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Sustainable Production: Definition, Comparison, and Application

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Abstract

In what follows, I analyze the various definitions of sustainability that have been established in a diverse set of disciplines – the economics definitions of weak, strong, and environmental sustainability, the ecological definition, and the authoritative definitions enumerated in the Brundtland Report and Agenda 21 – and I argue that strong sustainability is the superior definition of sustainability in terms of production. Applying this definition to industrial firms via policies that harmonize producer actions with sustainable productive activity will require a fundamental readjustment of both producer and consumer behavior.

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I. INTRODUCTION

The terms "sustainability" and "sustainable development" are being invoked with increasing frequency in civil discussion and policy debates that concern our economy and its economic agents, especially industrial firms (Kates, 2005). Decision makers are more and more often being instructed by experts and constituents to "act sustainably" and to enact policies that lead us down a path towards "sustainable development" (Norton and Toman, 1997). In a context of increasing environmental damage from industrial and economic development, and with "an economy that is destroying its natural support systems" (Brown, 2002), sustainability is taking on an increasingly important policy role. According to entrepreneur Paul Hawken, "We are drawing down resources that took millions of years to create in order to supplement current consumption" (1993). Our current and future problems, including global climate change, ozone dissipation, pollution, resource depletion, and population growth, are daunting but nevertheless urgent and relevant to the survival and future prosperity of the human species. In order to address some of these problems that stem from firm activities, such as pollution and resource depletion, the concept of sustainable production needs to be clarified, applied, and placed into the decision-making calculus used by our leaders and policy makers to define our future.

"The debate on sustainable production often ends in discussions on the feasibility of far-reaching changes in relation to the competitiveness of companies. Industry itself and policy-makers tend to back away from engaging in profound processes of industrial transformation" (Green, Groenewegen, and Hofman, 2001). This quotation frames the problem of moving towards sustainable production while dividing the issue into two separate yet equally important halves. Initially, moving towards sustainable processes in industry is made difficult and complex because of the nature of the word "sustainability"; despite decades of conflict, discussion, and compromise, no consensus exists on an accepted definition of sustainable production or sustainability itself (Figge, 2005). The debate on sustainable production stems primarily from the difficulty business leaders and policy makers encounter when they set out to define and characterize sustainability. After a reasonable agreement on the definition of sustainability is reached, the second problem of application and implementation arises. Using a pragmatic definition of sustainability to guide and influence public policy is troublesome because, leaving aside sustainable behavior in other areas of society, sustainable production alone implies far-reaching changes in our economic system and productive behavior.

In what follows, I analyze the various definitions of sustainability that have been established in a diverse set of disciplines – the economic definitions of weak, strong, and environmental sustainability, the ecological definition, and the authoritative definitions enumerated in the Brundtland Report and Agenda 21 – and I argue that strong sustainability is the superior definition of sustainability in terms of production. Applying this definition to industrial firms via policies that harmonize producer actions with sustainable productive activity will require a fundamental readjustment of both producer and consumer behavior. The interplay between firms and the environment in an "extended circular flow" model discussed by Common (1995) will be examined and suggestions will be made concerning how our system must change to make production sustainable. Although government intervention will play an instrumental role in achieving the societal goal of sustainable production, firms are in the best position to monitor and control their activities if they see such actions as profitable and in their long-term interests.

II. THEORETICAL DEFINITIONS

The first and primary step in moving towards sustainable production is to select the "best" definition available among the wide array of possible definitions of sustainability. This definition, when applied to the production processes of industrial firms, should assure that a company's activities can be maintained indefinitely while improving human welfare through the creation of beneficial goods and services. In general terms, sustainability concerns itself with intergenerational equity and justice over an infinite time frame. Sharon Beder's claim that "the central ethical principle behind sustainable development is equity and particularly intergenerational equity" (2000) would not be criticized in spite of the disagreement surrounding sustainability. Essentially, sustainability is the idea that we should leave future generations no worse off than we were during our lifetimes. One school of thought supported by resource economics argues that sustainability should be operationalized as non-decreasing utility over time (Howarth, 1997). Others construct models that label a growth path as sustainable if and only if consumption is non-decreasing as time approaches infinity (Faucheux, Muir, and O'Connor, 1997). This general requirement of non-decreasing welfare over time is the foundational definition of sustainability upon which all other definitions are based.

The economic definition of sustainability known as weak sustainability posits that the value of the total capital stock must not decrease over time in order for an economic process to be labeled as sustainable. The total capital stock is defined as the physical capital stock, machinery and productive capability constructed by man from his environment, plus the natural capital stock, the productive capacity innately provided by our environment. Therefore, weak sustainability relies heavily on the substitutability of physical capital for natural capital, assuming that different forms of capital are substitutes (Figge, 2005). The criterion can be reduced to a mathematical formalism: weak sustainability is achieved if an economy saves and consequently invests more that the total depreciation of the physical and natural capital stocks (Gowdy, 1999). An economic process can be weakly sustainable if total physical capital formation exceeds physical and natural capital depreciation; drawing down on the stock of natural resources is acceptable if a compensating investment is made in the physical capital stock. The Hartwick rule is the quintessential operational requirement for weak sustainability: all the scarcity rent, or user cost, from the exploitation of a scarce resource must be reinvested in the physical capital stock (Howarth, 1997). Since the exploitation of a scarce resource draws down the finite natural resource endowment and depreciates the natural capital stock, reinvestment of the scarcity rent assures that the total capital stock does not decrease over time.

The weak sustainability criterion is very dependent upon its assumption of near-perfect substitution of physical capital for natural capital as the natural capital stock is depreciated, exhausted, and converted to physical capital. The validity of this assumption is questionable in the real world since many elements of the natural capital stock, such as waste sink and resource base services, have no clear physical capital-based substitutes. Even with an assumption of continuing technological progress, including the advancement of human capital and knowledge, it is unclear if we can substitute machines and education for dwindling mineral and energy resources (Norton and Toman, 1997).

Examples such as the physical devastation of Nauru documented by Gowdy and McDaniel (1997) give reason to doubt the sufficiency of the weak sustainability criterion in practice. The small island of Nauru was extensively strip mined for phosphate rock during the 20th century, and the people of Nauru were partially compensated monetarily for this environmental destruction. The majority of the island was eventually rendered uninhabitable through the mining process, but the citizens of Nauru were able to establish a large common fund to finance education and a relatively high standard of living. Even with the yearly income provided by the fund, it is unclear whether the people of Nauru are better off after the weakly sustainable development of their island home.

There are other compelling cases against weak sustainability as a sufficient criterion for intergenerational fairness. One line of reasoning takes the preferences of future generations as unknown and assumes that we are using the non-decreasing utility condition for sustainability. We need to bequeath a bundle of capital goods to future generations that enables them to produce a basket of goods and services that yields at least as much utility as we enjoyed in the current period. This so-called structured bequest package contains "specific endowments of reproduced capital, technological capacity, natural resources, and environmental quality" (Howarth, 1997). However, since the preferences of future generations are unknown, we cannot select an appropriate package that will guarantee non-decreasing utility if the natural capital stock is depreciating and losing its capabilities in exchange for physical capital stock investment. For example, assume that our current weakly-sustainable development path results in the extinction of an endangered species (all user costs are re-invested per the Hartwick rule). Since we do not know how much future generations would have valued that species in their preference system, the current generation is unable to sufficiently compensate future generations with an increased physical capital endowment.

In his analysis of the conditions for physical capital substitution in the presence of risk, Frank Figge showed that limits on the substitution between different types of capital exist when risk is accounted for (2005). Since decisions on the use of natural and physical capital are subject to risk, weak sustainability is insufficient to enable perfect capital substitution. Therefore, Figge concludes that, "If society is risk averse, diversity of natural and human-made capital must be preserved to achieve Sustainable Development even if the different forms of capital are substitutes" (2005). Diversification of society's capital portfolio is needed if risk aversion is assumed because a diverse package of both physical and natural capital is well-insulated from both economic and natural shocks. Consequently, weak sustainability's presupposition that the natural capital stock can be constantly drawn down upon for physical capital stock investment is inherently flawed even if the different types of capital are substitutes, which is contestable. This conclusion points away from weak sustainability as an effective measure of intergenerational fairness in the presence of risk and risk aversion.

In contrast to weak sustainability, strong sustainability dictates that the value of the natural capital stock must not decrease over time as the value of the physical capital stock holds constant or increases. Therefore, strong sustainability assumes that different forms of capital, specifically natural and physical capital, are complements, not substitutes as was assumed by weak sustainability (Figge, 2005). The strong sustainability criterion avoids many of the pitfalls of weak sustainability because the assumption that different types of capital are substitutes is relaxed; physical and natural capital are complementary and necessary in the long run. According to the formalism of strong sustainability, an economy is sustainable if and only if the rate of capital stock formation meets or exceeds the rate of capital stock depreciation for both the physical and natural capital stock. Because judging the value of the natural capital stock and its depreciation rate is complex, strong sustainability does not have any easy operational rule like weak sustainability and its Hartwick rule. Also, strong sustainability depends on limited substitutability between different types of natural capital since this fact is the justification for the non-decreasing natural capital stock value qualification. This is reasonable because substitution between the different functions of the natural capital stock, such as between the waste sink and amenity services, is nearly impossible.

Because strong sustainability maintains the value and composition of the bequest package, future generations will be able to maintain our level of consumption since they have the same bundle of capital goods available to them. The strong sustainability criterion implies a well-balanced and diversified portfolio of capital goods in the long run, so risk will be reduced and risk-averse future generations will be better off than if they just had a large endowment of physical capital. A few operational principles of strong sustainability are discussed by Howarth: the precautionary principle and the use of safe minimum standards (1997). The precautionary principle mandates a reserve of resources now to prevent catastrophic future effects of current activity, and safe minimum standards dictate the protection of unique natural assets unless the costs are intolerably high. Criticism of these principles and of strong sustainability falls along similar lines of reasoning; valuation of the natural capital stock and definition of "intolerably high" costs are prohibitively expensive and impractical. However, strong sustainability could theoretically achieve its aim of intergenerational fairness if applied properly.

Environmental and ecological definitions of sustainability offer viable alternatives to the strictly economic definitions of weak and strong sustainability provided previously. A development path is environmentally sustainable if the values of the output flows from different types of natural capital do not decrease over time. The flows from a resource in terms of the rate of extraction should equal or be less than the natural replenishment rate. This ensures that the rate of extraction never exceeds the maximum sustainable yield, the greatest possible rate of extraction that does not draw down on the resource base itself. Therefore, the maximum sustainable yield is equivalent to the maximum growth rate of a renewable resource. The implication of this statement, and a weakness of the environmental sustainability criterion, is that harvesting a non-renewable resource at any non-zero rate is unsustainable because the maximum sustainable yield for a non-renewable resource is zero. Under an environmentally sustainable regime, economic agents do not harvest from non-renewable resources because their maximum growth rate is near zero; only renewable resources are used in production processes.

The term "ecological sustainability" will be used to refer to a series of criteria defined and listed by Brown in a 1996 edition of *The Futurist*. Approaching the problem of defining sustainability from a strictly ecological standpoint, Brown proceeds to explain what an ecologically sustainable global economy looks like. These criteria go beyond restrictions on resource flows and would lead to a stable ecosystem that maintains a balance between human and non-human life. Brown's eight criteria are listed in this order: the crude birth rate equals the crude death rate, soil erosion does not exceed soil formation, tree cutting does not exceed tree planting, the fish catch does not exceed the sustainable yield, the number of animals on a range does not exceed the range's carrying capacity, water pumping does not exceed aquifer recharge, carbon emissions equal carbon fixation, and the rate of species loss does not exceed the rate of species evolution (1996). These requirements would lead to a natural capital stock that is non-depreciating, and the qualification of zero human population growth means that the pressure to expand due to overcrowding is non-existent. Although this list of eight criteria is a good macro-level guide to maintaining the environment and ensuring the survival of the human race, on an individual firm level these ideas do nothing to motivate sustainability and its micro-level operation.

III. AUTHORITATIVE DEFINITIONS

The previous four definitions of

sustainability were theoretical in focus, while the following four definitions are official declarations from respected governmental and environmental groups. The first extensive definition of sustainability was offered in *Our Common Future*, a 1987 report of the World Commission on Environment and Development, also known as the Brundtland Report (Davis, 2000). According to the Report, sustainability is defined as meeting "the needs of the present without compromising the ability of future generations to meet their own needs" (Kates, 2005). Due to the frequency with which this definition is cited in scholarly papers and articles (Howarth 1997; Beder 2000; Davis 2000; Kates 2005; Common 1995; Roome 1998), the Brundtland Report's brief initial characterization of sustainability was very influential and could be characterized as the *de facto* standard definition. The Report states that human needs are basic and essential; economic growth, income equality, and intergenerational equity are needed for fairness and active citizen participation (Kates, 2005). The Brundtland Report gave sustainability meaning and laid the groundwork for many other definitions and interpretations to follow, but the definition given is too vague and nonspecific to be operationally useful to firms. Nevertheless, the Report encouraged critical thought on the part of business leaders and professionals about how they could move towards sustainability and sustainable production (Davis, 2000).

Founded by Karl-Henrik Robèrt, the four principles of Natural Step promote a vision of sustainability that focuses on thermodynamics and natural cycles (Spencer, 2005). According to Robèrt, substances from the Earth's crust should not increase in nature, substances produced by society should not increase in nature, the physical basis for the productivity and diversity of nature should not be diminished, and we should be fair and efficient in meeting basic human needs (Davis, 2000). The first three criteria basically state that the natural capital stock should not be systematically depreciated, while the final criterion dictates efficiency and fairness in providing for basic human needs. The Natural Step principles were engineered from their inception to be applicable to business activities on a small scale; the Natural Step organization encourages businesses to think critically about how they can customize and apply them to their individual organizations and production processes. In particular, the third criterion is very similar to the strong sustainability concept.

The Coalition for Environmentally Responsible Economies, formed in 1989, formulated the CERES Principles as the cornerstone of their efforts to encourage a business transition to sustainability. Among many others, the main components of the Principles are protection of the biosphere, sustainable use of resources, reduction and disposal of waste, energy conservation, and risk reduction (Davis, 2000). The Principles focus on protecting and restoring the environment while minimizing waste output and energy input. Also, emphasis is placed on product and workplace safety, organizational transparency, auditing, and full consumer information. Like the Natural Step, the CERES Principles were intended to be applied to individual businesses to move the economy closer to the sustainable ideal as defined in the Brundtland Report. Businesses have been receptive; initially the adopters were already known as green companies, but over time some members of the Fortune 500 have endorsed the Principles.

The United Nations Conference on Environment and Development, commonly known as the Earth Summit, produced Agenda 21 in Rio de Janeiro in 1992. Agenda 21 attempted to define the role of business and industry in working towards sustainable development through sustainable production. In particular, Chapter 30 of the report goes into specifics by stating that "cleaner production technologies throughout product life cycles, environmental management systems, and market-based economic instruments" were the principle techniques that businesses could use to move towards sustainable practices (Davis, 2000). Upon its inception, no mechanism was formed to implement Agenda 21, but later a concept known as eco-efficiency would serve as a proxy for a formal implementation regime. To empower eco-efficiency, defined succinctly as the delivery of quality life-enhancing goods with minimal ecological impact, the Business Council for Sustainable Development lists business strategies that contribute to sustainability and sustainable production (Davis, 2000). This list focuses on the efficient use of energy and material resources, minimizing waste in production, and the creation of a durable, useful, and recyclable product. The eco-efficiency concept becomes appealing to businesses through its emphasis on efficiency and the potential for subsequent cost savings.

IV. STRONG SUSTAINABILITY IN CONTEXT

After exploring and evaluating eight different definitions of sustainability, strong sustainability should be used to evaluate sustainable production in the context of the "extended circular flow" model of Common that I will explore. I select strong sustainability because its definition yields the highest probability of ensuring intergenerational equity – non-decreasing consumption/utility – when applied to producer and consumer productive behavior. Strong sustainability overcomes the limitations of weak sustainability by dropping the unrealistic assumption that different types of capital are substitutes, and strong sustainability has flexibility in implementation that the ecological and environmental sustainability criteria lack. Also, the ecological and environmental criteria speak broadly about the environment and fail to give businesses any useful rules concerning their micro-level behavior. While the specific governmental and organizational definitions of sustainability (Brundtland, Natural Step, etc.) have been applicable and pragmatic, they are either too broad or too specific in nature to be useful to all firms. The Brundtland Report is a framework at best, Natural Step and CERES are primarily focused on environmental preservation, and Agenda 21 establishes useful guidelines but is no guarantee of equity. The extended circular flow model, along with strong sustainability in the context of the model, will now be defined and briefly analyzed.

Michael Common introduced a modified circular flow diagram that includes the natural capital stock and its economic functions in *Sustainability and Policy: Limits to Economics* (1995). In this circular flow diagram, the environment is added as the overarching context of human economic activity. Four primary functions of the environment as an economic agent are identified by Common: the environment as a resource base, waste sink, amenity service base, and life support system. Additionally, resource and waste flows are constructed between the natural and physical capital stocks, along with recycling as an end-of-pipe solution. Initially, resource flows from the resource base are converted into physical capital and are used by firms in production processes. Waste flows from these producer processes, consumers, and the physical capital stock (depreciation) then return to the waste sink. Recycling creates a feedback loop of limited scope by converting some of the waste flows into resource flows that can be channeled back into the production process.

In the extended circular flow model, a production process is strongly sustainable if the environment's ability to provide the services of the natural capital stock is not diminished. Put another way, the natural capital stock's capacity to serve as a waste sink, amenity service base, resource base, and life support system cannot be negatively impacted by firms if they want to produce sustainably. Since substitution between the subsystems of the natural capital stock that perform these functions is limited, firms must rely on substitution among different types of natural capital within a particular subsystem. If production causes some form of environmental damage to a particular subsystem of the environment, only through the appreciation of a substitute in that specific subsystem can a firm ensure that its production process is strongly sustainable. Using the model proposed by Common, it is apparent how firms can begin to make their operations consistent with the strong sustainability criterion.

In general, there are four ways that firms can move towards strongly sustainable production processes in the long run. First, increasing the recycling rate will reduce pressure on the resource base due to increased resource availability and reduce waste flows. To achieve this, firms should design more durable and recyclable products (Davis Sept., 1997) or encourage recycling through education, awareness campaigns, and consumer recycling incentives. Second, directly reducing waste flows through more efficient production processes or conventional end-of-pipe solutions can also slow the depreciation of the natural capital stock. Although end-of-pipe solutions have been typically used in the past to control waste flows, some innovative firms have found that focusing on the efficiency of the production process can result in greater gains at a lower cost (Roome 1998; Capra and Pauli, 1995). Third, preserving the indirect amenity service and life support functions of the environment will ensure the continued operation of these vital natural capital services. Maintaining park reserves, forests, breathable air, and livable areas are the primary ways businesses can complete this goal. Fourth and finally, a variety of options are available to firms to reduce the extraction rate of resources from the resource base, including the use of a more efficient production process that operates on renewable energy and material inputs.

V. CONCLUSION

In summation, I have defined, explored, and assessed eight competing definitions of sustainability. After assessment, I asserted that strong sustainability is the most appropriate criterion with which to judge if production is sustainable. Sustainable production will require a fundamental readjustment of both producer and consumer behavior, and this fact was evident without further analysis when strong sustainability was framed in the extended circular flow model. Although taking such steps to move towards strongly sustainable production should be profit-enhancing and in the firm's best interest, the actual managers and business executives may disagree because the environmental cost they impose on the natural capital stock and on society is mostly unregistered.

Large changes in our social and economic systems are implied by strong sustainability because, barring miraculous technological progress, our current growth path is unsustainable. A fundamental shift towards renewable resources, such as wind and hydrogen, will eventually transform our economy (Brown, 2001). Only by moving towards strongly sustainable production can we assure intergenerational fairness and an adequate quality of life for our children and subsequent generations. It will take concerted, concentrated effort on the part of both consumers and producers to achieve this aim. Wishful thinking and academic parlance are necessary but not sufficient to guarantee a better future for humanity and our unique planetary home.

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