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RECONCEPTUALIZING VALUE CREATION WITH LIMITED RESOURCES

James K. Hazy, Mariano Torras, Allan S. Ashley*

Abstract

In traditional economics and finance the notion of value creation is virtually synonymous with the net present value of cash flows. Such a characterization implies that all of the uses of resource inputs, such as raw material and energy, are known and that their value is priced into commodities markets. It also fails to allow for the opportunity cost associated with the depletion of resources which, with advancing technology, might reasonably have future uses far greater in value than can be achieved at present with current technology. Stated differently, in traditional valuation analysis the option value associated with scarce resources –when new technology or knowledge can be applied to them– is not addressed. In the present work, we define technology leverage as representative of this effect. We then address the problem of sustainability of organizations by stating four propositions and examining their implications for government policy and for firm governance.

Keywords: resources, sustainability, value creation

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* James K. Hazy. Adelphi University. hazy@adelphi.edu. 908-713-9820
Mariano Torras. Adelphi University. torrasm@panther.adelphi.edu
Allan S. Ashley. Adelphi University. ashley@adelphi.edu

RECONCEPTUALIZING VALUE CREATION WHEN RESOURCES ARE LIMITED

In traditional economics and finance the notion of value creation is virtually synonymous with the net present value of cash flows. Such a characterization implies that all of the uses of resource inputs, such as raw material and energy, are known and that their value is priced into commodities markets. It also fails to allow for the opportunity cost associated with the depletion of resources which, with advancing technology, might reasonably have future uses far greater in value than can be achieved at present with current technology. Stated differently, in traditional valuation analysis the option value associated with scarce resources –when new technology or knowledge can be applied to them– is not addressed. In the present work, we define technology leverage as representative of this effect. We describe an analytical approach to address this gap in the literature, centered around the notion of technology leverage. We then address the problem of sustainability of organizations by stating four propositions and examining the implications for government policy and for firm governance of incorporating the full impact of scarce resource utilization into value creation measurement, decision-making, and the distribution of the value thus created among various stakeholders.

Traditionally, value is assumed to be created when physical resources are identified, appropriated, processed, and distributed such that output revenue exceeds total cost –including investment costs– and thus leads to cash flows. Yet such a conceptualization of value created is generally limited to shareholder value. In contrast, we argue that value is created upstream from decisions regarding its distribution, whether to shareholders or others. Value is created within the firm when it has access to resources and when knowledge and technology are effectively leveraged against said resources through the firm's organizational capabilities and operational know-how. Once created, the entirety of value may be distributed to shareholders, but more often only part of it is. Other stakeholders often benefit as well, such as labor (employees or management), customers, government, and the community.

Considered in this way, value can be measured using cash flows, but only when accounting for all of the relevant costs, including the opportunity costs associated with resource scarcity, for example, when a scarce mineral is no longer available for perhaps unknown uses in the future.. On the other hand, distributions—even excess distributions to labor or management in the form of above market compensation—should not impact the value creation calculation. In such a framework, value is not synonymous with accounting profits nor with flows only to shareholders. Rather, it is the sum of benefits created by technological leverage of resources (defined below), and accruing to *all* stakeholders.

We can think of the efficiency with which value is created as the ratio of output value to units of input (labor or resources, or indeed both), and is a measure of the technological leverage applied to scarce natural resources in the creation of economic value. Note that, so defined, when the price of input resources increases due to growing scarcity, technology leverage remains constant ceteris paribus even where profits decline. When resources are considered scarce and there is sufficient variance in technology leverage, consumption of natural resources by low technology leverage industries is particularly costly because less of that same resource is made available for high leverage industries, be it in the present or the future. The use of natural gas to burn for heat may have low technology leverage, compared with transforming it into polymers, plastics, or pharmaceutical products (high technology leverage activities) is one example. As will be argued later, although there is a tradition of maintaining that pricing mechanisms in commodity or factor markets account for this effect, we argue that markets alone do not fully compensate for the differential effect of technology leverage. Future gains in knowledge that increase technology leverage are not accounted for in today's markets, and the value-creating potential of new knowledge is not bounded in any strict sense.

Finally, because evolutionary, cognitive, and other processes lead to increased organization and complexity, and because knowledge and technology are products of such processes, it is plausible that technology leverage increases over time. If so, resources conserved for the future may ultimately be consumed by higher technology leverage activities. The negative value created by uneconomical consumption of resources today is in such a case likely to be systematically underestimated. This is especially so when one considers the large scale macro dynamics.

After briefly reviewing current conceptions of value, resource utilization, and sustainability, we describe a new perspective based upon explicit assumptions about how value is created. We suggest four propositions derived from our assumptions, and discuss their implication to governmental policy and firm governance in a global economy with limited resources. In the final section, we discuss future research directions.

CURRENT PERSPECTIVES ON VALUE AND SUSTAINABILITY

Before suggesting a new approach to understanding value creation, we briefly review current thinking regarding value, technology, and resources which implies that a rethinking of current perspectives is both timely and appropriate.

The Theory of Value Creation

The literature on value theories in economics and finance is truly encyclopedic and, because of obvious space restrictions, is for the most part beyond our present scope. Debreu's (1959) monograph is a useful starting point, however, because in it he sets down a self-contained axiomatic, mathematical treatment of the notion of value, and his principal results still underlie most economic theory in use today. Debreu highlighted some limitations of such an analysis in his treatment of value, and subsequent work built upon these implicit assumptions. As he puts it:

> *One may stress here the certainty assumption made, at the level of interpretations throughout the analysis… according to which every producer knows his future production possibilities and every consumer knows his future consumption possibilities (and his future resources if resources are privately owned—otherwise only the future total resources need to be known) (p.xi).*

We focus precisely on the informational limitations that render the above assumptions unrealistic. In what follows, we challenge the manner in which such reasoning has been applied. While it is recognized that these assumptions are not literally true, this fact has not always been recognized in their application. Specifically, we are concerned with the assumption that "every producer knows his future production possibilities," is not always considered and we elucidate the implications that devolve from the assumption that every producer knows, "his future resources if resources are privately owned" and the total resources for resources that are publicly owned.

Resource Based View of the Firm and Other Resource Approaches

In the same year that Debreu published his monograph, Penrose (1959) introduced ideas that would form what came to be called the resource-based view of the firm. Her fundamental insight was that, contrary to insights obtained using traditional economics methodology, firms can find positions within the environment where they can sustain competitive advantage in ways that can increase firm longevity. As Barney (1986, 1991) and Peteraf (1993) later pointed out, this apparent anomaly within economic theory resulted from sustained preferential and sustainable access to resources. When knowledge is explicitly included in the equations (Makadok, 2001, 2002) we may conclude that preferential access to resources and proprietary knowledge with respect to processing resources can indeed result in the sustained production of economic rent and thus sustained competitive advantage even in competitive markets. Toyota's lean production system is an example of this.

So according to this line of reasoning, firms which set as their purposes 1) the acquisition of the preferential access to resources and 2) the accumulation of knowledge, proprietary or public, (the latter increasing the leverage with which resources can be processed) are the most likely to achieve firm longevity independent of pursuit of maximum profits. Whether or not achieving maximum profits is consistent with firm longevity depends on information access since, recalling Debreu's quote, economic theory assumes perfect knowledge by producers and consumers, and explicit equality between the present and future uses or resources.

Under such a pristine theoretical framework, maximizing profits is synonymous with firm longevity because perfect knowledge is assumed. However, when uncertainty is considered and practical considerations are included, significant differences result. For example, both labor costs and resource costs must be minimized to maximize accounting profits, at least in the short term. The short-term tradeoff is clearly in the interest of capital in the face of uncertainty. By ensuring that capital receives its maximum return on investment, a return that can be recycled into other projects and purposes as situations change, capital retains its flexibility as unforeseen circumstances alter the prospects of each organization independently. The benefit to capital remains tenable even though the labor –or, more generally, human capital– that is being eliminated includes knowledge or technical know-how that may provide critical flexibility as a particular organization struggles to adjust as its circumstances change.

Likewise, while surplus resources or "organizational slack" (Cyert & March, 1963), may be indispensable to the organization in enabling it to adapt in future situations, such excess resources must be shed if profits are to be maximized. Capital does not care because it maintains its flexibility, but the other stakeholders suffer. Thus the maxim of "maximum profits" necessitates eliminating flexibility for the organization in return for a unique benefit that accrues to capital. By accumulating profits, capital retains the flexibility necessary for its aims, but it does so at the expense of the same flexibility that would benefit the organization that capital has supported.

One might argue that the notion of resource sustainability does not apply, precisely in a world where human knowledge and technologies can be utilized to develop viable substitutes for resources that may have been exhausted. The received wisdom in economics, in fact, is that we never literally run out of resources. Increased scarcity is reflected in a rising price, until the price chokes off further demand and the "backstop" technology or resource is summoned as a substitute (so-called relative scarcity). Moreover, most "green accounting" methodologies employed by economists (e.g. El Serafy and Lutz, 1989) assume (implicitly –we doubt that many would make such a claim) that *in situ* resources and fixed capital (e.g., tools, machines, etc.) are essentially substitutable. One therefore might conclude that concern over sustainability is at best overstated and at worst pernicious insofar as company profits are concerned.

We have two responses to such a claim. First, it is undeniable that we live today in a world where natural resources, not labor, is the limiting factor in production. One hundred fifty to 200 years ago, one might have reasonably argued that it was the reverse: human impact on resource stocks and the natural environment was minimal, and labor was relatively scarce. But such a claim would never withstand scrutiny in today's global, heavily populated, and mass-consumption-oriented world. Basic economics dictates that in such a changed world we should be economizing on our natural resources, not continuing to pretend that they are "free" assets.

Second, despite seemingly limitless human ingenuity in relation to technology, we must recognize there must be some limit to how efficiently we can use our resources. Relative scarcity might reign supreme as concerns individual resources, but when we consider the *aggregate* of exhaustible resources extant worldwide, these must be considered scarce in an absolute sense. To be sure, there is enormous uncertainty over when resource limits might be reached, but we must also consider the untold spillover effects of resource mining and general ecological consequences that remain poorly understood. With complex systems such as our natural environments, non-linearities are likely to be present; in other words, minor costs associated with environmental impact might suddenly become huge costs as an ecological threshold is breached. This may or may not be a problem for private business, but it *is* directly relevant to value creation in general.

We argue that exclusive focus on return to capital is unsustainable behavior, and that such behavior has led to shortened lives of specific organizations. On the other hand, maximizing more broadly conceived value is consistent with sustainability (though even here probably only a necessary and not sufficient condition). If economic rents can be assured by virtue of preferential positioning within resource fields, that is, access to certain resources not available to others, then profit maximization (fundamental to a firm's survival in the capital markets) is subordinated to the goal of sustainability. While, as we have seen, pressure to maximize profits can operate against the interest of the firm, when a firm establishes itself in a preferential resource or knowledge position, flexibility is retained within the firm, and less value is transferred to capital. Short term accounting profits are not maximized because knowledgeable people are retained and excess resources are stored, both of which reduce accounting profits. Such flexibility supports firm sustainability and leads to the following proposition:

> *Proposition 1: When all else is the same, there is a positive relationship between an organization's ability to appropriate excess knowledge and resources within the firm and the firm's longevity.*

It brings to mind an intriguing research question: What if organizations in general and firms in particular did not maximize profits as their singular objective? What if, instead, firms pursued longevity, and thus access to resources in general, with financial capital being only one of these resources? In such a case, firms might appear to be "maximizing profits" insofar as they try to retain access to capital resources, but they would actually be systematically deceiving the capital markets in pursuit of their larger purpose. This posturing is analogous to firms attempting to appear "environmentally friendly" in an effort to retain access to raw materials, or "worker friendly" (i.e., cultivating an image, for example, as one of the best companies to work for) in an effort to retain access to workers. As discussed in the next section, the implications of this possibility are legion.

Before exploring these questions, we should make clear that we recognize the benefits that result from the discipline of active capital markets within the economy. Such discipline has been and will remain critical to continued economic growth and prosperity. We simply point out that as useful as a capital-centric perspective has been for defining the modern economic system, it oversimplifies the dynamics at work in the economy. The consequences over the long run may be severe. Relying on price signals as indicators of value is misleading, but the inaccuracy of price as an indicator of value may not be troublesome as concerns the private company in a micro context. The difficulties arise in the macro context: repeated and persistent mismeasure of value creation result in erroneous decisions which, taken in concert, may produce disastrous outcomes. Of course there is no manner of knowing what the effects will be *a priori*, since the macro economy is so irreducibly complex. Yet there is much to be gained from exploring some of the dynamics and sector interrelationships. This is the intent of our research.

RECONCEPTUALIZING VALUE CREATION AND SUSTAINABILITY

When scarcity of naturally occurring resources and their permanent depletion are included in the framing of the problem of value creation, different outcomes are inevitable. In this section we look at key definitions and assumptions underlying such an approach and explore their implications. We develop propositions that form the basis of a new conceptualization of value creation and sustainability as a representation of the "purpose" underlying human organizing activity.

Technology Leverage Defined

We first define *technology leverage*, τ', to be the instantaneous rate of change of output value creation from changes in units of the input resource, that is, it is a first derivative of the function, , that converts input units into output value. In equation form:

$$\tau'(r^i) = d\,\tau(r^i) / dr^i = dr^o / dr^i$$

Where r^i are the units of input resources ***i***,
$\tau(r^i)$ is the function that describes the conversion of input units i to output value, r^o, and $r^o = \tau(r^i)$ is the value of output due to input units i.

Technology leverage is a companion metric to l*abor productivity*, the ratio of output value per unit of labor, which measures how effectively technology is used in support of human effort. Labor productivity recognizes the scarcity and value of labor and thus seeks to maximize the economic benefit that devolves from every labor hour. Technology leverage, in contrast, measures the impact of knowledge and technology on the output value devolving from non-labor inputs to production. By measuring and maximizing technology leverage, one would recognize the scarcity and inherent value in natural resources and seek to maximize the economic benefit that devolves from every unit of natural resources consumed.

Although technology leverage, τ' (i.e., $\tau'(t)$, for a given firm), varies over time, it can be estimated at any moment by assuming τ to be akin to the standard production function in economics, and τ' to be the constant ratio of output value to units of non-labor direct inputs. One would expect that when there exist alternative uses for a given resource and different available technologies across industries, there will be a significant difference in technology leverage across industries given the same resource input. This leads to the following proposition:

> *Proposition 2: When different outcomes across firms depend upon the same input resource, there is a positive relationship between the market value of technological knowledge deployed and the level of technology leverage, τ', realized in the processing of the resource*

The normative precept that technology leverage should be maximized in human organizational systems, both economic and political, represents a profound point of departure from prior economic theory, particularly when "free goods" such as air, water, land, sea, etc., are considered to be scarce inputs. Not only does such a notion come into conflict with the normative approaches that currently dominate debate within finance and economics communities, i.e., that profits should be maximized (sometimes at the expense of the environment), it also has profound policy implications of its own. These are discussed in a later section. Before addressing normative matters, however, it is important to consider some real-world examples of technology leverage and consider their practical implications.

Variance in Technology Leverage Across Industries on the Same Resource

If we support Proposition 2, and if we assume that there are differences in the value of technology –such as, for example, between that provided by the internal combustion engine and that offered by the synthetic construction of carbon fibers or pharmaceuticals– then there is also a wide variance in technology leverage deployed within the economy. Some industries would consume a resource with technology contributing relatively little to output value. Others might realize greater output value from the same resource input, owing to superior technology.

Consider for example some of the varying uses for fossil fuels. As a possible example, at the low end, the energy industry burns unprocessed fossil fuels, heavy oil, natural gas and coal, to heat homes, a conversion process that would seem to have a relatively low technology leverage on oil--it simply burns the fuel and then it is gone. Progressing up the scale, the petrochemical industry refines oil resources into more efficient fuel products such as gasoline, kerosene etc. that can be used to power transportation and other services. We might assume that this use of fossil fuels is characteristic of a medium technological leverage activity because the oil resource is being used to move and thus utilize other resources within the economy. On the high end of the scale, the plastics/synthetics industry uses fossil fuels, e.g., natural gas, as an input to produce a wide variety of synthetics such as plastics, fabrics composite materials used in many other industries. This use has high technology leverage (why?). All of these uses for the same natural resource, fossil fuels, potentially produce very different value within the economy.

Silicon is another example of a resource with high variance in technological leverage. As one low leverage possibility, sand can be gathered and sold to make artificial beaches for tourists around the world. In contrast, a fistful of sand can make a silicon wafer that can then be used to make thousands of microprocessors, surely an example of high technology leverage on silicon.

Perhaps most important, commodity pricing, such as pricing for fossil fuels or sand, is based upon total demand across industries (Debreu, 1959) even though demand may be quite different across different uses of the same input resource. Market pricing does not take into account variations in the value of outputs that derive from differences in technology leverage on resources even though the value to the economy may be vastly different depending upon the specific use. Price, in other words, reflects the "value" to society given the presumably perfect – but in reality far from perfect– state of knowledge. Low technology leverage uses that have high demand may deplete scarce resources which could turn out to have very high value using future technology. In these cases, these resources have real option value that is not being priced into the market. Again, while this may have little import to a private firm, but in the long run the squandered option value that would be a direct consequence of sort-sighted resource use might carry significant costs to society.

Does technology leverage matter? A thought experiment.

It is immediate from the preceding that ingenuity, scientific advance, and knowledge accumulation are the bases for any variation in τ'. Innovation within an industry and within a firm produces gains in technology leverage. The structural changes that occurred in the auto industry during the late twentieth century are a useful illustration of how technology leverage can change an industry. A well-known Japanese company, Toyota, introduced lean manufacturing techniques which had much higher technology leverage on input resources, in part by significantly reducing inventory requirements. Because Toyota had much less capital at it disposal than did its American competitors, it was compelled to achieve higher technology leverage. The fact that poorly capitalized firms can achieve higher technology leverage than their better capitalized competitors has significant implications, particularly in situations when resources become scarce.

In his book *Guns, Germs and Steel*, Jared Diamond describes how in human pre-history, domestication of plants and animals led to more, and better production of, crops. The focus, not surprisingly, is on the increased productivity of human labor –a small number of farmers could feed an entire village– leading to surplus resources and ultimately to social and political organization. There is another story hidden between the lines of this tale, however. Innovations such as harvesting better seeds, breeding stronger domestic animals, and developing new machines – examples of technology leverage– made it possible to obtain a larger harvest from a single ox, more edible grain out of a single seedling, and generally, more output per unit of input regardless of how many humans were at work, i.e., more efficient use of resources. These are the stories of τ'.

Consider for a moment a year of drought, a year when water is so scarce that only one farm can be maintained. Which farmer should be allocated the scarce water resource? Undoubtedly, the farmer with the most technologically advanced seed, domesticated animals, and machinery should receive the water because said farmer will produce the greatest yield on water. However, in a market based system, the farmer that gets the water is the one with the largest stockpile of cash accumulated from prior years when the necessary resource –water– was not scarce. Thus, to answer the question, we must determine if the farmer with the largest stockpile of cash would also, of necessity, have the best technology.

Received wisdom from traditional economics, built, we must recall, upon the limitations identified by Debreu, would assume that the market mechanism favors the farmers with the best technologies and therefore that, over time, such farmers would produce the most profit and thus accumulate the most cash. When water is plentiful, and essentially free, many seeds can be sowed and watered, and thus it is labor productivity that determines crop yield. However, when labor is plentiful but water is scarce, water must be conserved and a minimal amount of seed must therefore be planted in order to conserve the water. Thus it is the best seed technology, the highest yield seed, rather than labor productivity that determines overall crop yield.

An increasingly influential perspective in the management literature, the resource based view of the firm (Barney, 1991), with the addition of knowledge as a competitive differentiator (Makadok, 2001), is relevant to this analysis. According to this view, firms can protect their access to resources and knowledge and achieve sustained competitive advantage. Thus it is at least possible that a recently developed seed technology on a smaller farm employing less labor would be superior to the technologies in use on the larger farms. This seed if planted and watered would result in a higher overall yield. When water becomes scarce, however, it would be the farm with the cash that got the water.

As can be seen from this thought experiment, even in principle, free markets do not often function adequately when maximizing τ' rather than profits is the objective. The above example is increasingly relevant as labor productivity reaches all time highs and labor is global and ubiquitous. Previously plentiful resources such as air, water, land, timber, and fossil fuels, on the other hand are increasingly scarce. The extent to which natural resources are substitutable with other inputs is an open question, but their absolute scarcity in an absolute sense now make them the true limiting factor in production, and specifically value creation.

THE IMPLICATIONS OF RESOURCES ON VALUE

When resources are considered scarce, consumption of natural resources by low technology leverage firms –or, more broadly, industries– carries a cost to the whole(??) because less of that same resource is available for high leverage industries. In an increasingly constrained world resource market, such costs to the economy must be considered in the market mechanisms that set prices and determine value. Variability in input costs originating from technology leverage differentials become an additional factor in the net present value calculation in addition to the time value of money.

The implications of τ'

As we formally describe below, because of differences in τ' conservation is not simply a tradeoff between "using the resource now or saving it for later." Where the same resource is used in the same manner and with the same technology leverage but at different times, there is an economic argument that justifies its immediate use. In fact, any reasonable argument for conservation in such circumstances rests on moral or humanitarian, as opposed to economic, grounds.[1] [you need to do something about this footnote] The choice nets to preference.

There is more to consider with technology leverage, however. We must also include in the analysis the efficiency with which technology is used to leverage input resources into economic value, and how that efficiency might be different between consuming scarce resources today versus consuming them at some point in the future. When technology is included, this choice does not net to preference only, but implies the potential for a real value difference in present value terms. With changing technology leverage and –as is eminently reasonable– assuming uncertainty, scarce resources have option value.

Differences in Technology Leverage Implies Negative Cash Flows from Opportunity Costs

We argue that differences in technology leverage create differences in both the positive value achieved in consumption of resources and the negative value for the opportunity lost in depletion, and that such differences change the value equation. To be clear, the negative value for opportunity cost is created because scarce resources, when depleted, cannot be the basis for value created in the future, and such negative value is measured by determining forgone cash flows in the future. Although analytical methods for valuing options of this type are beyond the scope of this paper, the approach highlights and potentially quantifies the costs to the economy of depletions of hard minerals, water and atmosphere, fossil fuels, soils, forests, species diversity, diversity in organic and biological compounds, ecological systems, behavioral and social systems, and cultural diversity. Where traditional economic methods and models are silent on an important result from the evolutionary sciences –that diversity in and of itself is valuable in the evolution of complex systems– by including option value our approach incorporates the insight explicitly in our value calculations. From the above follows our next proposition:

> *Proposition 3: Assuming constant technological leverage (τ') over time and across industries, market pricing incorporates both the current and future value of resources, and there is therefore no economic benefit to conservation of resources beyond that suggested by the discount rate. When, on the other hand, $\tau'(t)$ is <u>not</u> assumed to be constant there are conditions where:*
>
> *1) Conservation of privately owned resources can be shown to have positive value to a firm and*
>
> *2) Conservation of public resources can be shown to have value for an economy overall.*

Stated differently, there is an additional criterion –which accounts for the true benefits of waiting– that should be met before resources are consumed. It is not unlike the precautionary principle that some argue should guide much environmental policy. We turn next to the difficult problem of calculating such a threshold value and incorporating these results in decision models.

The impact of non-zero value for conservation in decision making

A key result from the developing field of complexity science is that evolutionary, cognitive, and other processes lead to increased organization and complexity. In addition, an increase in knowledge and technology are natural products of these processes as physical and social structures. Unlike many other evolutionary changes that some (e.g., Gould) argue proceed in a non-directional fashion –i.e., may wax or wane over time– knowledge or technology may be characterized as a ratchet. It moves in only one direction, toward improvement.

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[1] When one chooses to consume resources today, benefit is realized today (approximately) in today's dollars. This is the positive value term in today's dollars from using the resource today. There is also a negative value term (opportunity cost), however, in the equation. This term can also be expressed in today's dollars and results because the resource (consumed today) can't be used in the future. In traditional economic theory, this opportunity cost is assumed to be captured in the pricing dynamics at work in the commodities *markets*. Current value and future value lost are by definition equated through the time value of money calculation (Debreu, 1959). Thus, these terms, current value versus opportunity cost, net to zero because, when on assumed a constant and consistent there is no difference in economic value between using something now versus latter *ceteris paribus*.

For example, DNA, or symbolic language, encode information about what works within the environment (Allen, 2001). As a result, it is reasonable to assume that, even in the face of generalized increases in input prices, technology leverage is an increasing function of time, because it is unlikely that a new technology will be adopted unless it increases the value creation equation. In other words, $\tau(t)$ is a monotonically increasing function, or $\partial\tau / \partial t > 0$. What such reasoning implies for conservation is that the longer one waits, the higher the technology leverage to be deployed against given resources. Because this effect is not addressed in most current economic models, it is fair to say that the negative value resulting from wasteful consumption of resources is likely to have been systematically underestimated in economic analysis. This leads to the following proposition:

> *Proposition 4: IF technological leverage, τ', is assumed to be a monotonically increasing function over time, and IF market pricing in use implicitly assumes that technology leverage is constant,*
>
> *THEN the opportunity cost in current dollars of using resources today versus at some point in the future will be understated AND if the rate of change over time in technology leverage is greater than the discount rate, the value of conservation of resources will be strictly positive.*

Future research finding support for our proposition would imply that there has been, and continues to be, systematic error in financial analysis supporting resource utilization decisions. Further, it would imply that the error leads to biased decisions favoring the use of resources in the present, at the expense of more highly leveraged uses in the future. Correcting for said bias would explicitly recognize the option value of conservation of resources within our economy.

POLICY AND GOVERNANCE IMPLICATIONS

With the above ideas in mind, we turn now to the normative questions about how analysts should incorporate these ideas into microeconomic decision models within the firm and in the markets. We consider remedies in two distinct arenas, governmental policy and firm governance.

Government policy implications

How can national and international policy be modified to more accurately measure value creation in national and global economies? Much more research is needed to fully understand the policy implications of this perspective. Some speculative ideas do come to mind, however.

One possible approach would involve defining certain scarce natural resources as within the public domain, although possibly under private control. These resources would be subject to consumption royalties paid into a fund that uses the market mechanism to invest in technology innovations, possibly through venture capital funds established for this purpose. A key challenge would involve determining available stockpiles of resources and forecasting technology leverage functions associated with each resource to determine the appropriate royalty level. The policy objective would be to provide appropriate incentives and funding so that economic actors would develop new technologies to better utilize diminished resources and achieve a sustainable economy. The royalties might be called technology development royalties.

Set at the right levels, it is possible that the royalties could replace other forms of taxation, at least in some countries. At the same time they would provide an incentive to reduce consumption to the lowest practical levels (although see discussion of the Jevons paradox in what follows). Doing so would encourage uses that take advantage of high technology leverage, encourage the development of improved technology, and increase the economic incentive to recycle materials already in service. Granted, the problem of setting royalty rates would be challenging, highly uncertain, and subject to political influence. However, the program could be phased in beginning with a pilot that used a simple and rather uncontroversial case. As an example, a royalty could be imposed on a hard mineral such as copper or uranium. Royalty proceeds might be used to invest in the relevant economies and to support an international board that sets the royalty rates and manages the system. Importantly, there would not be controls on who bought what, but rather a royalty that reflected opportunity costs that would be charged in all cases and without prejudice.

Firm Goverance Implications

An equally important question is how this approach to value analysis would impact firm choices. Perhaps the best way to consider the question would be to look at the manner in which financial markets would be affected if technology development royalties were added to the cost of inputs to production. The simplest and most direct mechanism to impact decision making within the firm is to influence if not change how shareholder value is determined. A technology development royalty would accomplish this. Because firms with low technology leverage have a larger percent of their costs tied up in acquiring natural resources, they would be the hardest hit.

Consider the copper royalty example described above. As the policy took shape and seemed imminent, traded shares of companies that use copper would immediately be priced down, and firms that used more copper would be priced down to a greater degree, as the cost of the royalty was priced into the market. This is because analysts would assume that the royalty payment was a tax, or an incremental cost, that fell to the bottom line in cash flow calculations. With end use prices being determined by market forces (assuming a sufficiently high degree of competition), the increased cost could not be passed through, at least initially, and the firm's after tax cash flow would be reduced by the pro rata amount. Consequently, regardless of how the firm's shares were priced, the effect would be to reduce share price by a proportional amount. As the royalty increased, profits, cash flow, and share price would be increasingly under pressure. The management of impacted firms would be forced to make strategic changes. For example, end user price could be increased to improve margins, and these increases would be met with reduced demand. Eventually, a new equilibrium would be reached with higher prices, lower volumes and less depletion of resources. The net effect would be a shift in resource utilization from low leverage uses to high leverage uses.

Yet greater efficiency resulting from higher technological leverage may lead to more, not less, resource consumption because of an implied cost reduction –the so-called Jevons paradox. This is potentially true for increasing gains for a single use, such as for internal combustion engines. As greater value is provided per unit of resource, volume increases in the case where the demand curve increases with price declines at a faster rate than the increase in profits from improved efficiency. The logic does not necessarily follow across knowledge intensive industries, however. Each industry is governed by its own price curve. In highly technical markets such as semiconductors or pharmaceuticals, knowledge content, rather than commodity costs, drives prices. Undoubtedly cases of increased consumption can be found, but they are far less likely than in the single industry case.

When economic incentives such as royalties are added to commodity markets that explicitly favor high technology leverage industries, more human and technical resources are likely to be directed toward increasing technical leverage. As royalties increase, consumption of the affected resource decreases, ideally approaching conditions for sustainable development. Even in low leverage industries, firms will mostly invest in technology that increased its technology leverage, at least in the long run. In such industries, consumption would likely increase for a given royalty level. Thoughtful policy could be implemented, however, whereby increasing royalties with time would require incremental technology gain just to maintain demand. Overall, this policy would have the treble positive effects of increasing royalty revenue for investment in technology, maintaining firm profits, and reducing the consumption of the scarce resources.

DISCUSSION AND FUTURE RESEARCH DIRECTIONS

Value is created by the judicious use of technology and knowledge in organizations, and by the enterprising actions of organizational actors as they transform input resources into valuable outputs. Such a conception makes value creation logically distinct from the distribution of value to stakeholders (including shareholders).

We argue that value creation can be understood in the context of the function, τ, that describes the output value of a firm in terms of its inputs, together with its first partial derivative, τ', which we call technology leverage. Technology leverage is relevant to sustainability arguments because it highlights differences in the possible uses of resources. Greater technology leverage implies greater realized value for the economy per unit of depleted resources. As a result, policy relating to resource distribution mechanisms should favor these uses over others. As we point out, traditional pricing mechanisms do not necessarily achieve this objective without some level of policy intervention. Such intervention is particularly urgent as previously copious resources become increasingly scarce

More research is needed to determine if the conclusions described are supported empirically and to determine if differences in the uses of scarce resources across industries cause aberrations in optimal distribution of resources as hypothesized. Moreover, research is needed to test the effectiveness of various policy choices intended to influence resource distribution and thus the depletion rates of increasingly scarce resources such as air, water, land, wildlife and fossil fuels.

We nevertheless hope to have called attention to two important issues. First, that value measurement must take account of opportunity costs, or more specifically the option value resulting from gains in technology leverage over time. Such costs are much higher at present than they once were because the limiting factor in production is natural resources, not labor. So long as such costs are not recognized in value calculations, resources are likely to become a greater constraint over time. Second, the complexity inherent in market processes increases exponentially with economic scope. Inaccuracies that may be tolerable for a private firm, if repeated across all sectors and industries, might produce decisions that result in intolerably high costs for society.

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