Stronger Together: Frameworks for Interrogating Inequality in Science and Technology Innovation

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Abstract

Over the past two decades undone science and inclusive innovation were developed to explain knowledge silos, and technology and development for marginalized communities. The undone science framework describes the systematic neglect of scientific issues that impact marginalized groups. Inclusive innovation framework emphasizes the need to produce innovations that directly benefit marginalized groups. Despite the similar goals of the frameworks, the undone science and inclusive innovation theoretical communities have not interacted with each other, and as a result, the insights from each framework fail to help other disciplines improve opportunities for marginalized groups. This paper compares the frameworks and shows how they can help development scholars and practitioners create better policies for marginalized groups. Because the frameworks emphasis slightly different issues, we believe that these two theoretical frameworks are stronger together.

INTRODUCTION

There is a longstanding interest in using science and technology innovation to address problems of inequality and economic development. For example, a common question in innovation policy, and one that drives the authors to pursue this field, is, “How can a low-income country transform into becoming a global innovation powerhouse?”. To answer this question the authors studied science, technology and development around the world. Williams (2019) works in India and Nepal examining non-profit organizations that develop technologies and drugs for poor, rural and blind patients (a non-market of non-users). Meanwhile, Woodson works in Brazil, South Africa and Kenya on the impacts of nanotechnology and 3D printing on development (Woodson 2015; Harsh et al. 2017).

Even though we share a similar passion for understanding the impact that technology has on marginalized communities, we approach the topic from two different intellectual frameworks. Williams bases her work on the undone science and undone technology theoretical frameworks in the sociology of ignorance. Undone science and undone technology scholarship comes from the academic disciplines of sociology, history, and science and technology studies, and highlights the fact that society’s values and norms shape science and technology production and distribution and durable inequality (Taylor 1995; Hess et al. 2016).

Much of the undone scholarship has focused on Western Europe and North American (Hess 2016; Frickel et al. 2010). Only recently have scholars expanded undone science and undone technology to examine knowledge production in developing countries. Williams (2017) used the undone science and undone technology frameworks to examine eye care in India and Nepal and Reyes-Galindo (2017) loosely draws upon undone science scholarship to study fraudulent molecular detector technology's diffusion in Mexico. Arancibia and Motta (forthcoming) use the undone science framework to explain how activists in Argentina generated scientific knowledge about environmental health and illness and utilized a variety of scientific and legal expertise to get certain types of pesticides banned.

On the other hand, Woodson focuses on inclusive innovation which combines insights from science and technology policy and development studies (Woodson 2015; Williams and Woodson 2012). Scholars studying inclusive innovation tend to come from economics or public policy backgrounds. They frequently draw upon concepts from evolutionary economics which seeks to correct assumptions in classical economics that people and institutions are rational actors. Rather, people and institutions are boundedly rational and make judgements as best as they can with the given information. People use heuristics, trial and error, and satisficing techniques to reach conclusions (Niosi 2008). From the beginning inclusive innovation scholars have primarily studied innovation in developing countries. The earliest studies of inclusive innovation examined issues like frugal innovation in India (Papaioannou 2014), or grassroots innovation in Brazil's social technology networks (Fressoli et al., 2014).

It is remiss that two frameworks studying similar social problems have not engaged each other. The lack of dialogue between inclusive innovation and undone science limits our ability to understand science and technology (S&T) issues in developing countries and marginalized communities. Since one intellectual framework alone cannot account for all S&T issues, this lack of dialogue also creates intellectual silos that prevent scholars from better understanding S&T's impact. For example, developmental economics might under appreciate how culture and history affect economic growth.

This paper compares the frameworks and shows how they can help development scholars and practitioners create better policies for marginalized groups. The paper begins by defining the frameworks and discusses the advantages and disadvantages of them. Then the paper uses the frameworks to analyze nanotechnology development in South Africa in order to highlight their different approaches on development. Finally, the paper ends by giving strategies on using undone science and inclusive innovation to make science and technology more inclusive.

Undone Science, Ignorance and Restricted Access to Normal Science

David J. Hess first discussed undone science in 1998 at the annual Society for Social Studies of Science meeting. Hess coined the term to underscore how particular science questions and activities are systematically underfunded to serve the interests of the powerful (Hess 2016; Woodhouse et. al 2002). One definition of undone science is "the systematic non-production of knowledge in the institutional matrix of governments, industries, and social movements…" (Frickel et al. 2010, 445). Undone science corresponds to negative non-knowledge, "that which is stifled or avoided when viewed from the perspective of those who would think or feel intuitively that the findings of studies might produce results damaging to their interests" (Warren 2015, 261).

This contrasts with nescience and ignorance in normal science. Nescience is when experts are unaware that they do not know something in the present time, but in retrospect they can recognize that they did not know something (Gross 2010). Therefore, nescience is extremely common as every scientific discipline has "unknown unknowns", or, information that they do not know is relevant to their field of study. Ignorance in normal science is the information scientists often call the "known unknowns". The main function of science is to identify something researchers do not understand (positive non-knowledge) and then ask more questions to better comprehend the phenomenon (Kuhn 1970).

In normal science there is positive non-knowledge which is different than the negative non-knowledge produced by undone science. Undone science asks two essential questions: first, whose interests are served by the existence of negative non-knowledge, and second, what actions by the underserved and their allies will address the inequality present? Neither governments nor corporations are a starting place for getting undone science done because they are often the main institutions that define priorities, fund projects, and give out awards to top scientists. Therefore, scholars can use the undone science literature to critically interrogate science and technology practices of governments and corporations.

Undone science scholars list four structural actions (or inactions) that contribute to ignorance. The first three occur within undone science, where non-knowledge exists because of the bandwagon effect, ethnocentric effect, or chilling effect, and the last occurs with normal science where access to knowledge is restricted.

Bandwagon Effect, infrastructure and negative non-knowledge

The bandwagon effect describes the production of undone science by blocking some (or all) of the necessary research infrastructure (e.g., human personnel, equipment, instruments, standardized inputs, test subjects, etc.), thereby creating research areas that cannot be studied and therefore non-knowledge. For every grant that is awarded, there are dozens other scientific studies not funded. Essentially, government or corporate officials prevent exploring particular areas of science, and thus, deem it insignificant. Though this sounds nefarious, there are legitimate reasons not to pursue certain lines of research. Most of society may deem a research program immoral (i.e., developing a biomedical research program to clone people for organ harvesting), or, given their limited resources, organizations may deem that a certain topic will not yield the most return-on-investment. This can lead to science funders following the same science bandwagons (Fujimura 1987; Whitley, Gläser, and Laudel 2018). Areas that seem desirable or fruitful by powerful interests receive more funding and attention. In contrast, areas that are not deemed important by powerful interests (but may be important to marginalized groups), receive no funding, and are effectively undone science. In current science policy, stem cell and gun research are clear examples of the bandwagon effect.

Ethnocentric Effect, scientific cultures and negative non-knowledge

The ethnocentric effect describes when scientific knowledge produced by one scientific culture is valued over others, and therefore, the science gatekeepers create negative non-knowledge. Research is shaped by a scientific culture in a specific temporal and geographic space, and often, scientists do not equally value knowledge from different scientific cultures (Hess 1995; Harding 2008). Instead some cultural identities are valued as having more credible knowledge than others (Englander 2014; Dotson 2014; Pereira 2018). For example, European Cartesian mathematics, African fractal-based sand divination (Eglash et al. 2004) and Polynesian indigenous marine navigational knowledge (Turnbull 2000) are all complex mathematical knowledges but are valued differently. European Cartesian mathematics is viewed as real science, while the other forms of knowledge are considered by many to be superstitions or cultural traditions. Since S&T funders and practitioners value European Cartesian mathematics more than the other mathematical knowledges, then it will receive research support. Meanwhile, the other types of math will be underfunded and the knowledge that could be produced from these neglected mathematical research trajectories will remain unknown.

The ethnocentric effect is often difficult to identify because it occurs through gatekeeping processes by colleagues and mentors that shape the epistemological worldview of a field (Dotson 2014). For example, mentors guide students to read specific scientific literature, journals accept particular types of scholarship, and esteemed science institutions honor only certain types of research. These gatekeeping processes are a "death by a thousand cuts"; the epistemological underpinnings of good knowledge production are slowly cut away by the knowledge practitioners who do not value a culture's knowledge. The de-valuation of alternative epistemologies frequently happens between competing nation states and ideologies (like capitalism vs communism) or divergent cultures and religions (Buddhist ethics vs Judeo Christian ethics).

Chilling Effect, discrediting and negative non-knowledge

The chilling effect prevents knowledge production and distribution by discrediting a line of research. By blocking the creation and flow of knowledge, the chilling effect creates negative non-knowledge and undone science. Frequently, the chilling effect happens when a government agency, company, or other elite institution has an incentive to ensure knowledge does not flow because the information would harm their organization. To prevent embarrassment, the organization simply blocks or discredits a line of research (Greenberg 2003). Such chilling effects are commonly encountered by scientists when they present new scientific knowledge that challenges the normal science in their field or runs counter to powerful interests in their field (Martin 1981). If a scientist is humiliated and ostracized by their supervisors and peers, then that scientist is less likely to freely share their research results in the future (Delborne 2008; Warren 2015).

Two well-known examples of the chilling effect in the United States come from the tobacco industry's efforts to minimize the distribution of information about side effects of tobacco usage ("doubt is our product") and the sugar industry's denial of research that suggests eating a lot of sugar could cause increased health problems including obesity (Howard 2016; Michaels 2005, 96 citing Reynolds tobacco; Sanabria 2016).

Normal Science and Restricting Access to distribution of knowledge

Normal science draws a sharp boundary between those who can produce certified knowledge (scientific experts) and those whom consume that knowledge (scientists or the public). Accessing knowledge is an important problem with social justice implications. The public regularly pays for research, but they cannot use the knowledge and technology generated from the research because access is restricted through mechanisms like firewalls, patents, and licenses to benefit for-profit companies (Parthasarathy 2017; Contreras 2013). The policies that shape this restricted access to science and technology typically occur during knowledge, science and technology diffusion in the market. The following section reviews the literature on inclusive innovation.

Inclusive Innovation

Inclusive innovation has intellectual foundations from public policy, economics and development studies. A founding father of innovation studies, Joseph Schumpeter, proposed concepts like creative destruction and the need for constant renewal for an economy to function (Schumpeter 1950; Martin 2012). Later these models were refined by scholars, like Schumacher, who wrote books about appropriate technology to innovate products to fit the contexts where they will be deployed (Schumacher 1973). Appropriate technology was novel because it emphasized that economic growth and innovation in developing countries would look different than rich nations. In poor nations, it might be more important to build factories that employ a lot of people instead of building a highly automated factory with limited jobs (Schumacher 1973). At its core the appropriate technology movement was concerned with the impacts that innovation would have on marginalized communities. However, the appropriate technology movement was criticized for promoting inferior and less efficient technologies (Willoughby 1990; Akubue 2000).

In the 1990's Prahalad emphasized inclusive capitalism and the fortune at the bottom of the pyramid. Prahalad's argument is that the poorest billion people, those at the bottom of the income pyramid, have tremendous capital as a whole even though each individual person may be extremely poor. If innovators make inexpensive products for the bottom billion, they could still make substantial profits. This is because over the next few decades the incomes of the bottom billion will rise, giving them more disposable income that allows them to buy more goods. As a result, there are enormous profit opportunities for companies if they can make products that meet this population's needs. A smart CEO should see the potential of this market and create products for them (Hammond, Prahalad 2004).

From models like appropriate technology and the bottom of the pyramid innovation, scholars developed a variety of other frameworks to explain inclusive innovation. One of the most prominent models is the ladder of inclusive innovation.

Inclusive innovation has a variety of definitions. One early definition of inclusive innovation that was created by a working group at the Organization for Economic Co-Operation and Development (OECD) is "harnessing science, technology and innovation know-how to address the needs of lower income groups (Paunov 2012, 9)." Similarly, Heeks, Foster & Nugroho (2014, 177) define inclusive innovation as "the inclusion within some aspect of innovation of groups who are currently marginalised". Their definition is broader than the OECD definition, because it considers that a community can be marginalized based on a variety of non-economic factors. The definition embodies much of the literature on horizontal inequalities showing that many inequalities are based on socially defined groups like gender, race, or religions (Stewart, 2000). For example, in some communities, ethnic minorities face unique challenges that keep them from going to school, getting a job or accessing capital. Acknowledging and understanding horizontal inequalities is crucial for better development policy. Policy makers and development practitioners cannot adequately help people if they only focus on increasing economic standing without considering the impacts of horizontal inequalities.

Inclusive innovation goes beyond traditional innovation. Traditional innovators often focus on individuals with economic, political or social power and develop new products to service them. Though innovation does not have to benefit powerful groups, the implicit and explicit incentives, such as laws regulations, subsidies and accolades, encourage traditional innovators to create for on middle and upper- income consumers. For example, Thomas Edison, Bill Gates, Steve Jobs, Elon Musk, and Mark Zuckerberg explicitly designed products for high income and powerful consumers of their time and were rewarded with high status and wealth. Inclusive innovation, on the other hand, must work against the status quo of traditional innovation to develop a product for marginalized groups with few accolades (Williams 2017).

One good framework to represent inclusive innovation is the ladder of inclusive innovation. The ladder of inclusive innovation as developed by Heeks, Foster and Nugroho and has six rungs to categorize increasing degrees of inclusion (see Figure 1 Ladder of Inclusive Innovation) (Heeks et al. 2013, 6; Heeks, Foster & Nugroho 2014, 178). The first rung, inclusion of intent, is an innovation with the goal to be inclusive, although it does not actually have to achieve inclusivity. Many of the failed development projects scattered across low-income countries sit on this rung. The second rung, inclusion of consumption, classifies innovations that are used by marginalized communities. There is a slightly higher threshold for an innovation to reach rung

2, but the innovation still does not need to have a positive impact on the intended population to reach this level. Several water schemes fit on this rung (Borland 2014). The technology is used by the intended population, but it is unclear if it benefits them. For an innovation to reach the third rung, inclusion of impact, the innovation must have a positive impact on the marginalized group. As the case study will show, many innovations can reach rung 1 and 2, but it is much more challenging developing an innovation that actually helps marginalized groups.

The fourth, fifth and six rungs evaluate the innovation through a broader lens. The fourth rung, inclusion of process, involves marginalized communities in the innovation process. Although this might seem an obvious requirement to create a successful innovation, many technologies that are supposed to be inclusive are not designed with the full support, consultation and input from any marginalized group. Instead, designers rely on I-methodology (Oudshoorn, Rommes and Stienstra 2004). The fifth rung, inclusion of structure, are innovations that are designed "within a structure that is itself inclusive" (Heeks, Foster & Nugroho 2014, 178). This means that the systems and institutions that fund, create, and produce innovations are inclusive.

Finally, rung six is the hardest level of inclusive innovation to achieve and the most amorphous. At the sixth rung, post-structural inclusion, innovations must change the discourse and frames of knowledge to be more inclusive. For innovations to reach this level, the assumptions about science, gender, and knowledge creation must change.

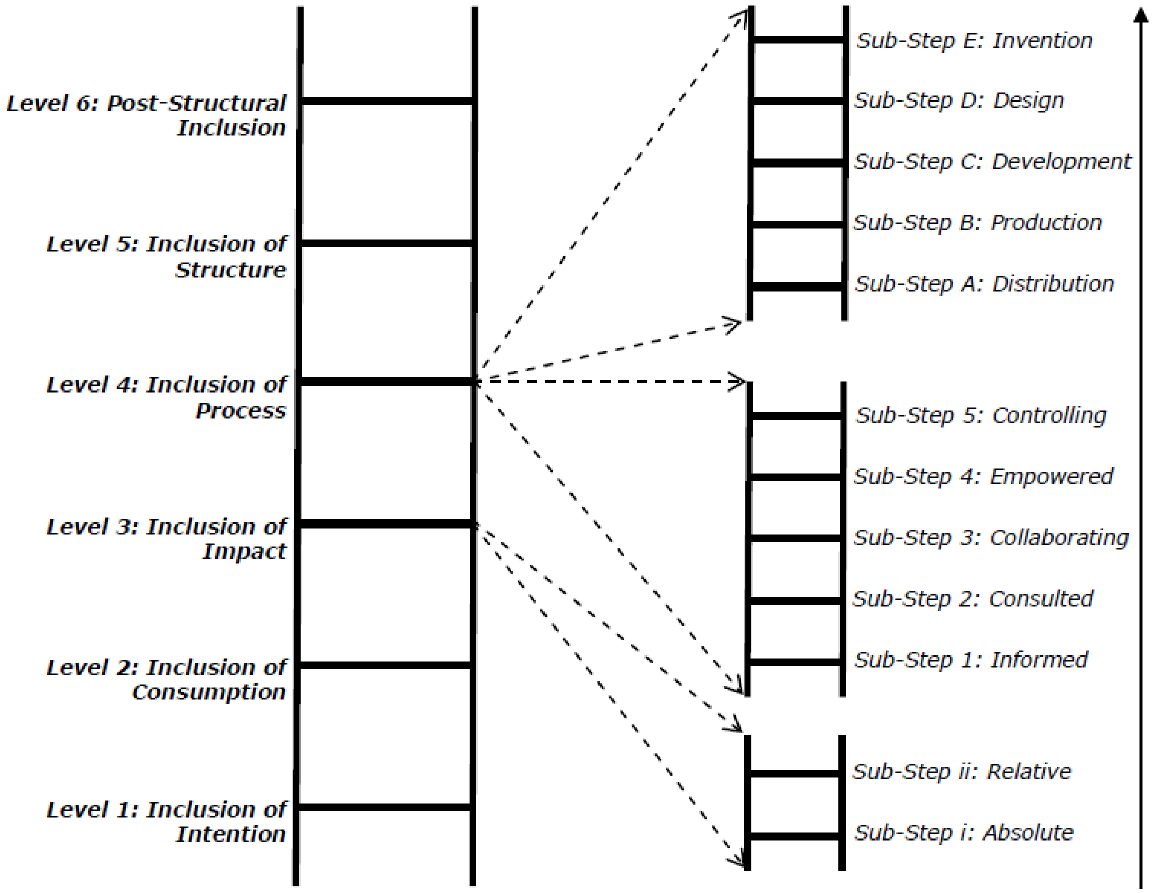

Figure 1: Ladder of Inclusive Innovation (from Heeks et al. 2013)

Comparison of Inclusive Innovation and Undone Science

Inclusive innovation and undone science have several commonalities. An underlying assumption of undone science and inclusive innovation is the normative belief that inequality and poverty is a problem that science and technology can reduce. Undone science emphasizes the generation of negative non-knowledge and inequality. It points out the underlying value system guiding knowledge and innovation production and the hidden inequality in research-agenda setting that biases new scientific knowledge and technology to attend to the problems of the elite and ignore the problems of the marginalized. Inclusive innovation suggests social science-based ways of implementing innovation projects to solve problems of inequality. Both frameworks are interested in structural and institutional change.

Second, undone science and inclusive innovation both expand the boundaries around who is authorized as an expert to do science and make S&T decisions. The theoretical frameworks are interested in expertise from inside and outside of the invisible college; people who are not credentialed in the same way as experts, but still interested in propelling science. Sometimes undone scientists are lay scientists or scientists who are outside the mainstream. Other times, undone scientists are disciplinary experts interested in social problems. Likewise, the upper rungs on the ladder of inclusive innovation specifically indicate the need for including marginalized perspectives to make an innovation more inclusive (Heeks et al. 2013). Heeks et al. (2013) discuss grassroots innovation as central to inclusive innovation. This is a convergence with undone science because, as Hess (2016) discusses, social movements that form industrial transition movements are key ways that local organizers and activities can influence larger social change by including recent technologies and information into the socio-technical system.

In addition to the convergences between these two theoretical frameworks described above, there are significant divergences. The first difference relates to their focus areas. Inclusive innovation judges the equity of tangible outcomes, while undone science uncovers un-examined problems of inequality. The theoretical framework of inclusive innovation is closely related to seeing tangible equitable outcomes through making and distributing a recent technology or by changing an institution, standards, or regulations. The action oriented nature of inclusive innovation is especially apparent given that a founding document for this theoretical framework was written by the OECD (Paunov 2012). By its nature, the OECD is a policy organization with a mission "to promote policies that will improve the economic and social well-being of people around the world" (OECD 2017). Thus, it is evident the inclusive innovation ladder is already used by policy-makers as a tool to judge the equity of an innovation. Not every paper drawing upon the inclusive innovation ladder may have explicit policy recommendations, but the goal remains to influence governments and policy.

Although undone science is not as action oriented as inclusive innovation, it still provides practical insights to practitioners. By uncovering un-examined problems such as a failed market of non-users, scientific research that has been hidden or blocked by special interests, or ignored scientific research questions, this theoretical framework points towards new research questions, scientific agendas, and ways of valuing technology products. In contrast to the inclusive innovation ladder, these new questions and valuing processes come through critique instead of through comparison with an idealized protocol.

Another difference between undone science and inclusive innovation is their approach to knowledge diffusion. Undone science explicitly tracks the non-diffusion of non-knowledge by critiquing whether it has been intentionally (or unintentionally) prevented from flowing and whether strategic ignorance is used to support elite interests (Sanabria 2016). Similarly, undone technology questions the non-diffusion of immaterial non-artifacts because of the primacy of shareholders enforcing a profit incentive in companies (Williams 2017). Furthermore, both undone science and nescience suggest that some things are impossible to know for both technical and financial reasons (Hess, 2016). Inclusive innovation employs a subtle belief that knowledge is always accessible, it just needs to be translated and circulated to the correct entities.

In summary, the two frameworks ask different questions. Inclusive innovation asks, "What is the next step to make science, technology and development more inclusive?". Meanwhile, undone science asks, "How can we better understand whose interests block science and technology development and dissemination?" and "Whose interests are not considered during agenda-setting?".

Undone science and inclusive innovation share an overt orientation towards social change, although, they work towards it using different approaches. While both are theory-oriented, inclusive innovation is more of a heuristic tool with a checklist to determine an innovation's level of inclusivity. Such a tool is useful to compare one innovation to another. Meanwhile, undone science provides a suite of concepts (interested parties, chilling effect, bandwagon effect, ethnocentric effect, non-knowledge, negative non-knowledge, non-market, non-artifact, non-users, non-producers). These concepts enrich analysis of the (otherwise hard to uncover) problems facing marginalized groups in the preliminary stages of research agenda setting. Table 1 summarizes some of the points of comparison between both theoretical frameworks.

Table 1 Undone Science versus Inclusive Innovation: Distinct Settings and Approaches

Theoretical Framework	Geo-political Location	Action	STP process	Intervention Tool
Undone Science	Primarily marginalized groups in the global north; but new research on marginalized groups in global south	Uncovering unexamined problems of inequality	Focused on the values and interests shaping S&T trajectories; broaden definition of knowledge and who can access it	Suite of concepts for critique: interested parties, bandwagon effect, ethnocentric effect, chilling effect, non-knowledge, negative non-knowledge, non-market, non-artifact, non-users, non-producers
Inclusive Innovation	Primarily marginalized groups in the global south	Comparing equity of tangible outcomes to ideal model	Engage marginalized groups early in STP research agenda-setting and policy-making	Heuristic Tool: Ladder of Inclusive Innovation
Together: Undone science and Inclusive Innovation	Both global north and south	Targeting the agenda setting in research, design and development	Creating new structures that engage marginalized communities in research, design and development	Combine the suite of concepts from undone science and undone technology with the heuristic tool from inclusive innovation to ask perceptive questions about new structures of inclusion

CASE: NANO-TECH IN THE GLOBAL SOUTH

To show the similarities and differences between undone science and inclusive innovation, we use both the frameworks to analyze a case study on nanotechnology R&D in South Africa. The case study illuminates the accomplishments and shortcomings of the theoretical frameworks to help marginalized communities in nanotechnology. Even though the case study is only one situation in a unique context, some of the problems faced by South African policy makers are repeated in other places and contexts throughout the world.

Background

Nanotechnology has many definitions, but in general, it is the manipulation of matter between the 1-100nm (Balogh 2010). At this scale, matter behaves differently, and scientists can make many novel products because the particles are so small. For example, scientists hope to use nanotechnology to create new medicines, stronger and more flexible materials, more efficient batteries and solar cells, and new types of water filters (Salamanca-Buentello et al. 2005). For 50 years, scientists have discussed building and designing technologies at the atomic scale. In 1959 Richard Feynman discussed writing the encyclopedia or the head of pin or creating tiny robot that can swim through the blood stream and fix problems (Feynman 1959). Since 1959, scientists have regularly improved their ability to manipulate manipulating matter at the nanoscale, and in 2000, the USA started the National Nanotechnology Initiative to promote nanotechnology research (Roco 2011). This was followed by an explosion of other nanotechnology initiatives around the world (Maclurcan 2010).

In addition to research intensive counties in Europe and Asia, many countries in low and middle income countries started nanotechnology programs (Maclurcan 2010). Despite the expensive cost of conducting nanotechnology R&D, low and middle income countries got involved in the research because they believed nanotechnology would be the next major technology revolution and they did not want to be left behind in their major technology shift (Hassan 2005).

South Africa started their national nanotechnology initiative in 2005 with an investment of about R170 million rand (26 million USD) (Claassens and Motuku 2006). A core tenet of the initiative was that the country would focus on industrial and social technologies that best help their country thrive (Department of Science and Technology South Africa 2005). Within the industrial cluster the country would invest in R&D on chemical and bio processing, mining and minerals, and advanced manufacturing and within the social cluster the initiative focuses on water, energy and health technologies.

Undone science and Undone technology: uncover the unexamined inequality

South Africa actively tried to overcome many of the traditional barriers for undone science and technology, yet, it hit many roadblocks. Nanotechnology itself is framed with traditional scientific terms, and hence, it marginalizes some knowledge. For example, nanotechnology R&D prioritizes western strategies to explore the field. Traditional technologies and medicines are overlooked as sources of potential research questions and knowledge. The initiative relies on mainstream normal science paradigms to design research problems, solve problems and manage the science infrastructure. Also, nanotechnology research is very exclusive because researchers are required to use expensive equipment. Unless a person is highly trained, they are excluded from nanotechnology R&D.

The nanotechnology initiative set up clear bandwagon effect. The initiative directly targeted certain areas of research and therefore deemed R&D outside of those focus areas as not relevant for the purpose. South Africa's nanotechnology initiative concentrated on very important areas that would help the entire population, but the unintended consequence was a strong bandwagon effect. For example, in interviews nanotechnology researchers in South Africa mentioned that the nanotechnology initiative directed their efforts towards the industrial and social clusters and scientists knew that if they would not be funded for research unless the projects closely aligned with those goals. From the government's perspective, the researchers' alignment with the nanotechnology clusters is a success because it shows that their science policies effectively shaped that research landscape. However, having a narrow research agenda creates a lot of undone science in the system.

Finally, we saw a case where the normal scientific development system prevented technology from researching marginalized communities. In one famous example, a South Africa professor developed a tea-bag water filter (Harsh et al. 2017). The idea was that a person could put a teabag shaped filter into a bottle of dirty water, and after a few shakes, the water would be clean. It was a potentially revolutionary innovation and had obvious benefits for people in low-income communities. However, developing, marketing and pricing the technology was a challenge. The water filter would help low income communities, but it was also appeal to hikers in wealthy countries. There was no market for filters in low income countries, and therefore, the teabag water filter for low income countries did not materialize as expected.

Inclusive Innovation: evaluate the degree of inclusivity

South Africa's nanotechnology initiative was geared towards inclusivity, and therefore, many of the initiative's goals promote inclusive innovation. Rung 1 inclusion of intent, is clear in the nanotechnology initiative. One major thrust of the initiative is developing health, water and food technologies that help the poor. The initiative also prioritizes capacity building for marginalized communities. These goals make the initiative easily meet the threshold for the first rung. It is harder to evaluate South Africa's progress on rung 2, inclusion of consumption, and rung 3, inclusion of impact. Nanotechnology is still a recent technology and very few nanotechnology products are available. One tangible example of nanotechnology being employed in the field, a rural school using a nanotechnology water filter, had many problems. At the time the scholars visited the school, the filter was not working, and the filter was about to be decommissioned and moved to a new school across the road. However, the engineers building the new school did not incorporate the new water filtration system into the design of the new school (Harsh et al. 2017).

There is also little evidence to support rung 4, inclusion of process. The South African National Nanotechnology strategy adopted by the Department of Science and Technology was primary developed and pushed through by the South African Nanotechnology Initiative (SANI). SANI is a group of academic and industrial researchers interested in nanotechnology. There is little evidence that South African officials discussed the plan with local communities as they developed their strategy. Instead, the national nanotechnology strategy was developed by bureaucrats and political leaders in the Department of Science and Technology (DST). Politicians are the representatives of the people, and hence the public had some voice in the room, but in general, marginalized communities had little control in developing the nanotechnology strategy.

In the water filter project at the school, the community was involved in the early discussions of building and operating the filter system. However, the community still has very little ownership of the system because it was located behind a gate on school property to ensure that it was not tampered with. Consequently, the community had no ownership of the system, but rather it seemed like a pet project of the school principal.

Despite not seeing a lot of evidence of inclusive innovation at the lower rungs, there is some evidence of inclusion of structure and post-structural inclusion. A key part of the initiative is education and capacity building and the government is especially keen to improve the education outcomes of marginalized communities. Throughout our time in South Africa, we saw a lot of evidence of the education system targeting marginalized communities such as women in STEM fields and low-income students. In addition, South African universities are a hub for researchers across Africa and there were many non-domestic African students studying at the universities with hopes of returning home to start their own research labs. These changes will promote structural and post-structural changes.

FRAMEWORK TO INTERROGATE INEQUALITY IN SCIENCE AND TECHNOLOGY

The above literature review and case study on inclusive innovation and undone science point to three strategies that individuals or civil society organizations can use to spur innovation for poverty alleviation.

Strategy 1: **uncover** the unexamined inequality before an innovation is proposed or marketed

Before policy makers even begin policy analysis, they must realize the undone nature of science and technology. The problems that policy makers consider as relevant are directly related to their worldview. To prevent themselves from following the standard science paradigms, policymakers should ask questions such as, whose interests are served by the existence of negative non-knowledge and who has social, political or economic power to decide which research problems are relevant. Policymakers must know that powerful interested parties intentionally and unintentionally prevent the research from being done by funding some research problems and infrastructure and not others. They should consider how their ethnocentric privilege and potential bandwagon effects impacting their thinking. It is impossible to be completely isolated from bias, but it is important to be aware that bias exists when working with various stakeholders and pursue systematic reflection to mitigate it.

Strategy 2: **maximize** the inclusion of marginalized communities in the innovation process during policy analysis

The inclusive innovation ladder is a useful tool to reference when planning international development projects. Are the researchers operating from rung 1 or rung 6? All the rungs of the ladder (2013) promote inclusive innovation, however, rung 4 is the most relevant for policy development. Policymakers can use rung 4 to guide their policy analysis process alongside the traditional policy analysis eight-fold path (Bardach 2000). For example, when constructing the policy alternatives, policymakers should consider whether marginalized groups are just informed of the project (sub-step 1) or do they control the entire process (sub-step 5)? Are marginalized communities only involved in the distribution of the solution (sub-step A) or are they inventing the solution (sub-step E)? It may be hard to immediately transform an overlooked group into inventors, but that is the direction policy makers should move.

Strategy 3: **evaluate** equity of tangible outcomes using the ideal model offered by Heeks et al. (2013) after an innovation has been produced and distributed

Later in the science and technology policy process, the inclusive innovation ladder and undone science framework can be useful for evaluating the degree of inclusivity for a project. Each rung of the ladder can be operationalized and used to determine the inclusivity of the project. It may be challenging to measure post-structural inclusion, but by considering all six rungs, the impact of projects on marginalized communities will be systematically evaluated.

Evaluators should also consider the groups that have access to the knowledge generated from their policies and programs. Do marginalized peoples have access to normal scientific knowledge that might impact their community? What social, political and economic structures are in place to ensure that marginalized people can easily access normal scientific knowledge that might impact their community? With the rise of open access initiatives, these questions are gaining more traction within research communities.

CONCLUSION

Both undone science and inclusive innovation are useful frameworks to improve the livelihoods of marginalized groups, but over the past decades these research communities have not interacted with each other. This research paper demonstrates how scholars studying undone science and inclusive innovation can draw upon each other's theoretical frameworks to further advance science, technology, and innovation policy for the needs and wants of less powerful groups. When paired together, their strengths each buffer the other's deficits. As demonstrated in the case study and tips for policy makers, the two frameworks are stronger when used together.

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