ and MVA $= 0$. But if the real interest rate at which investors can borrow deviates downward, all else constant, then the MVA rises, signaling the opportunity to earn economic profits. The increase in the demand for capital to invest in projects that promise a positive MVA pushes the price of capital goods upward. This is the Wicksell effect. Succinctly, at a lower real interest rate, the value of capital goods is higher because the present value of their output is discounted at a lower opportunity cost. The increase in the cost of production due to higher prices of capital and intermediate goods is captured as a decrease in net operating profits (after tax) or NOPAT.

It follows from the EVA cash-flow valuation (discussed above) that those projects that are either more forward-looking($T_{\mathrm{HR}} > T_{\mathrm{LR}}$) or have a larger financial capital($K_{\mathrm{HR}} > K_{\mathrm{LR}}$) are more sensitive to changes in the value of c (other things remaining constant). While D captures the financial interpretation of 'average period of production,' the concept of 'modified duration' (MD) captures Böhm-Bawerk's argument that more roundabout projects are more sensitive to changes in interest rates. Modified duration measures the sensitivity of the value of the product to changes in the discount rate, where the yield to maturity (the internal rate of return) is used as the discount rate. It is the semi-elasticity of MVA with respect to yield of the project.

$$\mathrm{MD} = \frac{\partial \log \mathrm{MVA}}{\partial \mathrm{IRR}} = \frac{-D}{1 + \mathrm{IRR}} \tag{12}$$

where IRR is the internal rate of return, paid (compounded) once per period.[17]

The application of this to Wicksell and Böhm-Bawerk's argument has a straightforward financial interpretation. MD measures the percentage change in MVA of a project for a change of 1 unit in the discount rate. As market interest

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[16]Even though this is the most common representation of Wicksell's natural rate of interest, its specific definition is model dependent. For a discussion of Wicksell's natural rate see Anderson (2005), Borio & Disyatat (2011, appendix).

[17]In the case where there is an alternating of positive and negative cash-flows, there can be more than one *IRR*. This is the financial representation of capital reswitching that played a role in the Cambridge capital controversies. Note, however, that to disregard the concept of roundaboutness due to reswitching would be as extreme as to disregard the concept of *D* because more than one *IRR* can occur in the case of irregular cash flows.

rates change, changes in the market prices (values) of durable assets will change inversely in a manner indicated by MD.

Consider the case where two projects that have the same MVA and time horizon ($T_{HR} = T_{LR}$) but different amounts of invested capital. The project that has the larger financial capital is more sensitive to changes in the interest rate even if both projects have the same D. EVA can be written as the difference between the NOPAT and the cost of opportunity of the capital invested, $EVA_t = NOPAT_t - c_t \cdot K_{t-1}$, where NOPAT is the net operating profit after taxes. Assume that for each project, c, K, and NOPAT is the same for every period.

$$\mathrm{MVA_{HR}} = \sum_{t=1}^{T} \frac{\mathrm{NOPAT_{HR}} - c_{\mathrm{HR}} \cdot K_{\mathrm{HR}}}{(1 + c_{\mathrm{HR}})^t} \tag{13}$$

$$\mathrm{MVA_{LR}} = \sum_{t=1}^{T} \frac{\mathrm{NOPAT_{LR}} - c_{\mathrm{LR}} \cdot K_{\mathrm{LR}}}{(1 + c_{\mathrm{LR}})^t} \tag{14}$$

If $\mathrm{MVA_{HR}} = \mathrm{MVA_{LT}}$ and $K_{HR} > K_{LR}$, then either $\mathrm{NOPAT_{HR}} > \mathrm{NOPAT_{LR}}$ or $c_{HR} > c_{LR}$. In this case, all else equal, a similar fall in c increases $\mathrm{MVA_{HR}}$ more than $\mathrm{MVA_{LR}}$ because $K_{HR} > K_{LR}$. Namely, a larger the project (in terms of K) has a larger convexity, meaning that larger financial capital projects MVA is more sensitive to changes in the discount rate. The two conflated terms, 'average period of production' and 'capital size' can be separated thanks to how EVA separates the cash-flow components. Note that this particular case of two projects with equal MVA and D but different convexity when K is different can easily be shown using EVA, but remains concealed in the traditional FCF approach because this methodology does not explicitly show the value of K in the cash flows. It should be noted, however, that the value of K is a market valuation of expected cash-flow, a valuation that is not independent of the resource-time that took place in the past.

A simple numerical example can illustrate this effect. Assume two projects that produce a positive EVA for ten periods, after which no more economic profits are earned—EVA is 0 after period 10. Assume also that $K_{HR} = 400 > K_{LR} = 100$ for each period; that $c_{HR} = c_{LR} = 10$ per cent. Then, it follows that with $\mathrm{ROIC_{HR}} = 12.5$ per cent and $\mathrm{ROIC_{LR}} = 20$ per cent both projects have the same MVA of \$61. Figure 2 shows a reduction in c (going from right to left on the horizontal axis) that results in $\mathrm{MVA_{HR}}$ growing faster than $\mathrm{MVA_{LR}}$.

3.4. *Capital Goods versus Capital Value*

It should be clear from this that capital value and capital goods, as usually understood, refer to different phenomena. Capital goods refer to durable production items of many shapes and varieties. What makes them valuable are the valuable uses to which they can be put. In an important sense they represent a kind of embodied production 'knowledge' (Baetjer, 2000; Lewin & Baetjer, 2011). When used appropriately in combination they facilitate the transformation of inputs into valuable outputs for sale. In an intuitive sense they represent an increase in the average

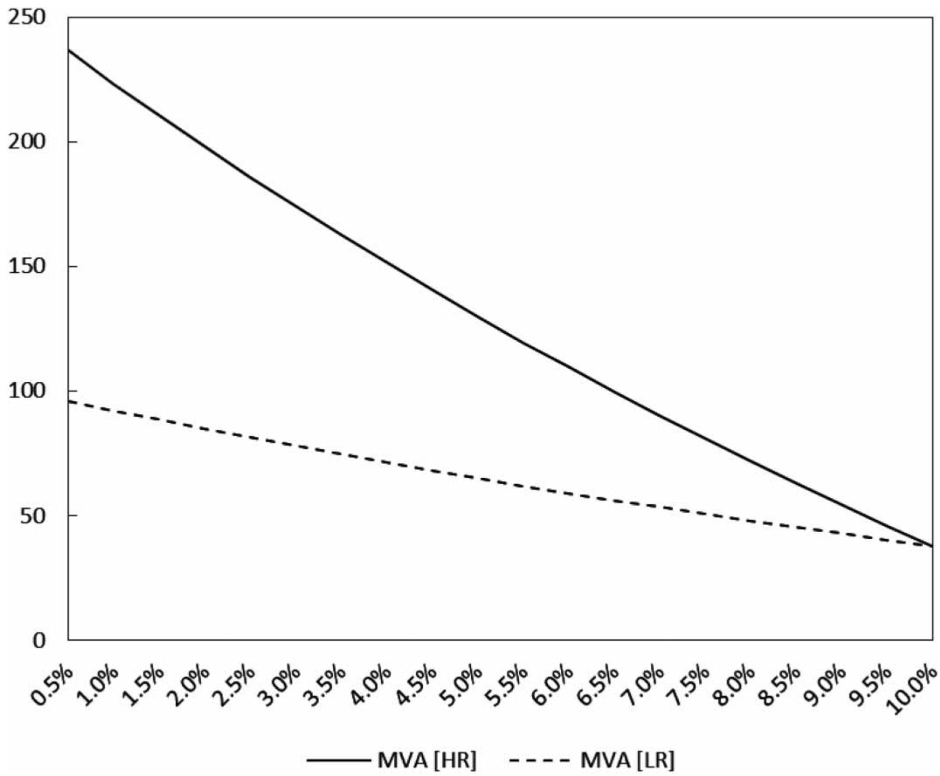

Figure 2. MVA sensitivity of two projects with different financial capital size.
Source: Authors own calculations. See Appendix C

period of production in that they are produced means of production that add, and therefore lengthens, the supply chain. But, by themselves, they do not represent an indication of the time taken until the emergence of the product. To try to capture this, Böhm-Bawerk (and later Hayek) used a device of imagining the application of resources per period of time and then tried to reduce the magnitude of time involved to amounts of resource units—like labor hours—required to produce the product, including those necessary to produce the produced means of production. As discussed, this approach contains irresolvable problems and, more importantly, does not allow one to capture the idea of 'capital-intensity' relevant to the interest rate sensitivity of different projects.

In this context, the idea of capital is about the relationship between value and time regardless of the physical form of the resources embodied in any project. Indeed, human-capital value is on a par with physical capital. A project that uses \$100 to acquire only capital goods and a project that uses \$100 to acquire \$50 in capital goods and \$50 in labor have the same 'capital value' of \$100. In financial terms, both projects have the same financial capital size as would appear in the EVA representation. Time and capital are related insofar as the different projects with the same financial capital and market value of a project may have different durations—implying that said capital values will respond differently to changes in interest rates. Projects that receive their returns 'later' rather than 'earlier' will be more sensitive, and in this sense they are more capital intensive—their value accumulates over a 'longer' period of time.

4. Concluding Remarks

The evolution of capital theory has been plagued by obscure terminology and intense controversy. Business-cycle theories, such as the Austrian theory, that make use of capital theory, have also seemed obscure and controversial. Despite these terminological shortcomings, different scholars have found in the Austrian theory a value-added explanation of business cycles and certainly of the two largest crises of the last hundred years, the Great Depression and the Great Recession. This paper contributes to a needed clarification of key concepts of capital theory (roundaboutness and average period of production) in the context of the Austrian business-cycle theory.

The different notions of duration, explained in this paper, shed light on these concepts. Menger's and Böhm-Bawerk's insights into capital theory and the Mises–Hayek business-cycle theory that builds on it can be interpreted using well-known financial principles. Put differently, the replacement of 'roundaboutness' for modified duration neither adds to nor subtracts anything from the substance of the Mises–Hayek business-cycle theory, but adds to its plausibility. Certainly, the significance of a clear representation of aspects of capital theory goes beyond this particular business-cycle theory. The approach we offer in this paper opens the door to further research. How does risk play a role in this framework and what role does it plays in the allocation of resources under different monetary policies? Even if expectations are not observable, what can empirical research show about monetary policy affecting activities with different interest rate sensitivity? And, even if the Böhm-Bawerk–Hayek representation of roundaboutness was developed before the notions of financial duration, one may wonder why this connection has not been noticed earlier?

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Appendix A. From FCF to EVA

The value of the business or project can be written as V.

$$V = \sum_{t=0}^{\infty} \frac{\mathrm{FCF}_t}{(1+c)^t} \tag{A1}$$

$$V = \sum_{t=0}^{\infty} \frac{K_t}{(1+c)^t} - \sum_{t=0}^{\infty} \frac{K_t}{(1+c)^t} + \sum_{t=0}^{\infty} \frac{\mathrm{FCF}_t}{(1+c)^t} \tag{A2}$$

$$V = K_0 + \sum_{t=1}^{\infty} \frac{K_t}{(1+c)^t} - \sum_{t=1}^{\infty} \frac{K_{t-1}}{(1+c)^{t-1}} + \sum_{t=1}^{\infty} \frac{\mathrm{FCF}_t}{(1+c)^t} \tag{A3}$$

$$V = K_0 + \sum_{t=1}^{\infty} \frac{K_t}{(1+c)^t} - \sum_{t=1}^{\infty} \frac{(1+c)K_{t-1}}{(1+c)^t} + \sum_{t=1}^{\infty} \frac{\mathrm{NOPAT}_t - \mathrm{NI}_t}{(1+c)^t} \tag{A4}$$

$$V = K_0 + \sum_{t=1}^{\infty} \frac{K_t - (1+c)K_{t-1} + \mathrm{NOPAT}_t - K_t + K_{t-1}}{(1+c)^t} \tag{A5}$$

$$V = K_0 + \sum_{t=1}^{\infty} \frac{K_t - K_{t-1} - cK_{t-1} + \mathrm{NOPAT}_t - K_t + K_{t-1}}{(1+c)^t} \tag{A6}$$

$$V = K_0 + \sum_{t=1}^{\infty} \frac{\mathrm{NOPAT}_t - cK_{t-1}}{(1+c)^t} = K_0 + \sum_{t=1}^{\infty} \frac{(NOPAT_t/K_{t-1})K_{t-1} - cK_{t-1}}{(1+c)^t} \tag{A7}$$

$$V = K_0 + \sum_{t=1}^{\infty} \frac{(\mathrm{ROIC}_t - c)K_{t-1}}{(1+c)^t} = K_0 + \sum_{t=1}^{\infty} \frac{\mathrm{EVA}_t}{(1+c)^t} \tag{A8}$$

Appendix B. Macaulay Duration Derivation for Two Projects with Equal MVA but Different *T*

It can be shown that if two projects have the same MVA, the same K, and the same c, $\forall t$, the project with the longer time horizon (higher roundaboutness, HR—compared with the one with lower roundaboutness, LR) has the higher Macaulay duration D.

We assume that $\mathrm{MVA_{HR}} = \mathrm{MVA_{LR}} = \mathrm{MVA}$ and that, $\mathrm{EVA}_{\mathrm{HR},t} = \mathrm{EVA_{HR}}$, $\forall t$; $\mathrm{EVA}_{\mathrm{LR},t} = \mathrm{EVA_{LR}} \forall t$. This implies $\mathrm{EVA_{HR}} < \mathrm{EVA_{LR}}$Consider the relationship between D for the HR project, D_{HR}, and D for the LR project, D_{LR},

$$D_{\mathrm{HR}} = \frac{\sum_{t=1}^{T_{\mathrm{HR}}} (\mathrm{EVA_{HR}} \cdot t)/(1+c)^t}{\sum_{t=1}^{T_{\mathrm{HR}}} (\mathrm{EVA_{HR}})/(1+c)^t} \text{ and } D_{\mathrm{LR}} = \frac{\sum_{t=1}^{T_{\mathrm{LR}}} (\mathrm{EVA_{LR}} \cdot t)/(1+c)^t}{\sum_{t=1}^{T_{LR}} (EVA_{LR})/(1+c)^t} \quad \text{(B1)}$$

$$\text{Let } f_t = \frac{1}{(1+c)^t}$$

then

$$D_{\mathrm{HR}} = \frac{\mathrm{EVA_{HR}}}{\mathrm{EVA_{HR}}} \cdot \frac{\sum_{t=1}^{T_{HR}} t/(1+c)^t}{\sum_{t=1}^{T_{HR}} 1/(1+c)^t} = \frac{\sum_{t=1}^{T_{\mathrm{HR}}} t \cdot f_t}{\sum_{t=1}^{T_{\mathrm{HR}}} d_t} \quad \text{(B2)}$$

$$D_{LR} = \frac{\mathrm{EVA_{LR}}}{\mathrm{EVA_{LR}}} \cdot \frac{\sum_{t=1}^{T_{\mathrm{LR}}} t/(1+c)^t}{\sum_{t=1}^{T_{\mathrm{LR}}} 1/(1+c)^t} = \frac{\sum_{t=1}^{T_{\mathrm{LR}}} t \cdot f_t}{\sum_{t=1}^{T_{\mathrm{LR}}} f_t} \quad \text{(B3)}$$

from which,

$$D_{\mathrm{HR}} = D_{\mathrm{LR}} + \frac{\sum_{t=T_{\mathrm{LR}}+1}^{T_{\mathrm{HR}}} t \cdot f_t}{\sum_{t=T_{\mathrm{LR}}+1}^{T_{\mathrm{HR}}} f_t} > D_{\mathrm{LR}} = \frac{\sum_{t=1}^{T_{\mathrm{LR}}} t \cdot f_t}{\sum_{t=1}^{T_{\mathrm{LR}}} f_t} \quad \text{(B4)}$$

Appendix C. MVA sensitivity of two projects with different financial capital size

Table C1

	ROIC = 12.5%			K = 400			ROIC = 20.0%			K = 100			
		Periods						Periods					
c (%)	MVA [HR]	1	2	3	4	5	MVA [LR]	1	2	3	4	5	$\frac{\text{MVA[HR]}}{\text{MVA[LR]}}$
10.0	38	10	10	10	10	10	38	10	10	10	10	10	1.00
9.5	46	12	12	12	12	12	40	11	11	11	11	11	1.14
9.0	54	14	14	14	14	14	43	11	11	11	11	11	1.27
8.5	63	16	16	16	16	16	45	12	12	12	12	12	1.39
8.0	72	18	18	18	18	18	48	12	12	12	12	12	1.50
7.5	81	20	20	20	20	20	51	13	13	13	13	13	1.60
7.0	90	22	22	22	22	22	53	13	13	13	13	13	1.69
6.5	100	24	24	24	24	24	56	14	14	14	14	14	1.78
6.0	110	26	26	26	26	26	59	14	14	14	14	14	1.86
5.5	120	28	28	28	28	28	62	15	15	15	15	15	1.93
5.0	130	30	30	30	30	30	65	15	15	15	15	15	2.00
4.5	140	32	32	32	32	32	68	16	16	16	16	16	2.06
4.0	151	34	34	34	34	34	71	16	16	16	16	16	2.13
3.5	163	36	36	36	36	36	74	17	17	17	17	17	2.18
3.0	174	38	38	38	38	38	78	17	17	17	17	17	2.24
2.5	186	40	40	40	40	40	81	18	18	18	18	18	2.29
2.0	198	42	42	42	42	42	85	18	18	18	18	18	2.33
1.5	210	44	44	44	44	44	88	19	19	19	19	19	2.38
1.0	223	46	46	46	46	46	92	19	19	19	19	19	2.42
0.5	236	48	48	48	48	48	96	20	20	20	20	20	2.46