How Sociotechnical Systems Adapt to Change: Reproductive Imaginaries in the Co-production of Assisted Reproductive Technologies

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Abstract

This paper addresses the topic of the dynamics of sociotechnical change of reproductive technologies and, in particular, the relationship between sociotechnical systems as described by TP Hughes and their environments. The co-production approach and sociotechnical imaginaries defined by S Jasanoff and SH Kim allow to explain the dynamics of technical change through the interweaving of technoscientific and social practices; and the concept of 'reproductive imaginaries' provides a better analysis of the back and forth adjustment between the system and its environment in a way that avoids the soft determinism that still persists in traditional accounts of sociotechnical change. I argue that reproductive technologies are co-produced with its environment in dialectical processes through specific technologies and reproductive imaginaries. Finally, I defend that this system performed adaptations even when it is mature.

Keywords: Sociotechnical Imaginaries, Large Technological Systems, Assisted Reproduction, Reproductive Imaginaries, Philosophy of Technology

Introduction

It is becoming increasingly difficult to ignore the growing of reproductive technologies in our Western societies. Reproductive technologies are often seen as disruptive technologies (e.g., Cohen et al., 2017) that are transforming some of our most fundamental concepts, such as motherhood, family, and kinship. However, the lack of a global perspective on the structure and dynamics of this complex sociotechnical system makes a challenge to estimate the scope of such changes.

The interactions of technological developments and society have been object of intensive study, mainly in Science and Technology Studies (STS) research field. In recent years, the understanding of the co-production of epistemic, technological, and social orders has gained relevance, that is to say, the way they jointly come into being (e.g., Felt et al., 2017: 9). Within this interdisciplinary field, the theory of Large Technological Systems (LTS) (Hughes, 1983, 1987, 1994) offers an account of the structure and dynamics of such systems that enables a holistic understanding of LTS, such as assisted reproductive technologies (ART).[1] From a historical perspective, Hughes explains the dynamics of technology and society through different phases in the development and

evolution of technological systems according to the predominant activity: "invention, development, innovation, transfer, and growth, competition, and consolidation" (Hughes, 2012: 50). These phases may overlap and do not always follow the same order. According to Hughes, technologies are more permeable to the influence of environment when they are young, while, as they consolidate and acquire style and momentum, they tend to adopt certain paths. This makes them less receptive to environmental influences and tends to shape them (Hughes, 1994).

Also, as technology historian Richard Hirsh argues, the value of LTS lies in "emphasiz[ing] that the motivators of technological change extend beyond the technical realm and have origins in the social world" (Hirsh, 2016 cited in Sovacool and Hess, 2017: 716). However, later developments in the LTS theory have focused on the structure, postulating new phases (i.e., Sovacool, et al., 2018) or adopting a multilevel perspective (i.e., Geels, 2007), and dispensing with cultural meanings and narratives regarding the technologies and goals for the society in which they are inserted. For some critics, they focus too much on the structure of the systems and neglect the agency of the users (Shove and Walker 2010; Rutherford and Coutard, 2014) or the power relations within the system (Smith et al., 2010). So, still there is no clear explanation of how the system and the environment are related nor the reasons why agents act. To the contrary, within STS studies, the co-production approach (Jasanoff, 2004) and the development of the concept of 'sociotechnical imaginaries' (STIs) (Jasanoff and Kim, 2015) provide more adequate tools to explain the dynamics of technical change through the interweaving of technoscientific and social practices.

In this essay, I analyse reproductive technologies as a sociotechnical system (Hughes, 1983) because it provides a better understanding of the evolution and dynamics of these technologies. I also use a co-production approach and STIs since they allow presenting a more detailed explanation of agents' reasons for action and their relationship with the system. In particular, I use the term 'reproductive imaginaries' to refer to the collective visions of the future related to reproduction that emerge and evolve with the sociotechnical system of ART.

Reproductive imaginaries are a type of STI and, therefore, it is important to point out that they are not merely collective visions about motherhood, infertility or kinship that are institutionally articulated in different cultures (see Table 1). Reproductive imaginaries are reflected in the

Table 1. Some types of reproductive imaginaries identified and their elements.

	Types of reproductive imaginaries				
Elements of reproductive imaginaries		System builders and ART system	Christian Groups	Socialist embriologist	Lesbian Couples
	Importance attributed to the family in the life project	Heterosexual nuclear family model			Homosexual nuclear family model
	Importance attributed to motherhood in the life project	Naturalisation of motherhood and reproduction			Social motherhood
	Infertility vision	Infertility as a disruption or problem: social pressure to reproduce			Problem in social terms. Partner does not have the necessary gametes
	Vision of ART	Technological fix	Unnatural; it threatens the life of cryopreserved embryos	Therapeutic	Technological fix
	The importance attributed to genetics in shaping kinship ties	Genetic kinship			Kinship based on social ties and legal arrangements

design of specific technologies and comply with certain techno-scientific projects (Jasanoff and Kim, 2009), whether articulated and promoted by nations or by organised groups such as corporations (e.g., Valencia Infertility Institute, IVI), social movements (e.g., feminism) and professional societies (e.g., European Society of Human Reproduction and Embryology, ESHRE) (Jasanoff and Kim, 2015). Moreover, reproductive imaginaries are plural since different visions can co-exist in tension (Jasanoff and Kim, 2015) in the same society, such as, for example, the degree of importance attributed to genetics. In addition, they are in a dialectical relation with technoscience and society (Jasanoff and Kim, 2015), so they are dynamic and can vary as the groups that support them change. For example, lesbian couples were able to access assisted reproduction and develop shared maternal projects in Spain thanks to certain legislative changes that other surrounding countries like Italy or Switzerland do not share. STIs codify both visions of what is attainable through technoscience and desirable ways of life. Continuing with the previous example, these imaginaries are committed to the diversity of family models achievable through assisted reproduction and, therefore, they should be understood in normative terms.

Reproductive imaginaries project certain forms of desirable reproductive futures and, in this sense, the axes of power such as gender, race and social class are involved in the imaginaries to the extent that they articulate the materiality of the subjects (collectives) that they maintain, the desires these agents project, and their sociotechnical practices. That is why the analysis must focus on the collectives committed to the "renewability of valued forms of life", the institutions in which these desires are expressed and the practices that allow them to develop those visions (Jasanoff and Simmet, 2021:5).[2]

My aim in this paper is to offer a better understanding of the dynamics of sociotechnical change in reproductive technologies and, in particular, the relationships between the ART system and its environment. My hypothesis is that ART perform adaptations to their environment in order to maintain itself, even when it is mature. These adaptations are the result of tensions between reproductive imaginaries-related forces within the system and in its environment.

To explain the tensions and dynamics of technological change, I use the forces of classical mechanics as an explanatory metaphor. Centripetal forces are real forces causally associated with the action of some agent outside the body on which they act. On the other hand, centrifugal

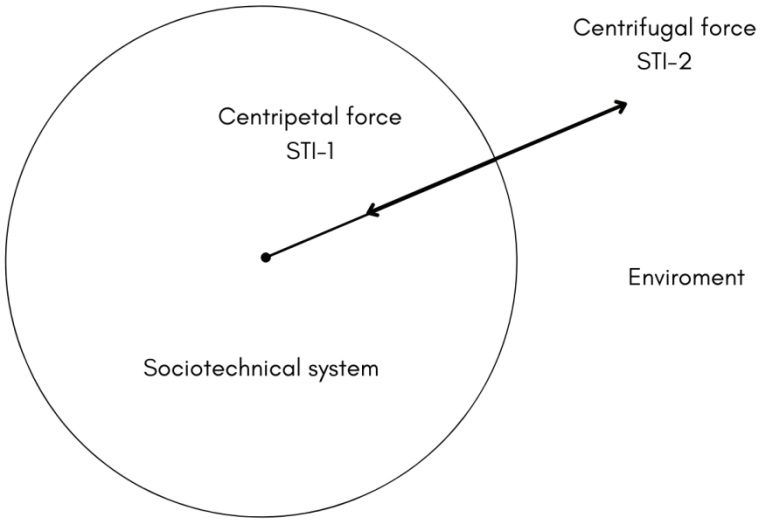

Figure 1. Representation diagram of the metaphor of the forces where the LTS and STI approaches are related. STI-1 corresponds to the imaginary of the system. STI-2 is a dissident imaginary (e.g., lesbian couples). Co-production is the continuous result of their struggle.

force is the tendency of an object to resist any change in its state of rest or motion (Newton, 1999). In my view, the STI of the system acts as a centripetal force that tries to capture the elements of its technological environment. In contrast, the dissonant STI of the environmental agents maintain pressure in the opposite direction (see Figure 1). As Hughes points out, when a system is young, it is permeable to its environment, while as it gains momentum it tends to exert determinism over its environment in an attempt to control it (1994). Dissonant STIs act as centrifugal forces pushing the system to open up by making adaptations in order to extend its dominance and maintain itself. This combination of approaches results in a methodology that focuses on explaining the reasons that guide the agents involved in technological change, without losing sight of the evolution of the technological system. The metaphor of forces anchors both perspectives and functions as an interpretative tool for the co-production process of the technological system and its environment.

Methodologically, this paper follows the phases identified by Hughes in the development of technological systems. The main features of these phases were used as criteria for analysing the phenomenon. Narratives and episodes were selected to illustrate the agents' reasons for acting and how reproductive imaginaries are constructed. The main features already described were also taken into account. For instance, during the invention phase, *A Matter of Life* (1980), the memoirs of Robert Edwards and Patrick Steptoe, proved to be an essential source for comprehending how their worldview translates into their decisions and how it impacts the IVF design. In subsequent phases, I selected scientific literature from major journals in the field of reproductive medicine and biology, such as *Fertility and Sterility*, as well as interviews with relevant scientists in the media and the community's own IVF histories as primary sources. This allowed me to explore reproductive narratives and imaginaries. To provide context and a comprehensive overview, I also consulted Martin Johnson (2011, 2019) and Kay Elder's (Johnson and Elder, 2015) works on the history of IVF[3] and Sarah Franklin's research on the interconnections between ART, the global economy, and transnational politics (Franklin et al., 2000; see also Salter 2022). Additionally, I used case studies such as gamete donation (e.g., Lafuente, 2017) and the use of ART by lesbian couples (e.g., Mamo, 2007) to outline scenarios of conflict and negotiation.[4]

Moving forward, in the following section, I introduce the concept of reproductive imaginaries in the context of the invention of *in vitro* fertilization (IVF). Then, I carry out a co-productive analysis of ART as a LTS through the phases postulated by Hughes after which I offer an explanation of the system's adaptations through different examples. Finally, I present my conclusions.

Reproductive imaginaries in the invention of IVF

To understand the scope and participation of reproductive imaginaries in co-production with ART, I think it is worth pointing out some constitutive elements already found in the origin and invention of IVF. During the 1960s and 1970s, a period in which research was carried out leading to the birth of the first baby in the world to be born through IVF, most gynecology and obstetrics professionals understood motherhood as a natural phenomenon desired by all "normal women" (Stanworth, 1987: 15). Those who rejected the 'maternal instinct' were considered selfish, deviant, or deficient as women (Badinter, 1980). In this period, the naturalization of motherhood was a solidly established representation in society. This way of understanding motherhood was inherited from the 18th century ideals of motherhood (Knibiehler, 2001: 53) and exerted strong ideological pressure on women to be mothers according to defined parameters within the framework of the nuclear family. A biological essentialism slips into this imaginary according to which the feminine is related to the maternal. This identification was strongly criticised by many feminist authors (i.e., Beauvoir, 1949; Badinter, 1980) who argued that there is no feminine essence, but rather cultural representations about what it means to be a woman (Tubert, 1996).

At the same time, the rise of neo-Malthusianism in the Anglo-Saxon world during the first decades of the 20th century gave rise to movements

for contraception and family planning. At the beginning of the 1960s, there was a remarkable increase in the birth rate in general, known as the *baby boom*, which also led women to be interested in contraception (Knibiehler, 2001: 88-89). With the popularization of the contraceptive pill and the intrauterine device (IUD), women began to take control over their fertility. As the historian Yvonne Knibiehler points out, "the biological function became the result of a decision: it was no longer a matter of passive reproduction, but of human procreation in which reason and affectivity intervened" in such a way that "when the desired child comes into the world, the joy must be total" (Knibiehler, 2001: 97-98).[5] It was an ambivalent and changing context in which traditional ideas of family and motherhood coexisted with social and technological changes (i.e., contraceptive pill, IUD), which also involved transformations in family and couple models.

In the 1960s and 70s, the main concern within the scientific community and gynecological field was overpopulation and family planning, while infertility was considered an irrelevant issue. Infertility only affected a minority of the population and was therefore not a major clinical problem due to concerns about population growth (Johnson, 2011: 258). However, those who would become known as the scientific parents of the world's first IVF baby, physiologist Robert G. Edwards and gynecologist Patrick Steptoe, differed from this dominant view (Johnson, 2011).

Steptoe was a family man and grew up in a happy family of eight brothers and sisters (Edwards and Steptoe, 1980: 11). He empathised with the women with reproductive problems who came to his office in the 1950s and 60s. The feeling of guilt that those infertile patients felt at not being able to become mothers and have their "own" family had a great impact on him during his medical school days. He felt a "rush of sympathy for them" (Edwards and Steptoe, 1980: 12) and that feeling accompanied him throughout his professional career. This empathy with infertile women and their husbands was also shared by biologist Robert Edwards, who came to strongly believe in the right of such couples to have their own offspring (i.e., Edwards and Steptoe, 1980: 101-102). Edwards, father to five girls with geneticist Ruth Fowler, repeatedly expressed a feeling of solidarity with the suffering of childless couples (i.e., Edwards and Steptoe, 1980: 40).

This empathy occurs within the framework of a shared worldview in which the family occupies a preponderant place. The common idea of family in this reproductive imaginary is made up of a heterosexual marriage union and its progeny. It is important to point out that, in this worldview, the family is incomplete in the absence of offspring, causing suffering. In addition, another very relevant idea reflected in the design of IVF is the generation of kinship ties based on the genetic relationships between family members.

Genetics was central to Edwards's thinking despite being rudimentary and alien to most reproductive biologists during the 1950s and 60s. As a physiologist, Edwards had trained alongside geneticist and reproductive biologist Alan Beatty, who influenced his interests and values (Johnson, 2011). The biological tie between parents and progeny was especially relevant. Edwards himself recalls how his "primary preoccupation was what it had always been- to study human embryology and allow women, who were seemingly forever condemned to a life of infertility, to bear their own children fathered by their own husbands" (Edwards and Steptoe, 1980: 86). Thus, it was not just about helping infertile couples become parents. The objective was to reproduce a specific family model and establish kinship relationships based on the genetic tie between both parents and their offspring.

The genetic tie between parents and offspring acquires special value in the Euro-American context where kinship relationships are understood in biogenetic terms. From this perspective, reproduction is seen as a fact of nature, omitting marriage as a social agreement and its role in the construction of kinship links (Strathern, 1992). The reiteration of this imaginary about how human relationships are built is a cultural practice (Strathern, 1992: 17) that has the effect of naturalizing the family. Thus, the nuclear family is seen in the Euro-American context as a natural phenomenon and "biological facts" acquire a prominent position, a relevant social meaning (Donoso, 2012: 44-45; Strathern, 1992: 19).

In this context, infertility is viewed as a disruption to the normal progression of life and an obstacle to the creation of the family which generates dissatisfaction, misery and suffering (Franklin, 2002). As the sociologist Sarah Franklin has pointed out, added to the social pressure to reproduce that infertile people experience is the idea that there is a kind of natural or biological impulse to have children that cannot be ignored. In the author's words: "It is represented as being genetically determined by our evolutionary heritage and essential to our survival both as individuals and as a species" (Franklin, 2002: 91).

This kind of 'reproductive instinct' or need to have biologically related children in order to transmit 'genetic inheritance' is a discourse that frequently appears in the field of assisted reproduction. Patrick Steptoe himself believed that "[i]t is a fact that there is a biological drive to reproduce" (cited in Stanworth, 1987: 15). Robert Edwards and his collaborator, David Sharpe, also shared this vision when considering that "the desire to have children must be among the most basic of human instincts, and denying it can lead to considerable psychological and social difficulties" (Edwards and Sharpe, 1971: 87). From this supposed biological impulse follows the idea that the formation of the family within the framework of heterosexual marriage is not so much a social convention as a natural progression of life itself (Franklin, 2002: 92) and, therefore, "the right of some couples to have children" (Edwards and Sharpe, 1971: 87) cannot be denied. Consequently, technoscience appears as the savior or helper for infertile couples and guarantor of that right. IVF is transformed into a technological arrangement that mimics nature.

The co-production of an LTS: from IVF to ART

Since the beginnings of IVF in mice in the 1960s, this technology has grown from an experimental technique to a complex technological system. The innovations and growth of IVF have made it easier for this technology to be placed at the center of an entire sociotechnical system in which other technologies orbit. The term assisted reproductive technologies (ART) is commonly used and I use it to refer to the large socio-technical system built from IVF.

Invention

The invention phase is relevant to understanding how certain ideas become part of the technologies we have. In LTS terms, the physiologist Robert Edwards and the gynecologist Patrick Steptoe could be understood as inventor-entrepreneurs or system builders. Most likely, Jean Purdy, co-developer of IVF, would not have been considered in these terms by Hughes, not only because she does not contribute to the story of great enterprising men, but also because her work as a laboratory technician could easily be classified as routine and lacking in creativity. Nevertheless, co-production allows shifting from inspired individuals or small groups to communities insofar as it maintains that, although imaginaries are collective, they can arise from individuals or small groups (Jasanoff and Kim, 2015). For this reason, although I will begin by giving greater relevance to the problems expressed by the system builders, I want to make it clear that the road to IVF has been a long one of research in reproductive physiology, technical developments in the preparation of laboratory samples as well as in obstetric and gynecological surgery and required the collaboration of other gynecologists (who supplied eggs for research), nurses, laboratory technicians and, of course, infertile women who desperately wanted to become mothers.

I shall start with a passage from Edwards and Steptoe's memoir *A Matter of Life* (1980), as it illustrates the extent to which both designers' beliefs about end-users and their reproductive imaginaries influenced the co-production of this technology. The team led by Edwards, Steptoe and Purdy at the hospital in the British town of Kershaw had been administering hormones for some time as part of the protocol to induce ovulation and obtain a greater number of mature eggs (and, ultimately, increasing the chances of achieving a pregnancy). After several failings, they concluded that these hormones had shortened the patients' menstrual cycle. Thus, in the course of egg collection, their fertilization, and the development of the embryos, the patient's body was preparing to menstruate. This made it really unfeasible for

them to be able to retain the embryos. However, without the hormones, they could only get one egg per cycle. Consequently, the team had to monitor each patient individually to retrieve the egg at the optimal point of maturation. Faced with this reverse salient, Edwards and Steptoe deliberated over the possibility of exchanging their patients' ovules in order to facilitate the uterine implantation of the embryo.

> "Of course we could have taken an egg from, say, Mrs A who had been given the fertility drugs, fertilized it with the sperm of Mr B and then transferred the resultant blastocyst into the womb of Mrs B who would not have received fertility drugs. Then without a doubt Mrs B would become pregnant – only the baby growing inside her would not have been her own, though her husband would have been the father.
> Patrick, seeing how much his patients longed to have babies, toyed with this idea of embryo transfer. […] Surely such a baby would be much loved by Mrs B?" (Edwards and Steptoe, 1980: 122).

After considering possible moral and legal problems, they decided to discard that idea. As Edwards briefly mentioned, it was too complicated and he was "against it" (Edwards and Steptoe, 1980: 122). Steptoe agreed with him.

This conversation between Edwards and Steptoe reflects how they were aware that a possible solution to the implantation problem they faced relied on egg donation (a common practice today). According to the account, Steptoe was more inclined than Edwards to offer this alternative to patients as a way of satisfying their desire to be mothers. They both agreed that a baby born this way would probably be loved. However, they were not certain. In addition, legal problems could arise, such as disputes over parental responsibility. Thus, they were faced with a series of complex circumstances in which both basically agreed that genetics played a preponderant role in establishing kinship relationships.

The manner in which Edwards and Steptoe addressed these critical issues and resolved this inconvenience marked the future course of *in vitro* fertilization. Rejecting egg donation meant opting for a less efficient path in technical terms. If they had chosen this route, they would have achieved a birth in one of their patients much sooner. However, the imaginary that guided their practices led them down a much more arduous path: from dropping hormone therapy to following the natural cycle.

The natural cycle strategy presented new difficulties and critical problems for the entire team at technical, organizational, and personal levels (Johnson, 2011). As Steptoe recalls, this new strategy involved changes in their practices: "It would no longer be possible to carry out operations when it suited me or my team" (Edwards and Steptoe, 1980: 146). To deal with these reverse salients, the team had to calculate the exact interval of time in which each patient's egg (only one) would be mature and aspiration could be performed by laparoscopy to then proceed with in vitro fertilization. If all went well, only one embryo would develop, although it might not reach the blastocyst stage (the optimal for transfer). If the embryo presented any problem during its development, it would have to be discarded and the procedure started again in the next cycle. However, even if the whole process had gone according to plan, the embryo could not be implanted and the pregnancy could not take place. It should not be forgotten that the patients were infertile. These were generally women having clogged Fallopian tubes due to infection, but there were also other causes, both known and unknown at the time, that could ruin all their efforts.

Ideas about family and kinship in the phase of invention and development played an important role in the expectations of end users. At this time, the end users were married heterosexual couples rather than individual patients. In the reproductive imaginary of the development of IVF, infertility and its technological fix were confined to the framework of the nuclear family. In the passage above, Edwards and Steptoe deliberated and moved forward without consulting their patients about possible drawbacks. From their parameters, their patients wanted their "own" children from their "own" husbands and therefore it was not enough to be able to offer them a child that was not genetically linked. This issue turned out to be crucial in redirecting their research practices. Thus, the final objective of IVF was configured: to

provide infertile couples with genetically linked offspring. At the same time, they clearly defined the profile of the possible users of this technology - infertile heterosexual couples for whom an opportunity had now opened up (Edwards and Steptoe, 1980: 185)-, thereby excluding other possible users, such as single women, something that changed as the sociotechnical system matured.

Finally, on July 25, 1978, Louise Joy Brown was born in Oldham. She was the first baby in the world to be born through IVF. Thirty-two years later, the success of this technological fix for infertility was distinguished with the 2010 Nobel Prize in Physiology or Medicine.

Development and Innovation

The road to the invention of IVF was long and winding. The British team resolved numerous challenges, both technical and social. However, in the 1970s there were other groups looking for techno-scientific remedies for couples suffering from infertility. The success of 1978 made it easier for many techno-scientific developments aimed at improving the effectiveness of *in vitro* to occur. These innovations mainly improved culture media and technical instruments for oocyte retrieval (needles, introduction of ultrasound in laparoscopy) and embryo transfer (cannulas), and adjusted hormone doses (Leeton, 2004).

A short time later, another technology, already anticipated by Edwards, was to prove an important turning point. The first use of deep-frozen semen was reported in 1983, and the first birth from a frozen embryo occurred in Monash, Australia, in 1984 (Mahadevan et al., 1983; Downing et al., 1985 cited in Leeton, 2004). Cryopreservation improved the efficacy of IVF because it favored the collection of a greater number of ovules and, therefore, the development of more embryos, increasing the chances of success and allowing the excess to be stored for other attempts. This surplus also led to the donation to other women and the development of gamete banks.

In this context, new inconsistencies began to emerge, not only in the form of ethical problems, such as what to do with surplus embryos and whether they have the right to life, but also religious ones. In 1983, Gamete intrafallopian transfer (GIFT) was offered in Ohio (USA) for the first time as an alternative, as it was considered *more ethical* by Christian groups. Christos Mastroyannis explains in *Fertility and Sterility* that "[o]bjections by the Roman Catholic Church to these techniques arise from an understanding of the procreative act as 'a physically embodied love act', a consequence of the heterosexual nature of the human race" (Mastroyannis, 1993: 389). In this procedure, the gametes were placed directly into one of the Fallopian tubes. They thought that in this way fertilization occurred in a more natural way.

These technologies competed with IVF, driven mainly by the strong influence of religion in the reproductive imaginary. Although the success rates using GIFT and its derivatives were initially higher than by using *in vitro* fertilization, improvements in the procedures made it easier for the latter to gain ground. As Lauren Bishop and her team explain, "given the minimally invasive approach of IVF, 78% of practitioners preferred this method over tubal transfer of gametes or zygotes" (Bishop et al., 2018: 206). These other technologies required the use of laparoscopy, which made them more invasive than *in vitro*, which already used the vaginal route. In addition, they carried risks, such as ectopic pregnancy and those typically related to the use of general anesthesia.

In the years following IVF, this technique coexisted and competed with other technologies with which it shared both objectives and users. In these other technologies, end users were assumed to also be (heterosexual) married couples (i.e., Mastroyannis, 1993: 390). Conflicting values also arose, demonstrating the dynamics of reproductive imaginaries; for example, the conflict between the value of genetic inheritance versus the value of the life of the excess embryo which could be adopted.

Other technologies also emerged around *in vitro* that led to the development of the technological system. The first micromanipulation techniques developed in the 1980s were partial zonal dissection and sub-zonal insemination, aimed at "enhanc[ing] the success of IVF in couples with male factor infertility" (Bishop et al., 2018: 207). Both can be considered important precedents for intracytoplasmic sperm injection (ICSI).[6] In 1992,

the success of ICSI with the birth of four babies was reported in Brussels, Belgium (Palermo et al., 1992 cited in Bishop et al., 2018). The use of ICSI doubled the fertilization rates as compared to previous ones (Bishop et al., 2018: 207). ICSI is considered almost as important as *in vitro* fertilization because it allowed to start "treating" the male factor of infertility (Palermo et al., 2018: 196). Like IVF, its purpose is not to cure through medical treatment, but to facilitate the creation of genetically based parent-child bonds through a technological fix.

By injecting round spermatids into oocytes (ROSI), two babies were born in 1994 in Paris, France (Tesarik et al., 1995). ROSI technology and its subsequent developments allowed men without sperm to become genetically linked fathers, something completely unthinkable until then.[7] These technologies sought to dispense with sperm donation, which was considered a less desirable alternative. The goal of these technological developments was to generate genetically linked blastocysts and, ultimately, babies. In this way, IVF is growing as a system, accommodating new technologies within its system and directing innovation towards its objective.

Transfer, Growth, and Competition

In IVF accounts, some groups generally stand out over others and this also shows the collaborative networks and rivalries of the early years. Births in the UK (1978), Australia (1980), the USA (1981) and, to a lesser extent, Sweden and France (1982) are frequently included in the accounts (i.e., Leeton, 2004; Brown and Steirteghem, 2018). However, the second IVF birth in the world was in India, two months after the birth of Louise Brown. In his protocol, physiologist Subhash Mukherjee included the use of hormones, the cryopreservation of the ovules (two obstacles for the British team) and the vagina as a means of access in oocyte retrieval. Another frequent omission is that of the first baby born in the Czechoslovak Socialist Republic in 1982 through the efforts of gynecologist and researcher Jan Tesarik and his team. It is not clear if this oversight is due to the fact that it was presented as an alternative to the protocol used in England. This procedure was performed while also doing reconstructive surgery on the uterine tubes, so it had a therapeutic purpose (Tesarik et al., 1983). In contrast to the British procedure, Tesarik did not wait for the embryo to develop. Another possible reason for it being overlooked might be the hostile politics and rivalry between capitalist and socialist countries during the Cold War.

The different protocols followed by both Mukherjee and Tesarik are an example of the reproductive imaginaries interweaving in their decisions and the final configuration of their technological developments. The paths to IVF were different, as was their reception in Europe and India. Also, there are differences between the contexts in which these teams had worked, the social and scientific perception of their work, and the tragic outcome of Dr. Mukherjee on both a professional and personal level (Ferber et. al., 2020). Although further investigation would be necessary, this example is indicative of the plurality of reproductive imaginaries as well as their situated and contextual character.

Groups excluded from the main narratives aside, collaborative networks developed alongside rivalries. Jean Cohen, a French biologist on the team from the town of Sevres, recalls how isolated groups were in different parts of the world, working in environments that were hostile and indifferent to their work (Cohen et al., 2005: 440). Anna Veiga, a Spanish biologist and the scientific mother to Victoria Ana (the first IVF girl to be born in Spain in 1984), explained in an interview that "[it] was not an impression, it was evident. There was tremendous competition between two groups, ours and the one led by Dr. Marina, also in Barcelona. We knew perfectly well that they were doing the same thing as we were. Frankly, it was a race" (Elcacho, 2012: 8).[8] Veiga also recalls the added difficulties of those years when there were still no specific training courses in higher education institutions (Elcacho, 2012).

Despite the rivalry, the groups shared channels of scientific communication, sometimes through scientific congresses, but mainly through scientific journals. The advances and difficulties of the different procedures tested, as well as the technologies and devices which drove them on were constantly reported in scientific journals such as the *American Journal of Obstetrics and Gyne-*

cology, Fertility and Sterility, *Lancet,* and, later, *Human Reproduction,* among others. In the 1970s, the American Society for Reproductive Medicine was one of the main focal points for research in the field and, by the end of the 1980s, the USA was a leading scientific power (Hobsbawn, 1995), attracting scientists from all over the world through its journals and conferences (Browm and Tarlatzis, 2005). In the 1980s the various groups began to develop scientific meetings of their own and created scientific societies (e.g., Browm and Tarlatzis, 2005). Thus, collaborative networks were formed which facilitated the transfer of techno-scientific results and the innovations that emerged around IVF.

Furthermore, a growth phase occurred and clinics proliferated in the USA, Australia and Europe (i.e., Leeton, 2004). In this period, new actors appeared on the political scene due to the ethical and legal problems that the development of these technologies aroused. Some of these issues were related to the legal status of children born through IVF and to the ownership and use of surplus embryos, as well as to the licensing and regulation of the practices carried out with embryos by assisted reproduction clinics and experimentation laboratories (i.e., Melo-Martín, 1998). The need to develop legislation to adapt to these new circumstances led many countries to convene expert committees to evaluate these new technologies.[9] One of the best known reports is the Warnock report in the United Kingdom (1984). This committee developed principles for the regulation of IVF and embryology that laid the foundations for subsequent legislation on the protection of embryos and their uses in research. In 1992 USA regulates the IVF industry, controlling the quality of the laboratories and forcing success rates to be communicated for consumer information. The guidelines and recommendations of scientific societies were insufficient and legislation was needed to protect the rights of infertile couples against misinformation and lack of transparency from the emerging industry. In 1999, ESHRE created the European IVF Monitoring (EIM) Consortium for data collection referring to legislation, public funding and registration systems on ART in different countries (Calhaz-Jorge et al., 2020).

Acquiring Style and Consolidation

During the 1980s, the use of reproductive technologies expanded rapidly, arousing misgivings in some social sectors as different as the feminist movement and the Catholic Church (Thompson, 2005). In the case of Spain, where the ART system has best matured, the volume of accredited centers has grown significantly compared to other surrounding countries (i.e., Alkorta, 2006). In the first decade since its introduction in 1984, the number of clinics grew to 190. After the economic crisis, in the short period of the past 5 years, the number of centers has not fallen below 300; in fact, over the past 3 years it has risen to 436 centers.[10] Since 2012, coinciding with the standardization of oocyte cryopreservation and the fact that the procedure was no longer labeled as experimental (Asensio and Palma, 2018: 81), these centers have not stopped growing. This is happening in a country where 80% of the centers accredited to offer IVF[11] belong to the private sector and where the Public Health Service's (PHS) portfolio of common services had excluded single women, lesbian couples and trans people from assisted reproduction until 2021 (Orden, 2021).

Spanish clinics, especially those in the Mediterranean arc, have become one of the main centers of attraction for so-called reproductive tourism (Lafuente, 2021; see also Vertommen et al., 2022). In this geographical area are found the pioneer IVF centers in Spain, such as the Institut Universitari Dexeus, the CEFER Reproduction Institute, the Bernabeu Institute and IVI. The latter merged with a leading American company in the sector in 2017, forming IVI-IRMA Global, a multinational represented in Europe, the United States and Latin America, after selling part of the company in the Middle East for 90 million euros (Muñoz, 2020). It has an average yearly turnover of 300 million euros and was recently bought for 3 billion euros (Casado, 2022).[12]

IVF has not only experienced significant changes at a quantitative level, achieving territorial and business transfer and growth at a global level, but it has also experienced qualitative changes, especially in the last two decades. The concept of 'platform technology' (Franklin, 2013) illustrates the nature of this technology as the foundation or support for various technological

deployments, without which they would not be possible, such as DGP, stem cell research and reprogenetics.

From the LTS perspective, I interpret these qualitative changes as the consolidation of the technological system and the acquisition of *momentum* (Hughes, 1987). IVF has become a complex and extensive technological system. This system is made up of other technologies (i.e., cryopreservation, PGD, artificial intelligence, etc.), artifacts (i.e., cannulas, Petri dishes, stretchers, etc.), scientific elements (i.e., books, conferences), organizations and institutions (i.e., courts, PHS administration), natural elements (i.e., gametes), and heterogeneous actors (i.e., infertile patients, fertile users, embryologists, gynecologists, psychologists, marketing teams, etc.), as well as connecting with other sociotechnical systems (i.e., PHS, the economic). Some of these systems and new technologies have come to constitute new fields using the embryos generated by IVF, such as stem cell therapies, thus moving away from the original function of the system (reproducing babies biogenetically linked to their parents).

The idea that the system has gained autonomy or "a life of its own" is indicative that it has matured and gained momentum (Hughes, 1987: 76). This autonomy is apparent. The sociotechnical system is sustained thanks to the social relations and institutions that participate in it (Jasanoff and Simmet, 2021). Some of these are the assisted reproduction units in PHS, private clinics (whether small or large companies), pharmaceutical companies, public and private research centers, governments and their legislation, scientific societies, associations of infertile patients, etc. In order for the system to behave in an inertial and apparently autonomous way, it is crucial that the interests of the system's social agents be focused around its function.

This explains why cryopreservation (of gametes, embryos, and ovarian and testicular tissue) and regeneration (of gametes and tissues) are two of the main lines of research and technological innovation. The cryopreservation of embryos and oocytes is an accepted and standardised procedure in clinical practice (Asensio and Palma, 2018) which facilitates the reproduction of genetically linked babies when people lack optimal gametes for spontaneous conception, either due to aging or being affected by various pathologies and/or treatments (e.g., cancer or endometriosis patients). Cryopreservation intervenes as a bridging and an accessory to *in vitro* fertilization. In contrast, regenerative medicine applied to assisted reproduction and its technological developments (i.e., platelet-rich plasma intra-ovarian infusion, ovarian tissue transplantation, artificial ovary and gametes) aim to restore reproductive function, and therefore ensure genetic linkage, although they are still experimental and need further evidence and evaluation (Sfakianoudis et al., 2020).

As I have argued so far, IVF is a technology that has grown to become a sociotechnical system whose function is to reproduce kinship relationships based on genetic linkage. In this sense, it has managed to articulate actors with heterogeneous interests, institutions and other technologies, becoming the center of ARTs.

System adaptations to the environment

A consolidated sociotechnical system like ART over time becomes increasingly impervious to the influences of its environment and acquires a tendency to configure it (Hughes, 1994). Matured systems tend to follow a particular path which is shaped by style. Thus, those kinds of systems also "tend to exert a soft determinism on other systems, groups, and individuals in society" (Hughes, 2012: 48) and "to incorporate the environment into the system, thereby eliminating sources of uncertainty" (Hughes, 2012: 47). However, following the case of ART, I have identified different adaptations to the environment. Thus, I try to explain the dynamic relationships between ART and its environment.

From my perspective, a system with style and momentum has a great centripetal force, that is, it has a great capacity to attract bodies towards the nucleus. IVF, whose function is to reproduce the links of genetic kinship, is at core of ART and other technologies within the system are adaptations that serve this function and its reproductive imaginary. The following example illustrates this. A heterosexual couple goes to a clinic claiming to have problems conceiving spontaneously. The

system operators, gynecologists and embryologists diagnose the woman with ovarian aging due to advanced maternal age and offer to replace her egg with a donated one.

Egg donation (or rather, the use of donor eggs) is one of the practices that has most contributed to raising the success rate of IVF (Lafuente, 2021) and is also one of the most used technologies in recent years in Spain.[13] The use of donor eggs in IVF means giving up the genetic tie of one of the parties, in this case, the woman.[14] As other authors have pointed out, these ovules "guarantee that the heterosexual couple conceives while maintaining the male genetic line" (Lafuente, 2021: 121).[15] In this way, the genetic link of the male, who is the undisputed father of the future child, is ensured and the system's reproductive imaginary is accomplished, while the identity of the mother is uncertain and must be reconstructed discursively.

Donated eggs become a technological solution to a problem of nature and the value of genetics is replaced by epigenetics and the gestation process (i.e., environmental factors and lifestyle can alter the expression of genes, thus, the baby's physical characteristics and health). In this context, the role of epigenetics as an enabler of the transfer of a kind of unique "substance" to the baby during gestation takes on fundamental relevance insofar as it facilitates the creation of kinship ties. Epigenetics is valued and occupies a relevant place within the system's imaginary as a substitute for genetics. According to Jenny Payne, the emergence of epigenetics in new conceptions of kinship may represent a paradigm shift to the extent that it redefines biological kinship (Payne, 2016: 494). Likewise, as Sarah Richardson (2021) points out, biomedical research in this field has proliferated in the last three decades, even though there is no clear consensus on the factors to consider or their correlations. From a critical review of the theories on the 'maternal imprint', Richardson's work shows the role of surveillance and control that these imaginaries exercise on mothers during pregnancy. Thus, through epigenetics, the ART system's imaginary restores the identity of the woman as a future mother and the role of the donor is overshadowed or estranged from the process by the product: the egg.

This technology reinscribes kinship ties in epigenetic terms for the woman within the heterosexual couple. This supposes an adaptation of the system in the face of a new reverse salient: the problematic ovum of the progenitor.[16] The system is adapted through the use of an IVF accessory technology which facilitates the reproduction of the IVF nuclear family model from 1978. The infertility taboo, still very much present in many reproductive imaginaries, operates in this context by contributing to the concealment of the donation if the couple so wishes (Fernández-Jimeno, 2022). Egg donation is one of the system adjustments to reproduce the same model of kinship.

In the above case, the reproductive imaginaries (and goals) of the clinic and the couple were the same. But, what happens when the imaginaries of a group of possible users differ from the system's imaginary? When the imaginaries of the environment and the system differ, a confrontation occurs, i.e., a fight between opposing forces. This conflict is resolved through negotiation or abandonment. An example of this is seen in the case of lesbian couples as users of ART.

In Spain, since the approval of the same-sex marriage law in 2006 and the change in social values, more and more lesbian couples are deciding to undertake social family projects (Imaz, 2014; Royo et al., 2020). This change in the environment placed the ART system face-to-face with a reverse salient: a new type of potential users appeared for whom the system was not prepared. One of the most common ways for these couples to undertake this project is through the use of artificial insemination by donor (AID) because it is a "safe and easy" way to carry out this project of joint motherhood. Lesbian couples think they can use these technologies to be mothers, but their project is conceived more in social rather than biological terms. Thus, the reproductive imaginary of lesbian couples differs from the reproductive imaginary of ART.

For gay and lesbian couples, the genetic link with their upbringing has not been so since they really lacked the means (Fernández-Jimeno, 2019). However, the introduction of the reception of oocytes from the couple (ROPA method) in private clinics' catalogs increases their options as consumers. This technology links genetically

to the woman who provides the egg and epigenetically to the woman who experiences the pregnancy. In this way, a discourse of "shared motherhood" is constructed in which the two women are mothers insofar as they share their "substance" with their child (Bestard, 1998 cited in Imaz, 2014). This technology favors a change in the reproductive imaginary of lesbian couples to the extent that they no longer have to "settle" for being social mothers through legal and social arrangements, and can be mothers "like any other couple" (Imaz, 2014). Behind these statements lies the desire not to be excluded from the social sphere and to resemble heterosexual couples. In this case, the centripetal force has won the conflict because it has managed to attract these couples towards the imaginary and the objectives of the system. In this process, the couple has cooperated with the system, sharing a reproductive imaginary and the system has adapted to a new type of users: lesbian couples.

This also shows the evolution of the imaginary of ART since it has shifted from exclusively targeting heterosexual couples to accepting a new type of users who brings along a new family model. Unlike the PHS, private clinics are companies that seek to maximise their economic benefits.[17] In this sense, reaching a new type of user is a good way to expand both their services and market. Private clinics adjust their company image (i.e., website, blog) to these changes in the environment because it allows them to broaden the spectrum of potential consumers. The use of ROPA method facilitates the reintegration of the difference in the nuclear family model. The technological system, far from being compromised, fulfills its function to the extent that it offers the couple a biogenetically linked child. In the case of lesbian couples who decide to use ROPA and in the case of those who persist in using AID and resist complying with the system (i.e., they have a high centrifugal force), both maintain a dependent relationship with ART. In the first case, they accept system's reproductive imaginary, while, in the second, at least one of them will maintain a kinship bond based on genetics, so that, in practice, they partially comply with system's imaginary. The only way not to depend on the system is to reject it.

Casuistry in the use of ART is very widespread since, in addition to the reproductive imaginaries of the users (system operators and end users), the medical condition of each patient must be taken into account. Frequently, the intentions or desires that underlie the imaginary cannot be satisfied in the way they were initially projected. This involves a process of negotiation and search through trial and error for the most appropriate technological fix. In these processes, the imaginaries of operators (embryologists, gynecologists, nurses) and patients (lesbian couples, heterosexuals, single women) may not coincide. Furthermore, reproductive imaginaries may change during the process, especially when patients have to overcome several failed attempts. In these cases, ART offers alternatives such as embryo adoption. The different technologies that constitute ART do not contribute equally to the main function of the system and may reinforce partially opposing imaginaries, especially when they are appropriated by unexpected users, such as lesbian couples. Despite this, an important reason why ART sponsors this type of practices is because, to a large extent, it is a business. Nevertheless, the imaginary of the system and its operators involves both the desire for patients to take home a healthy baby and the economic benefit of doing so.

Conclusions

In this paper I have analysed the role of reproductive imaginaries in the dynamics of technological change of reproductive technologies. First, I have explained this type of imaginary. I argue that reproductive imaginaries are collective visions of motherhood, infertility and kinship ties that are collectively maintained and carried out in the design and use of ART. These visions are dynamic and plural, so it is necessary to place them within social and cultural contexts. This facilitates the understanding of its plurality, even when divergences that are likely to enter into conflict coexist.

Subsequently, following Hughes, I have identified the phases of the structure of technological development in ART. In addition, I have shown the role of reproductive imaginaries in the process of co-production of ART and the environment in the different phases. System builders' imaginaries

played a decisive role in the invention phase of IVF and in establishing the function, but imaginaries that surpass Hughes' vision focus largely on the figure of great enterprising men. With the growth and transfer to other areas, the system continually ran up against reverse salients until it managed to consolidate itself.

Finally, in the fourth section I have explained the relationship between ART and its environment and how the system develops adaptations. The ART system and its environment are co-produced in dialectical processes through specific technologies. In these processes, tensions occur between the objective of the system and final users through centripetal and centrifugal forces respectively. Reproductive imaginaries and technical innovations are the means through which these negotiations and communication processes take place between the system and the environment. Thus, to continue exerting influence on its environment, the system adapts to integrate the elements of the environment and control them. If these elements were outside the scope of the system, they could not be controlled by it and the uncertainty would increase.

This case study suggests that applying co-production approach to LTS could be helpful to overcome the problem of the relation between the system and the environment, avoiding explanations in terms of soft determinism. Reproductive imaginaries have been shown to be explanatory tools of the reference frameworks that guide the technological practices of certain groups of users and operators and a key to a better understanding of the dynamics of LTS and their environment, providing a global perspective of change.

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Notes

1 ART refers to "all interventions that include the *in vitro* handling of both human oocytes and sperm or of embryos for the purpose of reproduction" (Zegers-Hochschild et al., 2017: 397), i.e., it includes *in vitro* fertilization (IVF). I will use ART to refer the system where IVF is included.

2 STIs are not the same as political agendas. Although both share normative prescriptions, STIs do not focus on defined and explicit objectives, so they are also less instrumental and politically responsible (Jasanoff and Kim, 2009: 123). They are also different from social values. STIs are ideas about what is desirable and, therefore, contain social values, but they include practices and courses of action that materialise those desires through institutions and social groups, as well as public actions (Jasanoff and Simmet, 2021: 2). Besides, STIs are not mere narratives or justificatory discourses of the science and technology that we have; they are rather the projections of possible futures through technoscience. They can be present in discourses and narratives, in the norms of a community and in metaphors and other cultural meanings. On the other hand, Jasanoff and Simmet (2021) emphasis the dynamic nature of STIs versus the static nature of actor networks.

3 See also the special issue "Symposium: The History of the first IVF births" at *Reproductive Biomedicine & Society Online* (2015).

4 Other case studies can help to understand the processes of negotiation between the system and its environment. For example, some ethnographies on egg freezing (Inhorn et al., 2022; van de Wiel, 2020) or studies on surrogacy (Smietana et al., 2018). For a systematic review of the main contributions of anthropology and sociology to the study of reproduction and ART, see Inhorn (2020).

5 Own translation.

6 ICSI requires sperm being selected and eggs being prepared by a biologist in the laboratory prior to the microinjection procedure, which is intended to induce fertilization. For a detailed description of ICSI, see Sara Lafuente (2017: 262-265).

7 In some men sperm formation is blocked. ROSI uses spermatids (cells with haploid genetic material in the phase prior to the final formation of the sperm) (see more in Tesarik et al., 1999).

8 Own translation.

9 See more about the ethical-legislative debates in the USA, Australia, Canada and Western Europe in D Melo-Martín (1998).

10 Data prepared by the author based on information collected from the 2002-2019 National Registry Reports on activities and results of assisted human reproduction centers and services (henceforth SEF Registry) and the National Commission for Assisted Human Reproduction Report (2022).

11 Own data developed from the SEF Registry.

12 For a broader view of the economic value of the global fertility market and global fertility chains see Vertommen et al., 2022.

13 Data from the SEF Registry.

14 It is different from sperm donation for many reasons. Between them, egg donation emerges in the context of IVF development and reaffirms its function. Sperm donation and artificial insemination by donor (AID) loses relevance in the context of the heterosexual couple with the development of IVF and, especially, with the introduction of innovations such as ICSI and ROSI.

15 Own translation.

16 Ovarian aging is one of the main causes of infertility in women in developed societies due to advanced maternal age (Agramunt et al., 2011: 129).

17 In contrast, the changes in public policies within the PHS have been motivated by the social and legal struggles of groups of discriminated women (Fernandez Jimeno, 2019).