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Analysis

Overcoming Scarcities Through Innovation: What Do Technologists Do When Faced With Constraints?

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ABSTRACT

The question that still divides many debates about sustainability is the possibility of technological substitution of scarce natural resources. While there is considerable debate among economists whether technology can mitigate scarcities through development of substitutes, there is little actual research on the mechanisms and limitations of this substitution process. In this study, I seek to build a bridge between scarcity and innovation literatures to study when technologists decide to develop technological substitutes. My starting point is the theory of technology as a recombination of existing mental and physical components. Combining this theory with modern scarcity literature that differentiates between absolute, relative, and quasi-scarcities yields a more nuanced framework for understanding both different types of scarcities, and how technologists decide whether or not to develop or adopt technological substitutes. This improves our understanding of the possibilities — and limitations — of scarcity-induced innovation. I then illustrate the use of this framework with two brief historical case studies about constraint-induced innovation. I conclude that the mainstream economic practice of assuming that substitution will occur automatically, even in cases of absolute scarcity, may hide extremely important phenomena from discussion and debate behind a veil of circular reasoning.

1. Introduction

An old maxim announces that necessity is the mother of invention. If so, shouldn't humanity rest easy, knowing that technological progress will ultimately overcome whatever environmental and other problems the future may bring? Even though debates between proponents of human ingenuity and its skeptics have raged at least since the famous bet between pessimist Paul Ehrlich and optimist Julian Simon (Sabin, 2013), the question itself is surprisingly underresearched. While the Simon/Ehrlich bet was ultimately decided in Simon's favor and many believe the flexibility of market economy can at least in principle mitigate any scarcity, critics have justly pointed out that there are no guarantees human ingenuity and flexible markets will always be able to overcome all obstacles.

Generally, however, the belief in the human ingenuity remains strong. Those who question the possibilities of technological development to mitigate environmental and social ills are often derided as "malthusians" or "luddites," since so far our economy has been fairly resilient despite warnings of imminent scarcities. The "Porter hypothesis" (Porter and van der Linde, 1995) and related research (for an overview, see e.g. Ambec et al., 2011) goes even one step further and argues that scarcities are not just obstacles to be overcome: instead, increasing scarcities such as those put in place by strong (environmental) regulation may even accelerate economic development, as they force companies to develop new technologies. However, quantitative evidence suggests that regulatory scarcities so far have had little effect on the rate of overall innovation (e.g. Newell et al., 1999; Roediger-Schluga, 2004). Nevertheless, even less sanguine observers generally believe that environmental challenges can be mitigated through technological change. Even if scarcities do not accelerate innovation as such, new technologies are believed to eventually replace legacy "dirty" technologies if sufficiently strong inducements, such as regulatory push and pull, exist (e.g. Horbach et al., 2012). This view is implicitly based on dominant neo-classical economic thought, where resource scarcities are eventually solved through substitution triggered by rising resource costs.

Increasingly, critics of mainstream economic thought[2] have expressed alarm that this formulation may not adequately cover the phenomenon of scarcity (Bretschger, 2005; Baumgärtner et al., 2006; Daoud, 2007, 2011; Raiklin and Uyar, 1996; Sahu and Nayak, 1994). These scholars argue that mainstream economics limits itself to the study of phenomenon of "relative" scarcity, which already presupposes

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[2] I use the term "economic thought" to separate research on economics from economics-influenced discussions in e.g. policy sphere, or what Kwak (2017) calls "economism".

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that "scarce" goods can be substituted for other goods or that more of the scarce good can be produced by reallocating resources differently (Baumgärtner et al., 2006). However, while innovation response to scarcities has been studied extensively at a macro level (see e.g. Bretschger, 2005), our understanding of what drives technological substitution decisions made by those who actually decide to develop new technologies — the "technologists" — could still be improved (Bretschger, 2005). The open question motivating this study is the decision-making logic of the technologists: when and why do they choose to develop technological substitutes, and when do they adopt other courses of action?

The task of developing empirically grounded insights into the microlevel dynamics of induced innovation largely falls to the lap of innovation studies. Accordingly, an emergent "ingenuity" research stream within innovation and management studies has studied the concept of constraints and scarcities and their impacts for innovation (for overviews, see Lampel et al., 2014; Gibbert et al., 2014; Gibbert and Välikangas, 2004). This research has found, for example, that financial constraints may in some cases result to better performance from groups engaged in innovative work (e.g. Scopelliti et al., 2014; Hoegl et al., 2008; Keupp and Gassmann, 2013; Weiss et al., 2014; Katila and Shane, 2005), or that some scarcities have been solved through innovative solutions (Korhonen and Välikangas, 2014; Gibbert and Scranton, 2009; Gibbert et al., 2007). Other works note that "bottom of the pyramid" approaches to lean product development can produce superior products (e Cunha et al., 2014). Nevertheless, there is a gap between these positive micro-level studies and generally negative high-level econometric findings (Newell et al., 1999; Roediger-Schluga, 2004). Some scholars caution against drawing too firm conclusions from the research, as the overall outcomes of scarcities and constraints do not seem to accelerate technological change (Roediger-Schluga, 2004) or may only result to somewhat quicker adoption of technologies that would probably have been adopted anyway (Korhonen and Välikangas, 2014; Yarime, 2007). If the latter case holds true more generally, the prospects of overcoming environmental and other scarcities through technology-enabled substitution become significantly bleaker.

This paper seeks to answer the call put forward by Bretschger (2005) and build links between the scarcity and innovation literature through (mostly) theoretical but empirically informed discussion of the prospects of technology in overcoming scarcities. This study also expands upon prior case studies of scarcity-induced innovation or technological substitution (e.g. Hoogma, 2000; Gibbert and Scranton, 2009; Roediger-Schluga, 2004; Korhonen and Välikangas, 2014) and helps explain why some technologies may be easier to substitute than others.

My focus is on the fundamental choices made by those who develop technologies, rather than on the organizations where the technologies are developed. While the latter are undoubtedly of great importance for understanding how scarcities can induce innovation, the behavior of organizations facing scarcities has been studied in numerous fine studies already (e.g. Weiss et al., 2014; Hoegl et al., 2008; Katila and Shane, 2005; Galunic and Eisenhardt, 2001; Noci and Verganti, 1999). However, these studies are usually limited to financial constraints (i.e. the standard economic scarcity) and do not generally consider whether the technology used might have some influence in the outcome. Furthermore, prior studies have not explicitly addressed the decision-making by technologists (as individuals or as a group), even though it is individual people who actually make the decisions whether or not to attempt to develop substitutes. While the motivations behind important technological decisions are undoubtedly complex, I will attempt to outline some possibly rational reasons why technologists sometimes choose to develop substitutes, and sometimes resort to other means to secure access to required resources or simply cope with the scarcity. Even though this question could be sidestepped in a standard neoclassical analysis by arguing that technologists develop new technologies when the costs of inaction exceed the costs of action, I believe that a more detailed unpacking of the substitution decision would be valuable for advancing our thinking about resource scarcities and technological substitution.

Unfortunately, this focus on technological decisions will require me to abstract out the indubitably important role markets play in scarcity responses: for the purposes of this paper, the resource allocation role of markets is assumed to happen through cost/benefit calculations comparing various technological options. That said, I believe that the analysis can be readily extended to cover the role of markets, should a need arise.

The discussion here is necessarily interdisciplinary, requiring insights from several different research streams. From economics, I build upon recent thinking about the nature of scarcities, and particularly on Daoud's (2007, 2011) concept of "quasi-scarcities" as an additional type of scarcity besides absolute and relative scarcities (cf. e.g. Baumgärtner et al., 2006). From innovation studies, I draw upon increasingly influential theory of technologies as recombinations of existing mental and physical components (e.g. Savino et al., 2015; Fleming, 2001; Arthur, 2007, 2009). This "recombinatory innovation" theory provides a simple yet detailed enough view into inner workings of technological systems and how they can change as a response to scarcities. A particularly valuable lesson learned from recombinatory innovation theory is that the technologies are not alike. The interdependence of technology's components, for instance, can influence the difficulty of altering existing technological systems. As such, it should help us to understand better how, and when, scarcities can help promote innovation that effectively substitutes the scarce resource — and when we should be suspicious of techno-optimist claims.

The paper is structured as follows: first, a brief review of the concept of scarcity in economics, including Daoud's (2007, 2011) concept of quasi-scarcities; second, an introduction into recombinatory theory of innovation, followed by the main theoretical contribution — a model of recombinatory, scarcity-induced innovation. Next, this model is applied to two brief historical case studies to illustrate the mechanism in action. Finally, a discussion and conclusions are provided.

2. Scarcity Economics: Perhaps Everything Isn't Relative?

A widely accepted definition of modern economics maintains that economics "studies human behavior as a relationship between ends and scarce means which have alternative uses" (Robbins, 1932, p. 15). As Baumgärtner et al. (2006) note, from this it is often concluded that economics is essentially about optimization under constraints, which are merely expressions of scarcities. However, Baumgärtner et al. (2006) and many others (for a review, see Daoud, 2011) have noted that modern, neoclassical economics defines scarcity only in a relative way. In this formulation, in order to obtain more of the scarce good A, one must give up something else, B. However, it is implicitly assumed that more of A will always be available, if only sufficient value of B is exchanged. In many cases, this is a reasonable simplification: as long as elementary resources are fairly abundant, giving up one consumption bundle ("A") allows the production of another bundle ("B"). Furthermore, people are often willing to accept such substitutions. Thus, goods are thought to be substitutable either on the production side or the preference side (Baumgärtner et al., 2006).

The extent to which this is the case in reality is, however, open to discussion. Many scholars argue that in practice, some resources may not be substitutable (e.g. Baumgärtner et al., 2006; Daoud, 2011, 2007; Tchipev, 2006; Raiklin and Uyar, 1996). Common examples include living species, which cannot be replaced if extinct; another example might be bread in a besieged, starving city (Baumgärtner et al., 2006). Although the distinction between essential and non-essential or "elementary" and "imaginary" needs may be fuzzy (Lähde, 2013), it seems