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Getting Undone Technology Done:

Global Techno-assemblage and the Value-chain of Invention

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Abstract

The global techno-assemblage shapes the continued lagging of southern countries and firms behind those from the global north. The biotechnology industry is one form of this assemblage and operates according to inter-related logics (i.e., economic, hybrid, and social) which are shaped by particular governmental policies, corporate decisions to minimize risk, and philanthropic efforts. Within this form, a non-profit ophthalmic consumables manufacturing company, Aurolab, in southern India creates new innovations. According to the "technology follower" conceptual framework by innovation studies and management scholars, biotechnology firms have two options to "move up" the international value-chain of invention: they must either "catch up" at a very high rate, or "leap-frog" up through research, design and development. Aurolab innovates to heal eye diseases. They focus on affordability issues through research and development as well as design and development. At Aurolab, they shift between these two strategies depending upon the drug or device they are working on. This paper considers additional incentives to re-focus firms on local needs-based technology according to a social logic. As Aurolab demonstrates, a new focus on technology to address structural inequality may be necessary to get "undone technology" done.

Keywords: undone technology, assemblage, value-chain of invention, leap-frogging, ophthalmology

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Introduction

Certain research questions, in science and in global public health, receive more attention from scientists, the public, and funding organizations than others. Hence the fact that billions of dollars have been given to fighting the Big 3 global health diseases in the global south (Moran et al., 2009): malaria, tuberculosis, and HIV/AIDS. Other neglected tropical diseases including both non-communicable diseases (i.e., injury requiring surgery; Ozgediz & Rivello, 2008) and communicable diseases (i.e., diarrhea, typhoid, leprosy and trachoma; see Moran et al., 2009) cause similarly poor health outcomes but do not receive nearly as much attention or funding.

Avoidable blindness is a problem that affects 39 million people worldwide and includes eye diseases that are: non-communicable (cataract, glaucoma, age-related macular degeneration, diabetic retinopathy) and communicable (trachoma, onchocerciasis). Unfortunately, avoidable blindness has largely been neglected by global public health programs: the biomedical sciences to treat many of these diseases are known, but patients frequently do not have access to surgical procedures, ophthalmic consumables, and pharmaceutical drugs. In other words, the research has already been done, but the design and development to make products for poor rural patients is not getting done.

Science and technology studies scholars have previously focused on elucidating the scientific production of knowledge gaps and ignorance (Frickel et al., 2010; Hess, 2015). Undone science exposes the systematic ignorance created by the military-industry-university research complex about specific research questions that are primarily of interest to persons who are non-elite and social movements (Hess, 1998; Hess, 2015). In comparison, this paper suggests that "undone technology" points towards the global power dynamics which shape the rewards of technology development. I argue that undone technology is a product or process that addresses problems of structural inequality by intervening in multiple stages of the artifact's lifecycle. This article illuminates how a non-profit firm operating in the global techno-assemblage can get "undone technology" done.

In the remaining sections, I will use the political sociology of science (Frickel & Moore, 2006) literature to reveal how the global techno-assemblage shapes the ability of particular individuals and firms to create inventions and innovations. The power dynamics of setting the research and development agenda in the U.S. has already been conceptualized by sociologists and political scientists in the political sociology of science literature. I will compare the concepts of undone science and orphan technology to my related new typology of undone technology. Next, I will explain the technology follower conceptual framework that emerges from innovation and management studies and its relationship to the hierarchical value-chain of invention. This hierarchical value-chain is apparent in my case of Aurolab. The many innovations produced by this non-profit technology firm offers an opportunity to extend Woodhouse's concept of "undone technology" (2010; Williams, 2013). I use my new typology of undone technology to explore how and why drugs and technologies are created to address the needs of persons with blindness and low vision in India. Finally, I suggest some implications for addressing structural inequality and for future work in the political sociology of science.

Global techno-assemblage of The Biotechnology Industry

Global assemblages emerge over time, and may involve new forms, reformations, or shifting forms (Ong and Collier, 2005 citing Deleuze and Guattari, 1987). The global biotechnology industry for devices and drugs is one such global techno-assemblage, emerging over time with the withdrawal of imperial forces (and thus public health medicines) from colonies. Post-colonialism meant the withdrawal of northern imperial military forces from the global south.

With no need to keep soldiers healthy (Johnson, 2008), such northern countries have no intrinsic incentive to innovate for communicable or non-communicable neglected tropical diseases that are more prevalent in the global south. Therefore, the biotechnology industry is one form of the “global techno-assemblage” which both deterritorializes international development and reterritorializes transnational networks of consumption and production.

Post-colonialism has also shaped Indian companies' emerging global prominence in the biotechnology and information technology industries. An independent India, under Prime Minister Nehru (1947-1964), had a grand imagination about state development projects especially dams and nuclear power (Abraham, 1999; Jasanoff, 2010; Bassett, 2009). Also, the government imitated models of excellence in technical education from MIT and other Western universities to create the Indian Institutes of Technology (Bassett, 2009). However, Nehru and colleagues also believed in the importance of local endogenous development for remaining financially independent and maintaining a sense of national pride and self-reliance (Jasanoff, 2010; Ninan, 2009). Meanwhile, the historical contingencies of being a former British colony meant that "British extraction science" helped to create good educational institutions in biology and chemistry (Tyabji, 2012). Also, the Indian Institutes of Technology had relationships with companies such as IBM which meant that lightly used "cutting edge" computer technologies were utilized to educate Indian students in the 1950s and 1960s (Bassett, 2009). The 1970 act abolishing patents on drugs and food was very important in India (Chaudhuri, 2013; Tyabji, 2012). It allowed more robust local industries to develop. Altogether, these early Indian policies allowed for endogenous development of biotechnology and information technology industries.

In the second decade of the 21st century, India has a well-developed biotechnology industry and information technology industry (Tyabji, 2012). The Indian Institutes of

Technology are highly acclaimed today and information technology fires the imagination about India’s leadership in technology globally (Radhakrishnan, 2011). Regulation is well established for pharmaceutical drugs and it is emerging for medical devices. This regulation involves two key government entities: the Government of India Central Drugs Standard Control Organization started in 1920 and the Drugs and Cosmetics Act in 1940 (Government of India, Ministry of Health and Family Welfare, 2014) and the India Patent Office and the Controller General of Patents, Designs and Trademarks (Government of India, Ministry of Commerce and Industry, n.d.).

The structural adjustment policies implemented by the Indian government in the 1990s, i.e., the World Trade Organization's Trade-Related Aspects of Intellectual Property Rights (TRIPS) which India ratified in 1995, removed some earlier industry protections (Tyabji 2012). Now the Indian patent policy regime prevents re-combinations of existing drugs into re-invented formulations to address local needs from being patented (Reid & Ramani, 2012). While this advantageously prevents multinational companies from "ever greening" their patents, unfortunately, it also removes the profit incentive for local companies to develop "low risk" drugs for local needs by making small tweaks in patented chemical formulas and gaining a new patent.

Meanwhile, from the 1990s onwards transnational partnerships and global drug development initiatives have expanded into India, but the result has been multinational companies increasingly using Indian firms for contract research and contract manufacturing (Abrol, 2004; Valdiya, 2010). Additionally, through Foreign Direct Investment, Indian pharmaceutical companies act as subsidiaries to the multinational companies for local production of globally marketed drug formulations (Chaudhuri, 2012; E&PW, 2012; Sampath, 2007; Tyagi and Chowdhry, 2015). Thus the resources and mission of these Indian pharmaceutical companies have shifted from endogenous technological development for local needs to technology and knowledge transfer to ramp-up local production for a global market (Abrol, 2004; E&PW, 2012; Valdiya, 2010).

Ong and Collier also note that "an assemblage is the product of multiple determinations that are not reducible to a single logic" (2005, p.12). The biotechnology industry is currently operating by three logics. The first is economic—the profit motive for firms. The second is encouraging research and development collaborations (i.e., public private partnerships) to share both financial risks and the rewards of intellectual property. The third is social, i.e., credit and status or the intrinsic satisfaction of "doing the right thing". This third logic does not work well alongside the existing market-based logics unless the profit motive is mitigated by de-linking research and development costs from product prices.

Within this global techno-assemblage, innovations are new products or processes that are novel to the organization, while inventions are novel to the world (and thus patentable). Technology leaders are those biotechnology firms (or companies) who capture high profits with patent monopolies for their novel inventions. Therefore, the global techno-assemblage actually awards a higher status to inventions as compared to innovations.

In the next sections I will challenge Ong and Collier’s (2005, p. 10) implication that sociological studies are too structurally oriented by suggesting instead that assemblages should be more structurally oriented. A deeper consideration of structures of power is very important, especially when thinking about the uneven power relations between the global North and global South that are embedded within innovation strategies. A constructivist analysis would usefully showcase how the positions of Indian firms in the global biotechnology industry (and thus relations of power) are historically contingent and have emerged and shifted over time. Such an analytical method is less able to identify the effects of long-lasting (but not fixed) power structures (Hess et al., 2016). North-South relations of power have been remarkably stable over the recent history of science, technology and development from the 1940s onwards with northern (formerly imperial) countries in dominant positions and southern countries in subordinate positions. The political sociology of science offers a toolkit of alternative concepts that helps to examine such structural inequality (Frickel & Moore, 2006; Hess et al., 2016).

A Typology of Undone Technology

A central concern of political sociology of science has been the study of ignorance and knowledge gaps in science. The concept, “undone science” (Hess, 1998; Hess, 2009; Hess, 2015; Frickel et al., 2010), helps to explain the U.S. military-industrial-academic research complex’s systematic inattention to particular problems of science and inequality. One way this systematic inattention is expressed is through a "research bandwagon" (Fujimura, 1988): the process by which junior scientists select scientific research problems that have already attracted funding rather than setting an original and novel research agenda. What these concepts cannot explain is how the drive to create intellectual property has affected design and development agendas around the world by equating a product’s value with its patentability.

The benefit of an increasingly market-based context for producing scientific knowledge and technology is that a lot of really innovative work is incentivized and thus reaches the public faster. The shortcoming is that the market context of research, design and development favors producing knowledge, science and technology production for those who can afford it. Firms, acting very rationally in the market, have no incentives to innovate when there is “market failure” (Murray & Townend, 2014; Uwland & Townend, 2014). Instead, technologies with market failure may be developed through the advocacy of technology and product-oriented social movements and industry reform movements which typically involve educated inventors, entrepreneurs, engineers, and middle- and high-income consumers with leisure time (Hess, 2005). Therefore, the same conditions of poverty and intersecting problems (i.e., poor education and poor nutrition) that lead to a potential technology's market failure is likely responsible for the absence of a social movement to address the technology needs of the world's poor.

One option to meet the needs of the world’s poor might be to re-characterize the definition of a market so that impoverished consumers are not equivalent to market failure. Along this vein, C. K. Prahalad and Stuart Hall's work (2002) on the "bottom of the pyramid" directs multi-national corporations’ attention to the potential profits from addressing the needs of the world's poorest 4 billion people with inexpensive products sold at high volume.

A second option is to look outside the military-industrial-academic research complex for public intervention by governments or non-profit organizations in the third sector (i.e., civil society organizations) to support research, design and development of technologies that address the needs of the world's poor (Hess, 2005; Hess, 2009; Williams & Woodson, 2012). One example of such public intervention is "orphan technologies", which are "innovations for which there is a need but no market" (Weiss, 2010; Weiss, 2013, p. 1201; Seelman, 2005). This definition comes from the U.S. Orphan Drug Act where, in 1983, the federal government started providing grants to incentive pharmaceutical companies to conduct research and development for drugs with projected markets with fewer than 200,000 people (Seelman, 2005). Examples of orphan technology are focused on consumer products and health technologies such as the Jaipur foot or other assistive technologies oral rehydration therapy to treat diarrhea or smokeless bio-mass cook stoves (see Weiss, 2010 and Seelman, 2005). These examples suggest that the STS literature should further consider undone technology as the systematic inattention of global capital to design and develop technologies for failed markets.

The work of science and technology studies scholar Edward Woodhouse (2010) indicates STS scholarship should investigate the politics of undone technology. Woodhouse (2010) coined the concept of “undone technology.” He examined non-violent military, policing, and security technologies made in the U.S. and asked: why have they not transitioned from proof of concept to widespread use (Woodhouse, 2010)? His work implicitly emphasizes the politics within public agencies (such as municipal, county and state police departments) that cause them to clamor for and purchase some technologies (i.e., military surplus tanks and drones/robots) rather than others (i.e., non-violent projectile weapons).

In this paper, I further expand the concept of undone technology into a typology. The key distinction separating the typology of undone technology from the concept of undone science arises from the multiple interventions in a technology's life-cycle.

There are several ways a technology can be undone along its life-cycle. A technology, like scientific knowledge, might be never researched, making it a known unknown (Hess, 2015). Dissimilar from scientific knowledge, a technology might also be: never designed or never developed (where here developed is defined as the testing and refining process a technology undergoes before viable mass production). Finally, a technology might be: never produced, never marketed, never distributed, or never utilized (Seelman, 2005). Without these four last stages, a technology is largely immaterial to the public, although it may exist in some circumscribed form known by a small select few. Each of these seven stages of a technology's life-cycle are integral to its value and thus are points of intervention to get undone technology done.

Getting undone technology done is related to the politics of technology in both its explicit and tacit forms. Explicitly purchasing a technology involves the following stages: marketing, distribution, and utilization. Here an intervention is possible in the politics of public agencies which already have purchasing policies which might be tweaked to better fit a public's ideological goal. Technology thus substitutes for a political decision made by the public (Winner, 1980).

Tacitly, the design of a technology has an embedded organizational configuration, i.e., flattened or hierarchical, which facilitates the technology's utilization by an organization or community (Winner, 1980). The research, design and development of a technology also has the power to configure who are users versus non-users (Oudshoorn, Rommes and Stienstra, 2004; Woolgar, 1991; Wyatt, 2004). Thus by purchasing a technology, users have tacitly agreed to allow themselves to be organizationally configured in a way that best suits the technology's adoption (Winner, 1980; Woolgar, 1991). In Figure 1 below, I suggest a typology of undone technology that includes a spectrum: from unknown immaterial technologies, to orphan technologies developed to address the needs of the poor, to undone technologies that address problems of structural inequality along multiple points of intervention in the life-cycle.

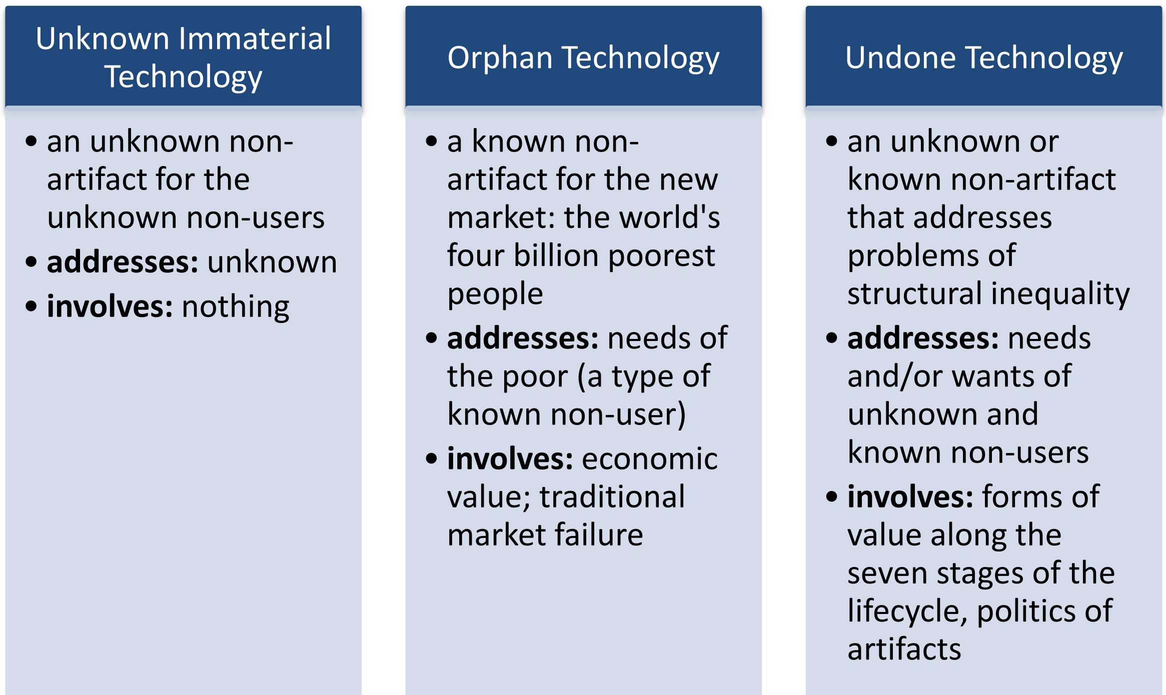

Figure 1 Typology of undone technology

While this typology is tentative, it suggests that more attention should be paid to undone technology by scholars and practitioners. This typology of undone technology helps us to consider global multinational corporations' systematic inattention to creating goods for the billions of poor people around the world and also points to the politics of non-artifacts.

This paper is based on data that I collected using the extended case method to investigate similar organizations in different countries (Burawoy, 1998; Glaeser, 2005). My global ethnography consisted of 10.25 months of participant observation, many hours of direct observation and 83 interviews completed from June 2009 through April 2013 at four eye hospital campuses: one each in Nepal, Kenya, India, and Mexico. From that larger data set, I used four interviews and a report that I created for the non-profit Aravind Eye Care System in India (see Williams, 2012) to write about the ophthalmic consumables produced by its subsidiary non-profit technology company, Aurolab. I converted currencies described by my interviewees from Indian Rupees to United States Dollars by inputting the date 1 March 2012 into the historical currency converter (http://fxtop.com/en/currency-converter-past.php).

Innovation to Address the Problem of Avoidable Blindness

A critical examination of the technology follower conceptual framework usefully highlights structural issues in the global hierarchical value-chain of invention. In this next section, I will describe examples from Aurolab, a non-profit biotechnology organization in southern India to reveal how a non-profit technology development firm can get undone technology done.

Technology Following and "Design and Development"

"Technology followers," as an innovation discourse, highlights structural issues in the global techno-assemblage. Firms located in less economically developed countries can choose a strategy of “catching up” through incremental innovations (Poolton and Barclay, 1998), "catching up" through a very rapid technology transfer rate (Forbes & Wield, 2000), or "leapfrogging" by designing high value products for local needs (Forbes & Wield, 2000, p. 1098, 1106). However, they are assumed to automatically start behind leader firms and leader countries located in the industrialized countries of the global north. The technology follower conceptual framework from innovation and management studies is problematic because it helps reify developmentalist discourse (see Escobar, 1994; Pieterse, 1991). Chen (2015) and Rajão & Duque (2014) in particular critique how modernization theory separates technology leaders in the northern countries (Western industrialized countries) and technology followers in the southern countries (less economically developed countries).

Postcolonial positionality affects a firm's available resources to innovate. The asymmetrical and historically contingent extraction of resources from specific countries (i.e., India) and development of novel inventions in others (i.e., multinational companies located in the U.S., U.K., Switzerland, and Germany) is now reflected in the hierarchy between the less economically developed countries of the global south versus industrialized countries of the global north (with their respective national education systems and national economies); this history shapes the current hierarchical value-chain of invention.

Not only history, but an economic logic shapes the hierarchical value-chain of invention in the global techno-assemblage. The hierarchical value-chain of invention demonstrates how a technology follower firm moves through stages of development. As the technology follower firm develops inventive capacity, it increases in global prestige and power: starting from working as a distributor selling existing technologies, to working as an original equipment manufacturer imitating existing designs, to becoming an original design manufacturer and finally becoming an original brand manufacturer with patented original inventions (Forbes & Wield, 2000 citing Hobday 1995).

Technology follower firms are in a variety of industries. Particular to this account is a technology follower firm in the biotechnology industry, Aurolab, that creates ophthalmic consumables, drugs and instruments to address needs and wants of patients with avoidable blindness.

Aurolab is a non-profit ophthalmic consumables and equipment manufacturing company that might be considered a "technology follower" of the larger, older American multinational company Alcon. In 1992, Aurolab launched with the explicit goal of endogenous technological development as a subsidiary of Aravind Eye Care System, a non-profit eye hospital organization with multiple hospitals and clinics across many campuses in southern India that is governed by the Govel Trust (a non-profit charitable trust). During typical cataract surgeries in India and around the world, the natural lens is removed from its capsule, but the posterior (or back side) capsule is left intact. The new intraocular lens is then placed carefully into the eye, supported in part by the posterior capsule. Ophthalmologists at Aravind wanted a local source of plastic intraocular lenses (IOLs) of high quality and low cost to implant into patients after their cataractous natural lenses were removed from their eyes through surgery.

Intraocular lens technology was "undone" in a way that was shaped by the global hierarchical value-chain of invention. Research and development (including manufacturing and clinical trials) had progressed from the 1940s until the 1990s primarily in the U.K. and the U.S. (Metcalfe, James and Mina, 2005). However, Aurolab was the first locally owned and operated intraocular lens manufacturing facility in the global south and now offers a broad portfolio of products to include instruments, ophthalmic consumables, and various pharmaceutical drugs.

They emphasize bringing products to market quickly at a lower cost with similar quality to the West.

In the examples I will describe, the inventive capacity of Aurolab is showcased. The chemistry team or design team at Aurolab is involved in changing the structure of a globally available drug or creating a new intraocular lens design. The novel drug formulation or product is manufactured to serve local needs and wants to address diseases of avoidable blindness.

> we are not commercially motivated …. This is due to … Aravind's system. [Me: OK] Because we are not a commercial company, we are a trust. [Me: Yes.] Public charitable trust. So all our trustees [do not allow] … exorbitant margin for any drug [or other product] (The second Aurolab employee, 2012).

From the above quote, it becomes clear that their disinterest in the profit motive is mandated by their management: the non-profit Aurolab Trust. The non-profit Aurolab Trust overlaps in membership with the Govel Trust which governs Aravind Eye Care System. Since they are governed by this trust, they refuse to sell their products through other companies that might compromise their mission. Although doing so would increase their profits, it is at odds with their mission.

Imitation and Catching Up Through Technology Transfer

Aurolab initially developed its intraocular lens manufacturing capabilities through a company in Florida that helped them to: design the manufacturing space; select and install production equipment; learn how to operate everything; and test the quality of their first batch of manufactured lenses. This is part of a typical turnkey technology transfer strategy for technology followers.

Through technology transfer they first developed the three piece intraocular lens that was considered cutting edge in the early 1990s. They quickly shifted from the three piece intraocular lens in 1992 to the single piece intraocular lens in 1994 following the designs of market leaders. However, as Aurolab's Managing Director points out, cutting edge technology is something of a moving target:

> If we don’t have any continuous technology transfer our products become obsolete quickly in the medical area. We cannot keep up with advancements (P. Bala Krishnan, 2012).

Above, P. Bala Krishnan indicates that Aurolab has a technology follower strategy where they imitate products originally developed for markets in industrialized countries of the global north. Aurolab uses strategy for their innovations in intraocular lens technologies, which follow behind globally known ophthalmic consumables multinational companies such as Alcon, Abbott Medical Optics (formerly Allergan), and Bausch and Lomb. However, P. Bala Krishnan's concern with the speed of advancement for "catching up" to intraocular lens technologies is only one small part of a larger story about innovation at Aurolab. Ultimately they found that by imitating a proven technology, Aurolab could ease into IOL production with the certainty of a product that has previously sold and will sell again.

When Aurolab began production of intraocular lenses they were a very small firm. With the confidence of intraocular lens sales, they also felt confident enough to move into other ophthalmic consumables such as ophthalmic pharmaceuticals. They also began to reinvent global ophthalmic pharmaceuticals locally, that is, they changed the interpretation, structure and use of an existing technology (Eglash, 2004), to address orphaned diseases of the eye organ.

Sometime after Aurolab started manufacturing intraocular lenses, the senior leadership team of Aravind Eye Care System visited Moorfields Hospital in the U.K., which had its own pharmacy with a small eye drop manufacturing unit. When they returned, they gave Aurolab a mandate to start a pharmaceutical unit to make eye drops. They started the pharmacy division of Aurolab in 1997 without using "turnkey technology transfer." Instead, the pharmacy division started as "technology followers" by using technical know-how to reverse engineer existing drugs. This was a “catch up” strategy to introduce ophthalmic drugs used in retinal surgeries in the West (e.g., Silicone Oils, Perfluorooctane, Indocyanine Green) to the rest of the world, e.g. South Asia and Africa, at a much lower price point. For example, they brought the cost of Silicone Oil down from 8,000 Indian Rupees ($162 US Dollars) to 1,000 Indian Rupees ($20 US Dollars). These drugs were the beginning of a broad portfolio of ophthalmic pharmaceuticals.

These examples of intraocular lens and ophthalmic drug development illustrate undone technology in the stages of development, production, and distribution for a known non-user. There was a market failure where low-income Indians were not able to afford the latest in cataract surgical technologies made for a global (and primarily Western) market of middle-income and high-income patients. The market failure was specific to rural low-income Indians, urban high-income Indians have access to circuits of capital and the latest and greatest health technologies and services. Therefore, Aurolab was addressing the needs of a particular local and poor non-user in the global biotechnology industry. Later, they could sell their own brand to other non-profit community ophthalmology organizations because of the brand recognition gained through their early leadership in the distribution of IOLs within the third sector market.

Aurolab’s local technology development fits with the focus on import substitution and endogenous technology development espoused by the Indian government which, before TRIPS, is enforced through high taxes on imported products. However, as a company, Aurolab has a unique focus on keeping the price point low for consumers which is informed by its ownership and management by a non-profit charitable institution. This emphasis means administrators at Aurolab must balance profits (which should cover their operation expenses) with low prices to support purchases by non-profit organizations such as Christoffel-Blindenmission (now called Christian Blind Mission) for their own poor blind patients around the world. Twenty years after Aurolab started, their market competition in India is fierce and the balance requires increasingly more effort to maintain.

> … we have seen so many cases where the competitors will go even [further] down [Me: Yeah] and we have lost our market share. Then we will not go into price wars and compete with that. Instead, we move the product features and we start playing in the other segment of the market. [Me: Ok]. So that's the real work (Aurolab Employee, 2012).

Here an Aurolab employee emphasizes that the "real work" is not only to keep the price low, but also to keep the organization financially viable so that they can remain in operation. In order to do so, they might become involved in "design and development" to capture a new segment of the market and move up the value-chain of invention.

Design and Development to Leapfrog the Competition

Another innovation at Aurolab was a new intraocular lens design that they launched called Truedge Aspheric. This product was designed with a square edge to prevent the occurrence of posterior capsular opacification also called secondary cataract. Additionally, the new product design had a second purpose of differentiating Aurolab's most inexpensive (and most popular) intraocular lens so that it might stand out in a now crowded market.

A problem occurs when, anywhere from four months to three years after the cataract surgery; the posterior capsule starts thickening due to the growth of cells. This cellular growth once again makes the lens opaque and hinders vision. A treatment option is to use a laser to burn away the cellular growth from the posterior capsule. However, a better option is to prevent the growth from occurring in the first place.

This poses an interesting design problem for Aurolab that they carefully considered as the market for their polymethylmethacrylate (PMMA) lenses, which they led in India and elsewhere in the global south in the mid-1990s, became increasingly crowded with other manufacturers of low-cost lenses in the mid-2000s. PMMA is a biologically unreactive plastic. This material had been used in the first successfully implanted plastic intraocular lenses produced in the 1940s in Britain, and has been used in many intraocular lens products since that time (Apple & Sims, 1996). Therefore, Aurolab chose this material because it was well-known and thus decreased their risk when they first started manufacturing intraocular lenses.

For this new product design, they desired to continue using PMMA while also addressing the problem of posterior capsular opacification. This would result in a low-cost lens that took advantage of their existing manufacturing capabilities and differentiated their PMMA lens from other lenses on the market. Ophthalmologist Dr. Richard Parrish (2014) writes, "the design of a … [surgical] device [or consumable] has little bearing on its price. The costs of bringing a product to market and the return on investment determine the ultimate value." Therefore, Aurolab's strategy of creating a new PMMA lens was low risk and would allow them to continue bringing high quality, low cost intraocular lenses to market.

In creating this new design, they found that several studies showed that the design of the lens mattered more than its material properties in preventing the occurrence of posterior capsular opacification (Buehl & Findl, 2008; Findl et al., 2010 [2007]; Nagata & Watanbe, 1996). Therefore, instead of using their research and development chemistry team to investigate a new material, they used their design team to figure out how to create a square edge on the PMMA lens.

When implanted in children, their new square edge PMMA lens design has been shown to have decreased posterior capsular opacification with better outcomes than a square edge foldable lens design manufactured by Alcon (Brar et al., 2008). However, comparing the outcomes between the two lens types was statistically insignificant (Brar et al., 2008). Thus, Aurolab's new Truedge Aspheric lens design was an inexpensive alternative to Alcon's lens with similar results. They could continue selling this Truedge Aspheric PMMA intraocular lens for the same price as their older PMMA intraocular lenses – $5.

With a novel intraocular lens design, Aurolab focused on "design and development" rather than "research and development" to meet the needs of low-income patients, differentiate their product from their competitors (so they could keep market share) by fulfilling a “want” of low-income patients, and also fulfill their operation budget. While this design innovation did not enable them to move up the value-chain of invention, it did help them to maintain their position of leadership in that value-chain both internationally and within India. This new design did not replace their old design, but was sold alongside to demonstrate their inventive capacity and ensure that they remained high-status in the third sector market for ophthalmic consumables. As such, this new design fulfilled both a 'want' and a 'need' by the known non-users.

The example of the Truedge IOL was an undone technology in terms of design, development, production, and distribution of technology for an unknown non-user. Design and development was part of strategic innovation to leap-frog the value-chain of invention. Instead of being imitators, they could become designers. So they further solidified their position of leadership within the global production of ophthalmic consumables by non-profit technology firms in India, Nepal and Eritrea.

After cataracts, glaucoma causes 8% of blindness (Pascolini & Mariotti, 2012). Aurolab set out to create a variety of orphan drugs; one, called Auroprost RT, is a room-temperature eye drop medication for treating glaucoma.

Reinventing Drugs for Known Non-Users Inside and Outside of India

Auroprost RT, launched in February 2012, is another reinvention that is suited to resource-poor areas (such as rural India) where patients are unlikely to have refrigerators needed for the original product Latanoprost. This is a product used to reduce the intraocular pressure of the eye for patients who are tested and found to have elevated intraocular pressure. Such increased intraocular pressure is typical of glaucoma patients and can lead to blindness. This form of blindness sneaks up on patients because the pressure increases gradually and inexorably causing damage to the optic nerve which is irrecoverable. Treatment is long-term to maintain any remaining sight by decreasing intraocular pressure and maintaining it at the appropriate low level.

The problem with the original formulation of Latanoprost is that this drug requires a "[c]old chain [where] you had to store [it at] two to eight centigrade" explains the second Aurolab employee (2012). Cold storage through refrigeration at 34-40F (1-4 C) generally requires electricity. Most patients are low-income and come from rural homes without electricity or refrigerators. However, in the heat Latanoprost will decompose and its "potential" drifts away with the air currents. Therefore, cold temperatures are required to keep the eye drops preserved in the 80-104 F (27-40 C) weather of southern India. This cold storage problem does not only apply to Indian patients with glaucoma, but also to glaucoma patients in other less economically developed countries in Asia, Africa, and Latin America. Clinicians find that patients are unable to comply with the prescribed regimen of care because they cannot store the medication in a way that maintains its stability and vitality.

The new formula created by Aurolab, Auroprost RT, can be maintained up to 86 F (30 C). The Auroprost RT is a more viable option for glaucoma patients who have to take one eye drop daily to maintain their current level of eyesight, but who cannot afford (or do not have access to) consistent electricity and a refrigerator for cold storage. Aurolab is consistent: for each drug they have at twin goal of making it affordable for patients and enough of a profit margin to maintain themselves. In the case of converting Latanoprost to Auroprost, the cost of raw materials helped set their lowest price of 150 Indian Rupees ($3 US Dollars). The closest competitor is less valuable to patients because it requires cold storage; ironically the competitor's version is also more expensive at 500-700 Indian Rupees ($10-14 US Dollars).

The last example of the room temperature Auroprost drug for glaucoma was an undone technology in terms of research, design, development, production, and distribution of technology for a known non-user. The need for this drug was indirectly indicated by way of physicians observing that glaucoma patients were not able to use the refrigerated drug and maintain their regimen of doses, and therefore had deteriorating eyesight. Working on a drug to remove the need for a cold-chain required the design to include a consideration of the contextual nature of the distribution process for the current non-user and future projected user.

At present the landscape of India consists of decentralized communities with many non-electrified rural villages clustered around and between electrified urban city centers and good public transportation (buses and trains) connecting people from rural areas to those city centers. This means the tacit politics of the room temperature drug represents an explicit decision made by the government of India: rural electrification is less important than other work (please note that this drug was developed before Prime Minister Narendra Modi's rural electrification push was announced August 15, 2015; Bansal, 2016). By purchasing a room temperature glaucoma drug, patients may just be making the cost-conscious choice. However, they also may be demonstrating that the value of a technology is not just based in an economic logic of price and profit, but also in a social logic of personal independence and contextual design.

Administrators and staff at Aurolab are proud to be the leader in the field of ophthalmic consumables in India:

> companies, now [there are a] lot ... in [the] ophthalmology field. [Me: Ok]... But since we are [a] pioneer and ...we are the number one in the ophthalmology. [Me: Ok] As far as concerned in India. [Me: Ok] Pertaining the product range and other things. Maybe revenue ... we are not number one. [Me: Ok] But if you see that number of products-- innovative products, specialty products-- we are ahead of all other Indian companies (The second Aurolab employee, 2012).

Because they specialize in ophthalmic consumables, they have built up a knowledge base in this small sub-field of the biotechnology industry, and lead this industry in India. However, this non-profit firm with a social mission has the corner on a viable profit-making global market because of: India's large population (roughly 1/5 of the people in the world), India’s high rate of cataract disease (roughly 1/3 of persons with cataract disease in the world), and Aurolab's ties to multiple non-profit eye hospitals and eye-disease focused philanthropic organizations that can purchase their products.

Recommendations for the Government of India

Future policies of the Indian government to support endogenous biotechnology industry may be informed by the multiple interrelated logics of the global techno-assemblage. Push mechanisms reduce the financial risk of development through, i.e., credits, fast paperwork, fee exemption, grants, or investment, whereas pull mechanisms reward the final product with a guaranteed market through subsidies, advanced purchase commitments, intellectual property rights, etc. (Uwland & Townend, 2014, p. 189-90). Pull mechanisms thus favor restrictive licensing and patent/ product monopolies of trade secrets which provide a deterrent for sharing new knowledge (Love, 2011, p.7). Regrettably, many of these existing mechanisms are geared towards drug development not technology development.

The "technology following" conceptual framework highlights the dominance of the economic logic in the global techno-assemblage. For the "technology following" conceptual framework the starting assumption is that all firms developing technology are primarily interested in increasing profits. Aurolab had a secondary interest in making profits, but their primary interest was in providing a service to people. This goal runs against the grain of a technology firm's typical core interest in making a profit. Therefore, it becomes clear that the technology follower conceptual framework has some limitations.

The idea of "catching up" and "leap-frogging" in order to "move up" the value-chain of invention in technological development sets boundaries around the rewards of technology development by defining it only in terms of economic value: technology leadership is equivalent to having the most profits and the value of any product is likewise defined as its ability to increase a company's profits. The "technology follower" conceptual framework is therefore not just shaped, but excessively influenced by an economic logic.

The incentives for a social logic appear to be underdeveloped in the global techno-assemblage. While Aurolab is credited in business case studies for its frugal innovations in health care (Ramdorai & Herstatt 2015; Rangan, 2006; Rangan, 2007), it is not otherwise rewarded in the industrial field. This social logic is more of a pull mechanism – they will not receive any credit for an intention to do good in general, but only after having proved that they have done the right thing. While there are awards to recognize individual ophthalmologists and social entrepreneurs (offered, for example, by member societies for ophthalmologists, the Government of India, and the Ashoka Foundation), there appear to be few external credit opportunities for Aurolab's needs-based technology. Aurolab is the global leader in low-cost high quality ophthalmic consumables, with a high volume of sales and a large market share, however they are rarely recognized by the major societies for the medical devices industry, or the pharmaceutical industry. This is likely due to the dominance of the economic logic in the global techno-assemblage: Aurolab’s goal to deliberately keep its product prices low means that it will never have a "blockbuster" invention, therefore the most common method of ascertaining a firm's leadership – the high economic value of its sales – will never be successfully applied to them. This could easily be changed by the Government of India which might start offering symbolic awards for needs-based technology to elevate the status of firms producing such orphan technologies.

Informed by the economic logic, the Indian government has a new tax policy in 2014 to offer incentives to local firms that have research and development units (Tyagi and Chowdhry, 2015). Will this new "push" mechanism, combined with existing push mechanisms, i.e. research grants from the Indian Ministry of Science & Technology, help to accelerate endogenous technology development? If so local firms, already attuned to the global hierarchical value-chain of invention, may try to move up the international value-chain by competing to invent the next blockbuster. Considering the accelerated technology transfer rate necessary for "catching up", it may be an ill-considered goal. Especially bearing in mind India's relatively small percentage of GDP devoted to research and development stimulus.

The Indian government could instead add new policies to support biotechnology firms across multiple logics. This would mean adding to the "push and pull" mechanisms of the economic logic, the hybrid logic of supporting more public-private partnerships (Reid & Ramani, 2012), as well as the social logic of symbolic awards and prizes. Alternatively, the Indian government could create new mechanisms that support "design and development" for the needs of less economically developed countries.

A monetary prize might serve to de-link research and development costs from product prices while also serving as a reward for needs-based technology development (Kay 2012; Murray & Townend, 2014 citing Love, 2011). Prizes can remove the profit motive built into patents by reforming the "pull" mechanism away from an emphasis on advanced market commitments and product monopolies (Love, 2011, p. 5).

There are several monetary prizes focused on neglected tropical diseases (Love, 2011); however, there are few such awards for needs-based technology development. In one example of such a monetary prize, Aurolab has received an entrepreneurship investment award for their new refractor design as part of a bi-lateral government endowment fund focused on "commercializing technologies with social impact" (United States–India Science & Technology Endowment Fund, n.d.). The durable design means that this refractor can be used in rural high volume eye screening camps. In a second example, a prize is offered by the Tech Museum of Innovation located in San Jose, California. "The Tech Awards" is a $50,000 USD prize that "honors innovators from around the world — individuals, non-profit organizations and companies — who are applying technology to benefit humanity. The technology used can be either a new invention or an innovative use of an existing technology" (The Tech Museum of Innovation, 2015).

Unfortunately, all of these monetary prizes place for-profit and non-profit technology development firms, with their unequal access to streams of capital and different market segments, in the same competition for social credit and a monetary award. Meanwhile, there does not appear to be any global public health prizes for undone technology on the same scale as those available for the non-profit Aravind Eye Care System and Tilganga Institute of Ophthalmology for their exemplary work in eye health care services (each were awarded $1 million USD by both the Gates Foundation and the Champalimaud Foundation). Monetary prizes of higher amount, with distinct entrance categories for non-profit companies, would likely help stimulate needs-based innovation.

Conclusion

While the literature on undone science has exposed the problem of asymmetrical scientific research agenda setting under neoliberal globalization, this case of Aurolab getting undone technology done has exposed the problem of unequal power to frame the rewards of technology development. Aurolab’s examples exemplify the tentative typology of undone technologies I described above. Undone technology addresses structural inequality by meeting the needs or wants of known or unknown non-users by intervening in multiple stages of the technology's lifecycle. By doing so, undone technology brings attention to problems of structural inequality, and turns our attention to forms of value beyond price and profit described by the economic logic of the global hierarchical value-chain of invention.

Aurolab's innovation strategies point towards a new question, who has the power to determine "leadership" in technology development? Aurolab, while not receiving global recognition by member associations for medical device manufacturers or pharmaceutical companies, is still (by its own account) a technology leader in ophthalmic consumables for markets in less economically developed countries. It appears that there is a “third sector” market emerging, controlled by non-profit organizations in the global South and North that does not value profit in the same ways as it is valued by neoclassical economics. This offers science and technology studies scholars an opportunity to identify alternative ways for how leadership in technology development might be defined and assessed.

A second new question is how is the "value" of a product defined and by whom? If a product's value is defined solely by the profit it can make the firm that launches it, then a technology bandwagon forms where there is a rush by firms to secure patent monopolies. This technological bandwagon is driven by a historically contingent hierarchical value-chain of invention: those firms and countries with early dominance in global intellectual property now set the terms by which technology catch-up is possible and constrain how other firms can move up the value chain. Future work studying undone technology might consider other types of value for defining a product. Instead of just the economics of labor value, might it be the freedom of expressive value or the sustainability of ecological value (Eglash, 2016).

Future analyses of undone science and undone technology in the global south may continue to shed light on issues of asymmetric research, design and development agendas globally. Additionally, I have demonstrated that the immateriality of undone technology invites further investigation of the tacit and explicit politics of these non-artifacts. Likewise, might the concept of undone technology shed light on how manufacturers identify and configure the potential non-users of their products?

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