Studies in Austrian Macroeconomics

Financial Foundations of Austrian Business Cycle Theory

Nicolás Cachanosky Peter Lewin

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ABSTRACT

In this paper, we study financial foundations of Austrian business cycle theory (ABCT). By doing this, we (1) clarify ambiguous and controversial concepts like roundaboutness and average period of production, (2) we show that the ABCT has strong financial foundations (consistent with its microeconomic foundations), and (3) we offer examples of how to use the flexibility of this approach to apply ABCT to different contexts and scenarios.

Keywords: Macaulay duration; modified duration; Austrian business cycles; average period of production; roundaboutness; economic value added, EVA®

JEL classifications: B53; E23; E30

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INTRODUCTION

It may be of interest to note that the advent of the financial crisis in 2008 and the Great Recession that has followed has triggered a renewed interest in the Austrian Business Cycle Theory (ABCT). Different scholars have either directly or indirectly referred to the ABCT to explain the 2008 crisis (Borio & Disyatat, 2011; Calvo, 2013; Diamond & Rajan, 2009; Hume & Sentance, 2009; Lal, 2010; Leijonhufvud, 2009; Meltzer, 2009; Schwartz, 2009; Taylor, 2009).[1] This came from the conviction that the recovery from the dot.com bust had been based on artificial foundations; that deep-seated structural characteristics were still in need of correction; that such adjustments were always costly and painful; and that the longer the necessary adjustments were delayed, the more painful and costly they would be. Economic activities in certain sectors had become unsustainable – most obviously the housing sector – and sooner or later would crash. It is not a new story.

This shared intuition has its foundation in the Austrian approach to the business cycle, which, in all of its versions, emphasizes the dangers of the misalignment of the structure of production brought about by bad monetary and credit policy. For this reason, ABCT is once again a topic of discussion in the press and among academics. In this paper, we reconsider a central concept in ABCT, namely, the notion of "roundaboutness" or the "average period of production" (APP) and show it contains more useful insights than heretofore revealed. The effect of monetary policy on APP is the distinctive aspect of the ABCT. But this is also the most controversial and confusing aspect of ABCT. The financial approach we propose brings clarity to this controversy at the same time it builds the financial-microeconomic foundations of ABCT.

In the following section, we consider the reasons for such a reexamination of roundaboutness and APP in relation to a growing recent theoretical and empirical literature. In the next section, we relate roundaboutness and APP to the concept of duration and related concepts. In the next two sections, we apply this to the ABCT providing a number of different specific applications with simulated illustrations and extensions to macroeconomic distribution effects, risk, and international contexts. We then conclude.

WHY A FINANCIAL APPLICATION TO THE ABCT?

Before getting into an analysis of the financial foundations of ABCT, we should comment on why we think this is important. There are mainly two related reasons. The first one is that, since Garrison's (2001 [2002]) *Time and Money*, most empirical and theoretical work on the theory has been constructed following his model. While this model is a clear and certainly a fruitful pedagogical tool to capture the core insights of the ABCT, it also imposes constraints and challenges to its further development.

Theoretical contributions are constrained by the assumptions of the model and, when it is a graphic model, by the fact that its development is limited to three dimensions (currently there is no mathematical development of Garrison's model that allows greater flexibility on this matter). Developing theoretical insights using this model can easily become too complicated to handle. The enhancements to the theory can be hard to understand and interpret.[2]

No less problematic are the constraints imposed on empirical work. Garrison's model makes use of the stages of production construct depicted in Hayek's triangle. This simple assumption is more problematic than its depiction suggests. A stage of production is an abstract tool (used to study capital theory).[3] Constructing a Hayekian triangle requires a set of subjective assumptions about how to identify separate stages of production given the available data; this means that a different set of stages of production can represent the same triangle. For instance, one or more economic activity can be present in different stages at the same time, like energy or financial services which are present along the whole production process. What should be the relative position of industries like these two? Second, there is the phenomenon of "looping," which is the problem that arises when two different industries supply inputs to each other. For example, the energy industry and the banking industry are suppliers to each other of their services. Which industry should precede the other as a stage of production? Third, it is possible that an industry identified as being at a particular stage of production may change its relative position over the course of a business cycle.[4] Fourth, Luther and Cohen (2014) argue that a stage of production can grow not only vertically (increase in value added) but also horizontally and this can significantly affect how the effects in the structure of production are interpreted if vertical changes are the only modification assumed to take place. The simplicity embedded in Hayek's triangle cannot be translated into the complexity of reality without facing nontrivial challenges.

Most contemporary empirical work, because it is inspired by Garrison's model, locates different industries in different stages of production and investigates whether the predicted behavior can be seen in the data (Lester & Wolff, 2013; Luther & Cohen, 2014; Mulligan, 2002; Powell, 2002; Young, 2005). As should be clear, this line of work requires a serious set of assumptions. An exception is Young (2012a, 2012b), who looks at the size of the triangle (roundaboutness) of different industries, rather than locating industries in different stages of production. There are a few other exceptions in the contemporary literature that instead of looking at Hayekian triangles look at the *interest rate sensitivity* of different sectors (Cachanosky, 2015; Cachanosky & Salter, 2016; Koppl, 2014).[5]

The second reason for studying the financial foundations of the ABCT is related to the reality of its microeconomic foundations. Austrians emphasize the role of "economic calculation" and the "realism" of their assumptions. If Austrians are right, then the ABCT should be able to fit into how entrepreneurs and investors *actually* make decisions, rather than building a model (Garrison's or otherwise) populated by economic agents who behave *as if* they lived in such a model. Because finance is economic calculation in practice, to study the financial foundations of the ABCT is also to study the soundness of the theory.

Succinctly, the ABCT should not be understood as Garrison's model, but Garrison's model should be understood as one of the many possible representations of ABCT. What we put forward in this paper is a rather new way of thinking about the ABCT that is free of the limitations of Garrison's model and also offers more realistic and solid microeconomic foundations. By doing this, we bring not only clarity and financial foundations to the ABCT as a whole, we also clarify ambiguities and difficulties associated with the concept of *roundaboutness* or *APP*.

ROUNDABOUTNESS AS FINANCIAL DURATION

The application of financial theory to capital theory is a project with much promise in terms of discovering new and valuable insights. We cannot explore this at length here. It is enough for this paper to focus on the relationship between *roundaboutness* or *APP* and the different notions of duration.[6]

Roundaboutness and APP: Böhm-Bawerk, Hayek, and Hicks

Eugene von Böhm-Bawerk (building on the work of Menger (1871 [2004])) attempted to capture the relationship between value and time in the concept of roundaboutness (indirectness). More indirect productive processes (taking more time) result in more (or better) consumer goods. Think of the message of the turnpike theorem – the longer way turns out to be "shorter." Although it takes time to build a fishing net, having done so, one will most likely catch much more fish with the same effort. Time wisely invested today results in significant time savings tomorrow due to the ability to produce more "quickly." The higher productivity results from the use of more (complex) productive methods involving means of production that are themselves the result of prior production ("produced means of production") known as capital-goods. Böhm-Bawerk's idea (1884 [1890]) of measuring average time as the APP 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 APP 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 T 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 in time from the emergence of the 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 (or other identifiable, measurable resource) inputs occur) to the total amount of labor invested N.

The first thing to notice is that APP should not be confused with a measure of pure-time. APP is a measure of input-resource-time. In an agricultural process, in which workers work the land with hand-driven plows, two workers working for three days may produce the same output as three workers working for two days, even though the latter process takes "less time."[7] The nature and size of the output of a whole economy depends, then, on the number and distribution over time of labor-units and capital-goods. This is the *time structure of production*. This is the intuition of the APP. It is not only *what* is being produced (like being at the right point of a production possibilities frontier) but also *how* it is being produced that is important.

Hayek (1931 [1967], 1941 [2007]) uses a triangle to represent this intuition where the APP is half-way along the base of the triangle.[8] Hayek's triangle puts together the APP and the stages of production. He presents a simple supply-chain model where each stage of production sells its output as input to the next stage of production until consumption is reached at the end of the process. 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 (Fig. 1). The height at the end of each stage shows the value added up to that point in the production process.

The horizontal axis measures roundaboutness and therefore is a measure of value-time, not of pure-time. The assumption is that inputs are applied uniformly over time. If the inputs were not applied uniformly, the graphical simplification would not suffice.

Hayek's construct improves on Böhm-Bawerk's by using a value measure rather than a physical measure (labor). By doing this, he comes closer to the Macaulay-Hicks formulation discussed later. In fact, it can be argued that Hayek's triangle is a special case of Macaulay-Hicks duration (more on this later). Despite carrying some of the pitfalls of Böhm-Bawerk's representation, Hayek's triangle is very intuitive and useful as an expository device. It shows that time-preference (and therefore savings) is what defines the degree of roundaboutness (i.e., number of stages of production in this case) that can be sustained (with a given level of technology). A reduction in the magnitude of consumers' time-preferences at the margin (the reluctance to postpone consumption and increase saving) allows stages of production to be added thus increasing the accumulated value added at the end of the triangle (once the economy grows as the capital stock increases). In other words, the increase in savings allows the move toward a more capital-intensive structure of production with a higher payoff at the end of the process. The interest rate, which is the slope of the Hayekian

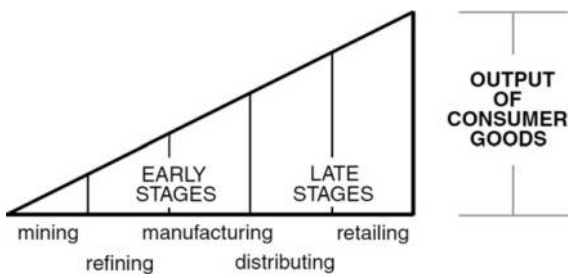

Fig. 1. Hayekian Triangle. *Source*: Garrison (2001 [2002], p. 47).

triangle, represents the opportunity cost or minimum value added required by each stage of production to be profitable. Since the base of the triangle has a time-related meaning (value-time), the slope of the triangle invites the interpreted that it is the discount rate of each stage of production. In other words, the hypotenuse of Hayek's triangle being linear (and not geometric) implies *simple* rather than *compound* interest (explained further later). It is easy to see how Hayek's representation has a more financial flavor than Böhm-Bawerk's.

An early contribution to the concept of APP to which the Austrian literature has paid little or no attention was the one by John Hicks who reformulated Böhm-Bawerk's APP in a more satisfactory manner. He realizes that the APP cannot be measured in physical terms. Böhm-Bawerk's attempt to do so in fact contradicts the essential insight of the Austrian School of Economics, namely, that the *value* of any resource-input depends always only on the *value* of the output that it (in combination with other inputs) is expected to produce. Trying to characterize a production process without recourse to the concept of input-value faces inescapable problems. Hicks much admired the work of the Austrians including the profound capital theory of Böhm-Bawerk, and sought in *Value and Capital* to clarify and rehabilitate the APP as a defensible and revealing value construct rather than a physical one.

Hicks's formulation (1939, p. 186) proceeds as follows: The market value added (MVA)[9] of any stream of T payments (cash flows) is given by

$$\mathrm{MVA}(T) = \sum_{t=1}^{T} \frac{\mathrm{CF}_t}{(1 + c_t)^t} = \sum_{t=1}^{T} f_t \mathrm{CF}_t \tag{2}$$

where CF_t are the future income payments expected by the investor, the 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 MVA with respect to the f_t as

$$\begin{aligned} E_{\mathrm{MVA}, f_t} &= \frac{E(\mathrm{MVA}(T))}{E(f_t)} \\ &= \frac{1}{\mathrm{MVA}(T)} [f_1 \mathrm{CF}_1 \cdot 1 + f_2 \mathrm{CF}_2 \cdot 2 + \cdots + f_T \mathrm{CF}_T \cdot T] \end{aligned} \tag{3}$$

or

$$E_{\text{MVA},f_t} = \frac{\sum_{t=1}^{T} f_t \text{CF}_t \cdot t}{\text{MVA}(T)} \tag{4}$$

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_{MVA,f_t} turns out to have a number of interesting interpretations.

Firstly, and obviously, E_{MVA,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.[10] So, if the discount rate is affected by interest rates targeted by monetary policy the *relative valuations* of the components of the productive capital-structure will be unevenly affected by monetary policy unless the heroic assumption of equal elasticity for all sectors is assumed. Those components of existing production processes that have a higher E_{MVA,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 [AP]* 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, italics 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.[11] The APP correctly understood is the discount-factor elasticity of capital value. Hicks's AP is identical to the concept discovered by Macaulay, known as Macaulay's duration, in 1938, to which we now turn.

Roundaboutness and Duration

There are three characteristics to take into consideration about roundaboutness: (1) the APP, (2) capital intensity, and (3) that investment is forward looking, not backward looking. We can use modern corporate finance to extend Hicks's AP to roundaboutness and, therefore, to the ABCT as well. In doing this, there are three relevant related concepts we need to present: Macaulay duration (D), modified duration (MD), and convexity (C).

Let NOPAT be net operating profits after taxes, let c be the weighted average cost of capital (WACC), and let K be the financial invested capital. The return over invested capital (ROIC) is NOPAT/K. Let the economic value added (EVA) be the difference between ROIC and WACC times the invested capital; EVA = (ROIC − c)K (cK is the per-period opportunity cost of any capital to be invested). Then, the value of a firm can be divided between the capital *already* owned plus the expected MVA which is the present value of future EVAs.[12] As we will show later, the EVA® framework provides more insights than the FCF approach; insights that are also aligned to the Austrian theory of capital and business cycles. Therefore, the MVA of a project is the present value of the expected stream of future EVAs for T periods.

$$\begin{aligned}\text{MVA} &= \sum_{t=1}^{T} \frac{\text{NOPAT}_t - c_t \cdot K_{t-1}}{(1+c_t)^t} = \sum_{t=1}^{T} \frac{(\text{ROIC}_t - c_t)K_{t-1}}{(1+c_t)^t} \\ \text{MVA} &= \sum_{t=1}^{T} \frac{\text{EVA}_t}{(1+c_t)^t}\end{aligned} \tag{5}$$

If there is a cash flow, then it follows that there is D associated to this cash flow. D can be represented as follows:[13]

$$D = \frac{\sum_{t=1}^{T} \frac{(\text{ROIC}_t - c_t)K_{t-1} \cdot \mathbf{t}}{(1+c_t)^t}}{\text{MVA}} = \frac{\sum_{t=1}^{T} \frac{\text{EVA}_t \cdot \mathbf{t}}{(1+c_t)^t}}{\text{MVA}} \tag{6}$$

Note that this representation has the three desired characteristics of roundaboutness mentioned above. It is directly related to time (t), it has an explicit measure of (financial) capital intensity (K), and is forward looking ($T > t = 1$). Note that the FCF methodology does not provide a measure of invested capital, a variable of particular interest within the Austrian theory. It should also be easier to see now that Hayek's triangle is an approximation to a particular (simple) case of D where there is a constant cash flow and interest is not compounded.[14]

MD (modified duration) and D are closely related to each other. D, besides being an APP, is also a linear approximation of the sensitivity of the price of the bond to changes in the yield-to-maturity (YTM), where YTM is the rate at which the bond is valued at par. MD is measured as the percent change in the price of the bond when YTM changes by one unit.

MD is, then, the semi-elasticity of the MVA with respect to YTM. MD and its relation to D can be represented by the following expression:

$$\text{MD} = \frac{\text{d log MVA}}{\text{dYTM}} = -\frac{D(\text{YTM})}{1 + \text{YTM}} \tag{7}$$

where D(YTM) is the duration of the investment evaluated at the yield to maturity. Thus, in general, while D is a measure of the APP, MD is the semi-elasticity of MVA with respect to the discount rate. This present value sensitivity to the discount rate is also a distinctive aspect of the ABCT. D and MD are closely related. In continuous (rather than in discrete time) time $\text{MD} = -\frac{D(\text{YTM})}{1+\frac{\text{YTM}}{n}}$, where $n \to \infty$ and therefore $\text{MD} = -D$. Namely, projects that involve a higher APP are also more sensitive to movements in the discount rate as the ABCT requires.[15]

The Hicks-Macaulay duration, however, is developed for (infinitesimally) small changes. In the face of discernible discrete interest rate changes, they do not yield an exact measure of the responsive change in MVA. The reason is that D as a measure of elasticity depends on the time value of money (something uncharacteristic for an elasticity measure.) D itself will change with the discount rate (as should be obvious since the formula contains present values). This is a "second-order" effect of a change in the discount rate that can be ignored only for small changes. One must then add in this second-order effect. This phenomenon is known as the "convexity" of the asset in question.

A cash flow with a larger C has a price (present value) that changes at a higher rate when there is a change in the YTM than a cash flow with a lower convexity. What is important to note with regard to the ABCT is that cash flows with a larger D (or MD) also have a larger C. This means that the more roundabout a project is, the more rapidly its associated MVA changes, reinforcing the effects described by the ABCT.[16] This is a point, which is not usually mentioned in the ABCT literature, and which becomes clear when exploring the financial foundations of ABCT.

A FINANCIAL APPLICATION TO THE ABCT

ABCT in General

Project Rankings are Affected by Changes in the Discount Rate

The distinctive aspect of ABCT in general is the effect of expansionary monetary policy (channeled through the financial markets) on the aggregate or average roundaboutness of the economy. Succinctly, starting from equilibrium, monetary policy that lowers interest rates provides an incentive in the market to increase the degree of roundaboutness beyond the point of sustainability. Because the central bank cannot keep interest rates low indefinitely, the increase in interest rates back to equilibrium levels makes the apparent profits of long-run and capital-intensive projects disappear revealing that they were not as profitable as had been assumed. The increase in the aggregate roundaboutness is the boom; the costly reallocation of resources back toward the "equilibrium level of roundaboutness" is the bust. The ABCT thus focuses on the effect of a change in the relative price of time (interest rates) with respect to the price of goods and services. This has a straightforward financial representation.

Consider the following two simple simulations. Assume first three potential investment projects. All three require the same capital investment of \$100. The first one is a *low roundabout* (LR) project that lasts for 5 years. The second is a *medium roundabout* (MR) project that lasts 10 years. The third one is the *high roundabout* (HR) project and lasts for 20 years. After maturity, the projects do not yield economic profits anymore and so the EVA equals zero. The ROIC for each project is 26%, 20%, and 17%, respectively. We assume constant discount rates and invested capital across time and projects:

$$\begin{aligned}
\mathrm{MVA}_{\mathrm{LR}} &= \sum_{t=1}^{T=5} \frac{(\mathrm{ROIC}_{\mathrm{LR}} - c)K}{(1+c)^t} = \sum_{t=1}^{T=5} \frac{(26\% - c)100}{(1+c)^t} \\
\mathrm{MVA}_{\mathrm{MR}} &= \sum_{t=1}^{T=10} \frac{(\mathrm{ROIC}_{\mathrm{MR}} - c)K}{(1+c)^t} = \sum_{t=1}^{T=10} \frac{(20\% - c)100}{(1+c)^t} \qquad (8) \\
\mathrm{MVA}_{\mathrm{HR}} &= \sum_{t=1}^{T=20} \frac{(\mathrm{ROIC}_{\mathrm{HR}} - c)K}{(1+c)^t} = \sum_{t=1}^{T=20} \frac{(15\% - c)100}{(1+c)^t}
\end{aligned}$$

Fig. 2 shows the MVA of each project at an initial discount rate of 10% (color black) next to the present value of the same projects at a discount rate of 6% (in gray). There are three important things to note about this scenario. First, as expected, the MVA of all three projects rise. Second, and what is the core argument of the ABCT, the relative MVA of higher roundabout projects rise with respect to lower roundabout projects. For instance, the $\frac{\mathrm{MVA}_{\mathrm{MR}}}{\mathrm{MVA}_{\mathrm{LR}}}$ ratio goes from 1 to 1.26. This means that the entrepreneur will prefer to invest in the MR project over the LR (assuming any increase in perceived risk is low enough). Third, this example also shows that not only

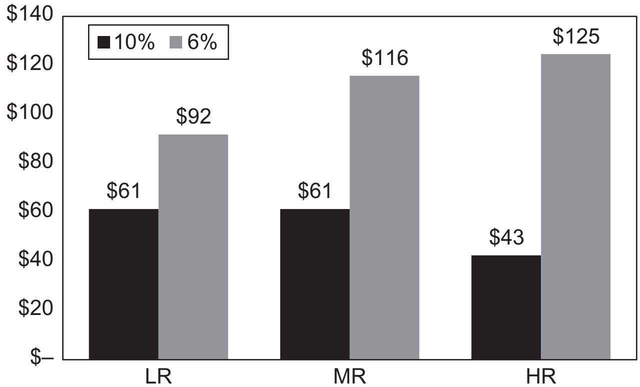

Fig. 2. Discount Rates Effects on the Present Value of LR, MR, and HR Projects by Different *t*. *Note*: Time horizons: $T_{LR} = 5, T_{MR} = 10, T_{HR} = 20$.

does the relative MVA change, but that the MVA ranking of the projects in the investor portfolio can change as well. When the discount rate is 10%, the HR project ranks behind the LR and MR projects, but at a discount rate of 6% the HR project climbs to the top of the ranking of the three projects.

Note one more important point. Even if for simplicity we have used a constant discount rate c, it should be obvious that the EVAs could be discounted at different discount rates (interpolated) from a yield curve. Austrians usually tie ABCT, which requires movements in the long-run interest rates (used for discounting long cash flows) to short-term interest rates (i.e., the Fed funds rate) as affected by monetary policy. Some critics rightly point to the fact that is not short, but long-run rates what would be affected. These critics are usually skeptical that the Fed is able to affect long-run interest rates. ABCT thus implicitly assumes parallel shifts of the yield curve. The approach we propose here, because it uses cash flows rather than macroeconomic aggregates, allows for different possible patterns of change in discount rates: from a constant c, to parallel shifts, or to change in the slope of the yield curve as well.

Certainly different scenarios can be built. We show in the above figure only one for the sake of brevity. Consider the case, for instance, where the HR project has a negative present value at the equilibrium interest rate but becomes profitable and raises in the ranking at a lower interest rate. This means that once the central bank revises its low interest rate policy, the project is not just less profitable than expected, but unprofitable. The need to reallocate resources that where locked-down in these unprofitable projects is more pressing than if the project is still profitable but less than expected.

Framing the ABCT in terms of financial calculations allows for the separation between two effects usually conflated in many ABCT expositions. It is not only that the more *roundabout* projects are more sensitive to changes in the discount rate, but also that the MVA ranking of projects under consideration in any investment portfolio depends on the discount rate. Note, however, that this type of *reswitching* presents no dilemma for the ABCT. The reason why the HR goes from ranking third to ranking first (and second if the interest rates increase from 6% to 10%) is because projects with higher D also have a higher MD (and also a higher C).[17]

Assume now that the difference in *roundaboutness* across projects is not because the time horizon of each project is different, but because K is different in each case. All three projects have a life of 10 years (again, after year 11 the investor assumes normal profits and therefore EVA equals zero). The K for the LR, MR, and HR project is \$100, \$200, and \$500 with a ROIC of 30%, 20%, and 12%, respectively. Then:

$$\begin{aligned}
\text{MVA}_{\text{LR}} &= \sum_{t=1}^{T=10} \frac{(\text{ROIC}_{\text{LR}} - c)K_{\text{LR}}}{(1+c)^t} = \sum_{t=1}^{T=10} \frac{(30\% - c)100}{(1+c)^t} \\
\text{MVA}_{\text{MR}} &= \sum_{t=1}^{T=10} \frac{(\text{ROIC}_{\text{LR}} - c)K_{\text{MR}}}{(1+c)^t} = \sum_{t=1}^{T=10} \frac{(20\% - c)200}{(1+c)^t} \\
\text{MVA}_{\text{HR}} &= \sum_{t=1}^{T=10} \frac{(\text{ROIC}_{\text{LR}} - c)K_{\text{HR}}}{(1+c)^t} = \sum_{t=1}^{T=10} \frac{(12\% - c)500}{(1+c)^t}
\end{aligned} \tag{9}$$

This scenario is shown in Fig. 3. Together with the previous example, these two scenarios allow for separating the two conflated dimensions in the concept of *roundaboutness*: (1) time and (2) capital. In the first scenario, we have three projects that have the same financial-capital intensity and, still, the three of them have different degrees of *roundaboutness*. The second scenario shows three projects with the same time horizon, but with different degrees of roundaboutness due to different financial-capital intensity. In fact, LR and MR have the same D. Thus, two projects with the same APP can have a different degree of roundaboutness. Roundaboutness, then, is neither time nor (financial) capital intensity by itself, but is the combined

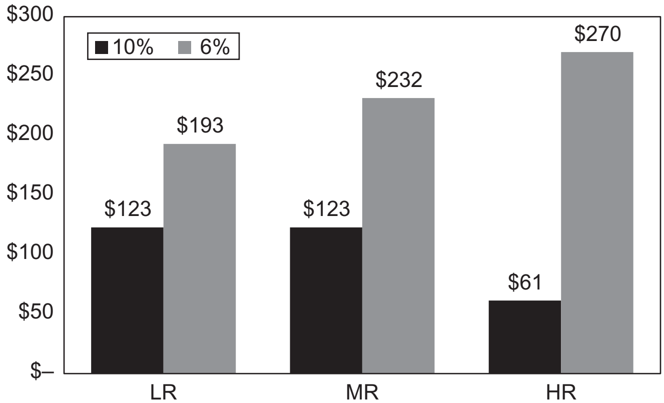

Fig. 3. Discount Rates Effects on the Present Value of LR, MR, and HR Projects Defined by Different K. *Note*: Financial-capital intensity: $K_{\text{LR}} = \$100, K_{\text{MR}} = \$200, K_{\text{HR}} = \$500$.

effect of both dimensions on the expected cash flows and therefore, on D and MD. This is another split that we would be unable to show if instead of using the EVA® literature we had used the standard FCF approach.

To summarize, in the EVA® framework, the ABCT story is captured as a down-up movement of c (opportunity cost) keeping other prices constant. Thus, the change considered is a change in the relative price of time (interest rates) with respect to the prices of final and intermediate goods and services (P). The effect of an increase in the price of factors of production is usually mentioned as a distinctive aspect of the ABCT. This occurs as the EVAs increase and the relative HR investors outbid the LR investors in the market for the factors of production. A decrease in c occurs *before* there is an increase in the price level of final and intermediate goods. This is why for the ABCT it is important that the monetary expansion is channeled as credit through the financial markets (and not, for instance, as government spending which would produce a different set of distortions that are discussed later).

Finally, it might be objected that our proposed scenarios are not ceteris paribus because each project has a different stream of EVAs (even if they are constant in time) rather than facing the same expected EVA at different points in time. However, to assign the same EVA at different points in time would yield different MVAs. To get the same MVA, a different EVA should be assigned to each project at one point in time. In either case, the ceteris paribus fails on the same grounds that our scenarios do. We think, however, that the scenarios we propose are more closely related to investment projects in the real world by considering a stream of EVAs and not only one EVA at a given point in time. Certainly assuming a constant EVA for each project is intended to simplify the scenarios.

Aggregate Roundaboutness

We can now move to the *roundaboutness* of the economy. For simplicity, assume now only two projects, one LR and one HR. The aggregate MVA for this economy is the sum of the cash flows. Assume also the same discount rate c for all periods and both projects.

$$\begin{aligned} \mathrm{MVA} &= \mathrm{MVA}_{\mathrm{LR}} + \mathrm{MVA}_{\mathrm{HR}} \\ \mathrm{MVA} &= \sum_{t=1}^{\infty} \frac{\overbrace{(\mathrm{ROIC}_{\mathrm{LR}} - c)K_{\mathrm{LR}}}^{\mathrm{EVA}_{\mathrm{LR}}} + \overbrace{(\mathrm{ROIC}_{\mathrm{HR}} - c)K_{\mathrm{HR}}}^{\mathrm{EVA}_{\mathrm{HR}}}}{(1+c)^t} \end{aligned} \tag{10}$$

The D of this economy would be a weighted sum of the duration of each project:

$$D = D_{\mathrm{LR}} \cdot \omega_{\mathrm{HR}} + D_{\mathrm{HR}} \cdot \omega_{\mathrm{LR}} \tag{11}$$

where $\omega_j = \frac{\mathrm{MVA}_j}{\mathrm{MVA}}, \quad j = \{\mathrm{LR}, \mathrm{HR}\}$.[18]

When the central bank lowers the discount rate, there are multiple simultaneous effects. First, $\frac{\mathrm{MVA}_{\mathrm{HR}}}{\mathrm{MVA}_{\mathrm{LR}}}$ rises. As capital is reallocated from the LR sector to the HR sector, K_{LR} decreases and K_{HR} increases. This means that the market share of HR projects increase as $\frac{K_{\mathrm{HR}}}{K_{\mathrm{LR}}}$ rises. Therefore, the MVA for this economy increases ("economic boom") since $\mathrm{MVA}_{\mathrm{HR}}$ increases more than $\mathrm{MVA}_{\mathrm{LR}}$ decreases. A way to see this is that $\Delta\mathrm{EVA}_{\mathrm{HR}} > \Delta\mathrm{EVA}_{\mathrm{LR}}$ as capital is reallocated. Also, because more K is being allocated to HR relative to LR, D for the whole economy also increases. The aggregate or average roundaboutness (D) of the whole economy is moving to a level that is not sustainable at the lower discount rates.

The ABCT has been criticized for not passing the rational expectations test. According to the rational expectations assumption, economic agents should not produce systematic mistakes. However, even in the absence of *systematic* mistakes, *mistakes* do matter. A financial framework like the one we propose here helps to show how this critique is misplaced. There are two important reasons.[19]

First, in the ABCT the misallocation of resources does not occur through a representative agent with rational expectations, but through the marginal entrepreneur. The question "how is it possible that otherwise smart entrepreneurs are so easily deceived by the central bank" is misplaced. The question implicitly assumes that all entrepreneurs make the same mistake, but the ABCT does not require such an assumption. Consider two entrepreneurs, one who thinks that the interest rates in the market are too low (savvy entrepreneur), and another one who thinks the low interest rates is a fair representation of the equilibrium conditions (naïve entrepreneur).[20] The naïve entrepreneur is willing to discount the expected EVAs of the projects in his investment portfolio at a lower interest rate facing higher MVA values than the savvy entrepreneurs. This means that the naïve entrepreneurs are not only willing and able to outbid the former entrepreneur in the market of factors of production (this is why ABCT predicts a rise in the price of factors of production), they are also willing to "lock-down" resources in projects with larger D (assuming no significant changes in risk). Thinking about ABCT processes in terms of financial calculations clarifies why it is not the same to err upward or downward with respect to where the equilibrium discount rates are supposed to be. Errors do not cancel out even if the mean of the errors is zero ("rational"). Also, consider that the entrepreneur who mistakenly thinks that the low interest rate is correct sees his error confirmed by the central bank policy. If central banks, which are in charge of making monetary policy, can mistakenly assess their monetary policy, why would an entrepreneur outside the central bank know any better?

Second, expectations are not only about market prices but are crucially about the behavior of "Big Players" in the market as well (Koppl, 2002, 2014). Because Big Players have the power to affect market prices, the entrepreneur needs to predict their future behavior as well. This means that entrepreneurs have a harder time forming the correct expectations, but also that expectations can be on the wrong track with respect to equilibrium prices but be right on the path taken by the Big Player. Note also that in the case of a central bank, a state monopoly that faces no competition, there is no clear market signal or process to signal mistakes until it is too late. But because the entrepreneur who mistakenly thinks that low interest rates are at equilibrium does not know he is wrong, what the central bank does is offer a confirmation bias that gets stronger the longer the Big

Player follows the out-of-equilibrium path (which, in turn, can raise doubts that the savvy entrepreneurs were "right in the first place").

Applied Cases of the ABCT and Variations on a Theme

Callahan and Horwitz (2010) argue that the ABCT is built using (Weberian) *ideal types* and that therefore there are different degrees of abstraction or generality of the theory. In a similar fashion, Garrison (1994, 2001 [2002]) argues that the ABCT allows for "variations on a theme" as the theory is applied to different scenarios. However, going from pure theory to applied theory requires the addition of auxiliary hypotheses (Lakatos), assumed conditions (Machlup), or assumed real-world conditions (Mises).[21] The EVA® framework presents the opportunity to gain precision by allowing one to investigate the conditions of different scenarios. We illustrate this with two examples, a housing bubble and the international effects of monetary policy. Recall first that:

$$\text{MVA} = \sum_{t=1}^{T} \frac{\text{EVA}_t}{(1+c_t)^t} = \sum_{t=1}^{T} \frac{(\text{ROIC}_t - c_t)K_{t-1}}{(1+c_t)^t} = \sum_{t=1}^{T} \frac{\text{NOPAT}_t - c_t K_{t-1}}{(1+c_t)^t} \tag{12}$$

The general ABCT case is the one we discuss in the previous section. Namely, the nonneutral effects of monetary policy on the MVA of projects with different D (due to Hicks's different elasticities, or MDs). This nonneutrality can manifest itself in two ways, by a change in the relative price of the projects but also by a change in the ranking of the projects.

In the case of the housing crises that led to the 2008 subprime crisis, there were particular policies in place to incentivize the acquisition of houses. The increase in the demand for housing should result in a relative increase in the price of houses with respect to other goods (Fig. 4). This means that the EVA of the housing sector increases for two reasons, through a decrease in c and through an increase in the NOPAT. Then, even if the production of houses is not the most *roundabout* activity, it is still possible to apply a variation of the ABCT to this particular case.[22] There is another reason why the housing bubble can still fall into an ABCT story. On the consumption side, housing services are very long term (*roundabout* in consumption).[23] That means that a reduction in

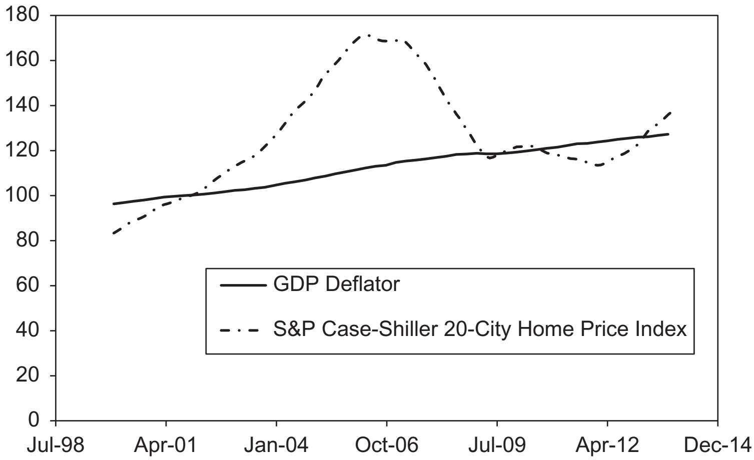

Fig. 4. GDP Deflator and Case-Shiller 20-City Home Price Index (December 2010 = 100).

mortgage rates will have a relatively large impact on the demand for housing, which would translate into a relatively large increase in the NOPAT in the calculations of the real estate producers. Housing is a relatively interest-sensitive sector of the economy. Because Garrison's model does not show the consumption triangle, this aspect of the theory is sometimes overlooked.[24]

Consider now the case of the international effects of monetary policy, in particular on the tradable and non-tradable sectors. The canonical version of the ABCT implicitly models a closed economy by assuming an international gold standard regime.[25] In the case of fiat currencies, there are several currencies, not only one for all countries as is the case of the gold standard. The ABCT needs to consider exchange rates if it wants to fit into contemporary monetary institutions. This means that there is a new price in the market, the exchange rate between fiat currencies, and therefore a new potential channel of distortions. Assume now that the MVA of the economy is divided in two sectors, the tradable (TR) and the non-tradable (NTR) sector. The first sector sells its output internationally but the second only domestically. Assume further, that the factors of production in each sector are acquired domestically and that the discount rate is the same for all periods and both sectors. The MVA of this economy can be represented as follows:

$$\text{MVA} = \text{MVA}_{\text{TR}} + \text{MVA}_{\text{NTR}}$$

$$\text{MVA} = \sum_{t=1}^{T} \frac{\dfrac{\overbrace{e_t P_{t,\text{TR}} Q_{t,\text{TR}} - W_{t,\text{TR}} F_{t,\text{TR}}}^{\text{NOPAT}_{\text{TR}}}}{K_{t-1}} - c \cdot K_{t-1}}{(1+c)^t} + \sum_{t=1}^{T} \frac{\dfrac{\overbrace{P_{t,\text{NTR}} Q_{t,\text{NTR}} - W_{t,\text{NTR}} F_{t,\text{NTR}}}^{\text{NOPAT}_{\text{NTR}}}}{K_{t-1}} - c \cdot K_{t-1}}{(1+c)^t} \quad (13)$$

where NOPAT is now income $(P \cdot Q)$ price level times quantity − less the costs of factors of production (W) times the quantity of factors of production (F). The exchange rate is represented by e. We can see now that an economy that expands the money supply through the credit market will produce two immediate effects, not only one. It will reduce c but it will also devalue the currency, increasing the value of e and giving a second source of increase to the MVA of the tradable sector. Therefore, just as the reduction of the c increases the aggregate D (roundaboutness) of this economy, in parallel there is a reallocation of resources from the NTR to the TR. We can construct other scenarios, such as one that considers international effects on exports and imports, (recalling that before the 2008 crisis the United States ran trade deficits).[26]

The financial framework we propose here offers the flexibility implied by "variations on a theme" but also provides specific variables and outcomes through which the variation in the theme has to manifest itself. It is not, then, that the ABCT is unable to capture economic effects that take place in the modern economy, but that the Garrison-Hayek model version of the ABCT (the main guide in contemporary ABCT literature) is not equipped to deal with some of the broader variations.

FURTHER EXTENSIONS TO THE ABCT

The previous section shows how to financially frame some important insights of the ABCT. In this section, we briefly discuss two extensions to the ABCT: the role of monetary nonneutrality on relative prices (Cantillon effects) and the role of risk in the ABCT.

Inflation and Cantillon Effects

Austrians have traditionally emphasized the nonneutral effects on relative prices of changes in money supply. Money neutrality should be understood as an assumption, not as a fact. For money to have neutral effects on relative prices (in the long run), the determinants of equilibrium (preferences, endowments, technology, etc.) must remain unchanged during the transition. Should any equilibrium determinant change from what it would have been sans the monetary expansion, the new equilibrium will differ from the previous equilibrium and monetary changes will be nonneutral in the long run. Neutrality is, of course, an assumption, not an undisputable fact. To assume, then, money neutrality could be useful if we want to isolate a theory from these effects. This is, in fact, what the ABCT does. The ABCT focuses on a particular relative price distortion, the reduction of c with respect to P. Cantillon effects, on the contrary, focus on changes in relative prices *inside* P (and W). For the ABCT to unfold, the theory does not need to take into account distortions inside P. The change in c alone, as we shown above, already produces nonneutral effects on the relative values and ranking of different MVAs.

Cantillon effects, however, are very important and can be the source of misallocations of resources. To see these effects in the framework we present here we can adapt the *value drivers* used in corporate finance to the economic problem of Cantillon effects. In the EVA® terminology, prices are captured in the NOPAT, which captures the profits (and losses) of different economic activities (similar to what we did between the NTR and TR sectors). Assume $j = 1 \ldots J$ firms and that each firm produces only one good. The NOPAT of the whole economy is the sum of all j profits (π). To take out the *value drivers* of this economy, we open the NOPAT in all j profits and we multiply and divide by total profits:

$$\text{ROIC} = \frac{\text{NOPAT}}{K} = \frac{\sum_{j=1}^{J} \frac{\pi_j}{\pi}}{K/\pi} = \frac{\pi}{K}\left(\frac{\pi_1}{\pi} + \frac{\pi_2}{\pi} + \cdots + \frac{\pi_J}{\pi}\right) \tag{14}$$

Since for any j firm $\pi_j = p_j q_j - w_j f_j$, it follows that *if* there are Cantillon effects, then the relative profits of each firm with respect total profits will change unevenly signaling different profit opportunities in the aggregated NOPAT. Note two outcomes of this representation. First, this type of misallocation does not require an increase in the aggregate D as is the case of the ABCT. Second, it is (theoretically) possible to have Cantillon effects without an increase in NOPAT and therefore without an increase in ROIC (aggregated EVA for the whole economy remains the same). Think of an increase in government spending financed with an increase in taxes that increases the demand of government acquired goods at the expense of reducing the demand in other markets. It should be clear from this framework, too, that investment decisions depend on relative *returns*, not on the level of consumption or government spending as Keynesian inspired models suggest.

Therefore, through this application of *value drivers*, it is possible to put in the same framework the effects of a low discount rate c plus the Cantillon effects on relative prices.

Roundaboutness and Risk

The subprime crisis brought attention to the fact that ABCT does not explicitly account for risk. A distinctive characteristic of the subprime crisis was the large investments in high risk financial assets. The ABCT should account for risk if it wants to be a competitive theory in explaining contemporary business cycles. It is not, however, that the ABCT does not consider risk *at all*. Because production takes time, the *risk* variable can be considered to be already implicit in the ABCT.

There are many ways risk can manifest itself. Economic activities with more volatile NOPAT are more risky than activities with a more stable NOPAT. Another way to account for risk is to unpack the discount rate c into two components, the natural rate of interest (i_N) and a risk premium (σ_c). If we want to capture the idea that projects with a longer time horizon are more risky than projects with a shorter time horizon because more things can go wrong, then we can express the discount rate as follows:[27]

$$c_t = i_N + \sigma_c \cdot t^{\alpha}, \quad \alpha \in (0,\ 1) \tag{15}$$

This allows some flexibility in how to handle changes in risk. For instance, a change in α has a larger effect on longer cash flows than in shorter cash flows because it changes the slope of the yield curve. A reduction in α makes the yield curve more horizontal, having a larger impact on the present value of later expected cash flows. Then the MVA of any economic activity can be captured by an expression similar to the following:

$$\text{MVA} = \sum_{t=0}^{T} \frac{(\text{ROIC}_t - (i_\text{N} + \sigma_c \cdot t^\alpha)) \cdot K_{t-1}}{(1 + i_\text{N} + \sigma_c \cdot t^\alpha)^t} \tag{16}$$

Let us mention two examples of how this can be used to describe different scenarios. First, a policy that reduces the risk of particular industries will bias upward the MVA of those particular industries (think of the role of Fannie Mae and Freddie Mac). Second, a reduction in the discount rates (due to an expansionary monetary policy) increases the aggregate D and moves the economy to a higher risk exposure. There is, also, an *income effect* through a higher perceived MVA that compensates for the higher risk being taken. It is not, then, that ABCT cannot account for risk. Because ABCT explicitly accounts for time it has already risk built into it. A financial framework, where risk considerations are usual, provides a suitable tool to account for this important variable.[28]

CONCLUDING REMARKS

This paper aims to establish the importance of the financial foundations of business cycle theories within the Austrian approach. Past endeavors have sometimes become embroiled in difficulties associated with ambiguities and indeterminacies connected to the role of time in investment decisions and how they are expressed in the minds of decision-makers and in the model. We hope to have provided a framework that avoids these difficulties and yields additional insights.

More specifically, we show how the concept or roundaboutness loses its mystery when a financial framework is applied. We show that to reject the distinctive thesis of the ABCT implies to reject the mathematics of financial duration. Our proposed approach also shows that the ABCT is consistent with how investors and entrepreneurs actually make decisions. These can be considered the microeconomic foundations of ABCT. Finally, with the aid of a few examples, we depict the flexibility that this approach has to deal with different scenarios and, by doing this, we clarity the effects of relative prices in the ABCT. We regard this exposition as only a beginning. Further theoretical work and, especially empirical work, within this framework, have much to investigate.

NOTES

1. For a review of this literature, see Cachanosky and Salter (2016).

2. For an example, see Young (2012a).

3. See also Hayek (1941 [2007], p. 74): "The term [stage of production], however, can be conveniently used for a grouping of the various kinds of capital goods according to their remoteness from ultimate consumption. In this sense it serves simply as a means of a further and very necessary subdivision beyond the usual rough division of goods into consumers' goods and capital goods […] When in the further course of this discussion the term *stage* is used, it will always be in this abstract sense and will not imply any reference to a division of the process between different firms or persons."

4. For an example of this phenomenon, see Young (2012b).

5. Note that this is a similar approach to that of Robbins (1934 [1971]).

6. We develop in further detail the topic of this section in Cachanosky and Lewin (2014), and Lewin and Cachanosky (forthcoming).

7. The matter would be significantly more complicated if we proposed to include the time taken to produce the plows (capital-goods) that they use. In principle, one could go back all the way to the world in which only "nature" and physical-labor existed. This backward-looking approach means that APP must refer to a situation in which inherited capital-goods are considered part of "nature" as a given endowment. Similarly, problems arise from the realization that labor-inputs may be of different quality, and capital-goods of different incommensurable varieties. The fact that input-resources are not homogeneous is responsible in no small measure for the inherent inapplicability of the APP as formulated by Böhm-Bawerk as well as for the extended capital controversies of the 20th century. See Cohen and Harcourt (2003), Cohen (2008, 2010), Felipe and Fisher (2003), Felipe and McCombie (2014), Kirzner (2010), Lewin (1999 [2011]), Machlup (1935), and Yeager (1976).

8. Consider a special case where the flow of inputs (i.e., units of labor-time) is constant over time. If the same amount of labor-time, l_o, is applied in each period, then, $\sum_{t=0}^{n}(n-t)l_t = \frac{1}{2}n\cdot(n+1)l_0$ and $\sum_{t=0}^{n} l_t = n\cdot l_0$ and therefore $T \approx \frac{n}{2}$. In this simple case, as in Hayek's triangle, each unit is "locked-up" on average for half the length of the production period.

9. Hicks uses the term "capital value." To keep our notation as homogeneous as possible, we use "market value added" instead of capital value.

10. 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

$f_t = f_1 = f_2 = f... = f_n$. For any configuration of rates, there is a constant f_t equivalent (yielding the same total present value). We use this in the text.

11. For a proof, see Hicks (1939, pp. 220–222).

12. If FCF is the free-cash flow, then $PV = \sum_{t=0}^{T} \frac{FCF_t}{(1+c)^t} = K_0 + \sum_{t=1}^{T} \frac{EVA_t}{(1+c)^t} = K_0 + MVA$. For a proof, see Cachanosky and Lewin (2014, p. 663) and Koller, Goedhart, and Wessels (1990 [2010], Appendix B). On EVA® methodology also see Stern, Shiely, and Ross (2001), Stewart III (1991), and Young and O'Byrne (2001).

13. This is a particular D using the flow of estimated EVAs as the projected cash flows, thus taking into account the opportunity cost (the value of the best foregone investment opportunity). We consider the EVA formulation to be advantageous for reasons explained in the text.

14. Note, however, that $D = \frac{\sum_{t=0}^{T} \frac{t \cdot EVA}{(1+WACC)^t}}{MVA} < \frac{1}{2}$ with a constant cash flow as is represented in the Hayekian triangle. For $D \approx \frac{T}{2}$ cash flows should grow at the same rate as the discount rate. Hayek is assuming constant growth. With simple interest discounting at that rate of growth $D \approx \frac{T}{2}$ which ties in with Böhm-Bawerk's measure (see also Dorfman, 1959). If, instead, we use normal compound interest discounting $D < \frac{1}{2}$. For further explanation, see Appendix A.

15. For information on the history, development and use of duration-related concepts, see Poitras (2007) and Weil (1973) and the references therein. For those needing an accessible introduction to duration see Kritzman (1992).

16. See Appendix A.

17. More complex reswitching patterns can occur with non-constant cash flows and with alternating between positive and negative cash flows that can result in more than one internal rate of return (IRR) or YTM. To argue, however, that because of this the Austrian idea of APP is unsustainable and unfounded would be tantamount to claiming that D, MD, and C are unsustainable and unfounded because it is theoretical possible to have more than one YTM in particular cases. See also Osborne (2005, 2014, chapter 7).

18. $D = \frac{\sum_{t=1}^{\infty} \frac{tEVA_{HR}}{(1+WACC)^t} + \sum_{t=1}^{\infty} \frac{tEVA_{LR}}{(1+WACC)^t}}{MVA}$. Multiply and divide each term by MVA_{HR} and MVA_{LR}, respectively: $D = D_{HR} \cdot \frac{MVA_{HR}}{MVA} + D_{LR} \cdot \frac{MVA_{LR}}{MVA}$.

19. For a more detailed discussion using EVA® of the effects on market share allocation in the context of the rational expectations critique to the ABCT, see Cachanosky (2015).

20. We borrow the terminology from Callahan and Horwitz (2010).

21. For a more detailed discussion, see Zanotti and Cachanosky (2015).

22. Of course, we are saying neither that all crises can (or should be) explained by the ABCT nor that other effects or explanations not captured in the ABCT cannot take place at the same time. It is an empirical question as to which produces the largest effect in a particular crisis.

23. In fact, a more complete understanding of the "period of production" should include the activities of the consumer (household production) to get to the ultimate services consumed (Becker, 1965).

24. On the housing crisis and the ABCT applied to this case see Ravier and Lewin (2012), White (2008), and Young (2012a, 2012b).

25. This does not mean that there is no concern about the effects on international flows or trade effects. See Haberler (1937 [1946], chapter 12) and Hayek (1933).

26. For an extension of the ABCT to an international context, see Cachanosky (2014a, 2014b) and Hoffmann (2010).

27. Note that if $\sigma = 0$, then $c = i_N$ and that if $\alpha = 0$ then $c = i_N + \sigma$. In both cases c is constant over time.

28. Compare with Cowen (1997) who focuses exclusive on risk leaves out roundaboutness. Roundaboutness and risk can, and should, go together.

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APPENDIX A: DURATION AND HAYEK'S TRIANGLE

Hayek's case is flow-input–point-output. Looking forward, l dollars is expended in each of the T periods. We assume this adds $(1 + r)$ to the value expended in each sub-period only (simple interest). r is the rate of increase and also the discount rate. To calculate APP $=$ D, we count only the inputs. The added value is simply Tlr over the production period. This is explained as follows:

V is the accumulated value at the end of the production period. PV is its present value discounted at r:

$$V = lT(1 + r)$$

$$\text{PV} = \frac{lT(1 + r)}{1 + r} = Tl$$

$$D = \frac{l\frac{T + 1}{2}\cdot(T)}{lT} \approx \frac{T}{2}$$

Note, D does not contain l, t, or r. So, Hayek's triangle is a very special case when we have flow-input–point-output, with a constant per-period expenditure of l and accumulating value according to simple, not exponential, growth.

However, in any realistic situation, D must contain r. This is the reason for the convexity of D. D itself changes with r. This was considered important in the literature because it seemed that APP was thus a moving yardstick – if it was not independent of r, how could you use it to measure the effects of changes in r? But Hicks showed that you could, because it was itself a strange kind of elasticity. It shows just how much of a special case Hayek's triangle (Böhm-Bawerk's case) is.

When we discount using compound interest, so that the later periods are more heavily discounted than the earlier, then the formula for D will contain l, r, and t. See Fig. A1.

$$\text{PV} = \sum_{l=0}^{T} \frac{Tl(1 + r)}{(1 + r)^t} = Tl(1 + r)\sum_{l=0}^{T} f^t$$

$$D = \frac{\sum_{l=0}^{T} \frac{tl(1 + r)}{(1 + r)^t}}{\text{PV}}$$

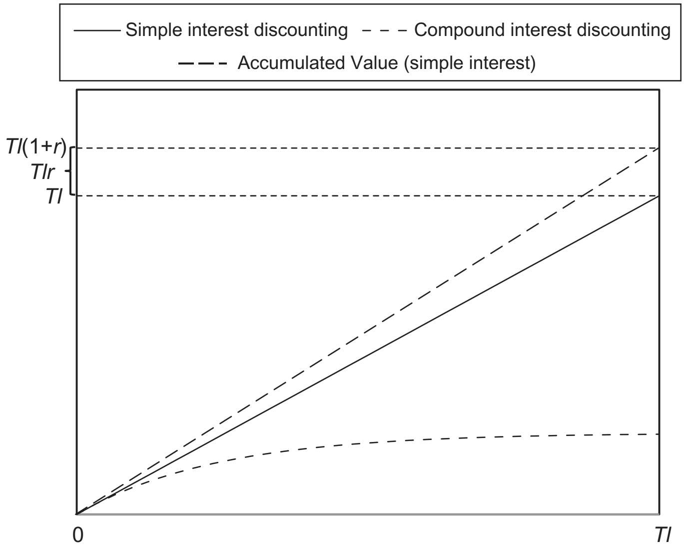

Fig. A1. Hayek's Triangle, Simple Interest Discounting, and Compound Interest Discounting.

APPENDIX B: DURATION AND CONVEXITY

We know that $\mathrm{MD} = -\frac{\mathrm{d}\ln(P(c))}{\mathrm{d}c} = -\frac{1}{P}\cdot\frac{\mathrm{d}P(c)}{\mathrm{d}c}$ and therefore that $\frac{\mathrm{d}P(c)}{\mathrm{d}c} = -MD{\cdot}P$, where P is the price (present value) discounted at rate c.

Convexity is defined as $C = \frac{1}{P}\cdot\frac{\mathrm{d}^2P(c)}{\mathrm{d}c^2}$.

Then:

$$C = \frac{1}{P}\cdot\frac{\mathrm{d}}{\mathrm{d}c}\left(\frac{\mathrm{d}P(c)}{\mathrm{d}c}\right)$$
$$C = \frac{1}{P}\cdot\frac{\mathrm{d}}{\mathrm{d}c}(-\ \mathrm{MD}{\cdot}P)$$
$$C = \frac{1}{P}\left[(-\ \mathrm{MD}){\cdot}(-\ \mathrm{MD}{\cdot}P) + \left(-\frac{\mathrm{dMD}}{\mathrm{d}c}\right)P\right]$$
$$C = \mathrm{MD}^2 - \frac{\mathrm{dMD}}{\mathrm{d}c}$$

Because $\frac{\mathrm{dMD}}{\mathrm{d}c} \leq 0$ and $\mathrm{MD} = \frac{D}{1+c} > 0$, then higher duration ($D_{\mathrm{H}}$) has a larger convexity than a low modified duration (D_{L}) cash flow.

$$C_{\mathrm{H}} > C_{\mathrm{L}}$$
$$\mathrm{MD}_{\mathrm{H}}^2 - \frac{\mathrm{dMD_H}}{\mathrm{d}r} > \mathrm{MD}_{\mathrm{L}}^2 - \frac{\mathrm{dMD_L}}{\mathrm{d}r}$$
$$\left(\mathrm{MD}_{\mathrm{H}}^2 - \mathrm{MD}_{\mathrm{L}}^2\right) - \frac{\mathrm{d}}{\mathrm{d}r}\left(\frac{D_{\mathrm{H}}}{1+r}\right) > -\frac{\mathrm{d}}{\mathrm{d}r}\left(\frac{D_{\mathrm{L}}}{1+r}\right)$$
$$\left(\mathrm{MD}_{\mathrm{H}}^2 - \mathrm{MD}_{\mathrm{L}}^2\right) + \frac{D_{\mathrm{H}}}{(1+r)^2} > +\frac{D_{\mathrm{L}}}{(1+r)^2}$$
$$\underbrace{\left(\mathrm{MD}_{\mathrm{H}}^2 - \mathrm{MD}_{\mathrm{L}}^2\right)}_{>0} + \underbrace{\left(\frac{D_{\mathrm{H}}}{(1+r)^2} - \frac{D_{\mathrm{L}}}{(1+r)^2}\right)}_{>0} > 0$$