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CHAPTER THREE

The Nano-now

Why do we need nanotechnology? Should we pursue its development simply because we can, or will it serve some set of greater needs, solve current problems, enable both economic and social advancement, or provide other benefits? Will these potential benefits outweigh possible risks? Authors and futurists like Drexler, Kurzweil, Joy, and others I have mentioned tend to agree about the revolutionary nature of the technology, if pursued to its ultimate form, and many scientists, engineers, and even hobbyists are pursuing what could be considered to be intermediate forms right now, with varying degrees of success, and with equally revolutionary implications. Importantly for the subject of this work, those intermediate forms implicate issues we have begun to explore here about the impact of intellectual property (IP), and the need to pursue alternate means of protection and reward outside traditional IP law. These researchers recognize that nanowares will eventually eliminate scarcity, fundamentally alter our economies, and enable innovation, fabrication, and entrepreneurial activity to be decentralized, liberating creativity in ways previously impossible.

Consider the difficulty just fifty to a hundred years ago encountered by someone who wished to bring an idea to the marketplace, much less earn back the cost of his or her investment. Skipping the part about first protecting one's idea through a costly and potentially lengthy patent filing, bringing most products to market meant accumulating capital, or working out a licensing or other contractual deal with a manufacturer who already had, or had access to, the infrastructure necessary to make the product. The difficulty and expense of moving any new item from idea to marketplace ensured, for much of the industrial era, that only organizations large enough, sufficiently capitalized, and capable of withstanding likely losses (like corporations) could risk bringing products to widespread markets. While artisans and small producers could produce items for local distribution, even throughout the industrial era, the scale of production, absent the efficiencies gleaned from mass production, ensured that the products could not be competitively priced, and that profit margins would remain slim. Industrialization (which mechanized production) and mass production (which increased and speeded

up the numbers of units that could be produced per worker per hour) afforded inventors efficiencies that helped ensure that if their product found a market, then demand could be met, prices lowered competitively (assuming no patent protection, which allows for monopolistic pricing for the term of the patent), and broad markets reached assuming the availability of some distribution chain.

Ideas are free. Turning ideas into something profitable has been, historically, risky and expensive. Innovation thus became the province mostly of well-financed geniuses, or large corporations, and often both working in tandem. Patents have certainly helped make certain investments less risky in the sense that risks associated with prototyping, testing, then mass-producing inventions could be taken as long as patents had been filed, alleviating some of the risks of other competitors entering the market first. The risks associated with capitalizing the process were offset by the monopoly enjoyed through the patent, allowing prices to be set so as to offset the additional expenses. Innovators who lacked access to capital took big chances when approaching potential financiers, or corporations who might agree to license their inventions, especially if they had not already begun to get a patent. Finally, even holding a patent was no guarantee of breaking even, much less not going bankrupt. For an individual inventor, a single patent is just a gamble, a hedge against the possible 'theft' of one's idea and its successful implementation by someone else. But holding the patent does nothing to create a market, nor to induce demand, nor even if there is demand does it ensure that demand will be sufficient to make a profit. Most patents never earn their holders any money. But corporations are able to hedge their risks by innovating in multiple ways at once, often holding patent portfolios with multiple potentially profitable innovations, assuming that many will fail, but that the few that succeed will pay for the losses on others.

For individual innovators who wish to enter the marketplace, the risks can be reduced only by paying up front for a patent, in the hope that the filing and attorney fees involved will be offset by either licensing fees earned by licensing the patent to a company that can afford to capitalize the manufacture and distribution of the product, or that by holding the patent, and marketing the product successfully to potential investors, enough start-up money can be raised to capitalize manufacture and distribution oneself. This is the system that has evolved, and it means there is still a

significant barrier to entry for inventors, or designers of new products, no matter how useful and potentially profitable they may be.

This process has been short-circuited, however, in one area of innovation: software. Two developments have made it possible for software products to enter the market with virtually no capital, besides the labor and creativity involved in coding the product. With the advent of software and the internet, production *and* distribution of one sort of product could finally be achieved with little or no capital besides the labor and creativity involved in coding the product. Software has proven to be a boon for some innovators who literally created multimillion dollar products in their homes, using their home computers, and successfully distributed their creations via the internet. Successful computer companies (even a certain hardware company called Apple) have started in people's garages, unlimited by the once-prohibitive costs associated with prototyping, manufacturing infrastructure, and distribution chains. Software liberated innovators from much of the risk (although not the uncertainty) associated with creating something new and hoping the costs of production are recouped. The costs of producing many useful and eventually profitable garage-built software products are frequently only the time and creativity of one or a small team of coders intent on creating the product. The costs of distribution via the internet are insignificant compared to distributing even small physical goods.

Nanowares promise to bring to the world of the physical the ease and low cost of designing, prototyping, creating, and distributing physical goods. They will be the new software, merging the world of information and communication technologies (ICT) with that of material goods. We should look carefully, then, at the impact of IP on innovation in software, and see what lessons it holds for nanotechnology. In fact, many of those who are at the forefront of creating a new infrastructure for a nanotech future have already begun to apply what they consider to be those lessons to new modes of product design, manufacture, and distribution.

A Bridge to the Future: The Trend of 'Micro-manufacturing'

Some of those who have been at both the academic and engineering forefront of nanotechnology are working to deliver some of the benefits it could provide long before actual nano-assemblers or true molecular nanotechnology (MNT) is perfected. A notable example is Neil Gershenfeld,

an MIT professor who founded the Center for Bits and Atoms there, and who has long taught a course entitled 'how to make (almost) anything' for master's students. The course developed the core of the idea behind Fab Labs, and informs a general movement to liberate the technology surrounding creating physical goods the way that software and the internet have liberated another, less-tangible mode of creation. The course itself has been made available as 'open courseware'¹ and includes the following modules: 'CAD, CAM and CAE; laser cutting, injection molding, 3-D printing and NC machining; PCB fabrication and layout; actuators and sensors; analog instrumentation; wireless and wired communications. Lecture topics include design tools, NC, waterjet and laser knife cutting, microcontroller programming, circuit design and joining and forming.' This core set of skills and tools is offered as capable of allowing one to actually make (almost) anything. Gershenfeld's book *Fab: The Coming Revolution on Your Desktop*² details some of the history, methodology, and potential envisioned by his ongoing project to make the world of atoms as malleable as that of bits. Taking his ideas out of the academy and into the world via 'Fab Labs', Gershenfeld is attempting to make available in a room-sized lab what he hopes one day will be true MNT on a desktop, tied to a computer.

The toolset that is available in a Fab Lab costs just around US\$50,000 (a figure which continues falling), and with it one can essentially realize any CAD/Cam-design as a working prototype, assuming the availability of materials. One of the goals of continually developing and refining the Fab Lab toolset, and in placing Fab Labs all over the world, including in many developing countries, is to open up potential routes to innovation, and access to markets, previously foreclosed due to the problems outlined above: capital and risk. Another goal is to eventually refine the toolset such that a Fab Lab could make a Fab Lab. To meet both of these goals and to help achieve these ends, Fab Labs are explicitly un-patented. The tools (including the complete specifications and parts lists) and the software upon which the labs run are open, available to the public for duplication free of charge. The Fab Lab Charter encourages openness, stating:

Secrecy: designs and processes developed in fab labs must remain available for individual use although intellectual property can be protected however you choose

Business: commercial activities can be incubated in fab labs but they must not conflict with open access, they should grow beyond rather than within the lab, and they are expected to benefit the inventors, labs, and networks that contribute to their success.³

The near future of Fab Labs includes greater availability of the tools of design and prototyping of new inventions, cheaper toolsets, and hopefully, more entrepreneurial activity. But the IP climate surrounding them might yet hamper their prospects. While users are encouraged to keep their designs open, they may yet seek IP protection. Precluding this would, of course, itself be an affront to openness as it would reach beyond the use of the tools and limit what innovators can do with their ideas. But IP regimes devised in the industrialized West have pervaded many of the countries in which Fab Labs are now available, spread through international treaties requiring developing countries to abide by Western norms. Innovators seeking to create new products, and intending to enter markets, will do so at their own risk just in case their designs infringe someone's IP.

Taking the Fab Lab goals and philosophy to their logical extremes, and the stated goals of many of the field's leaders, will result in replicating replicators, capable of cheaply producing not only prototypes rapidly, but even working parts. Eventually, as with the goal of Fab Labs being capable of being used to create Fab Labs, numerous other nascent technologies that are now under-developed may lead to the fabled convergence, or singularity, not from the nanoscale upwards – but from the meso-scale down. It is worth noting that most of these efforts are currently being developed as open source projects.

The dream of personal desktop fabrication is being pursued at more modest levels than Fab Labs, by open source development projects like RepRap and Fab@Home. These projects have reduced the toolset for cheap, easy, digital fabrication of objects to just one: digital, 3D printing. Three-dimensional (3D) printing is part of the Fab Lab toolset, and involves the creation of 3D objects by building up successive layers of some material, typically a polymer, although other materials are proving to be useful and capable of generating working models and parts, not just mere prototypes. Leapfrogging the marketing of professional tools, such as Hewlett-Packard's recently introduced DesignJet 3D (which retails for around US\$13,000),

projects like Fab@Home and RepRap have achieved reasonable 3D printer designs for a fraction of HP's desktop 3D printer. The parts for the current Fab@Home Model 2 cost about US\$1,600, and a growing number of parts can be 'fabbed' on a Fab@Home.⁴ The RepRap Mendel (the second generation RepRap) boasts materials costing only US\$520, and has many parts that can be made with a RepRap.⁵ The stated goal of each of these and similar projects, as with Fab Labs, is complete self-replication. The implications of success are quite revolutionary, perhaps as much so as fully realized nanotechnology will be.

A New Industrial Revolution?

Even before true MNT becomes a reality, the trends and projects discussed above promise to alter the nature and economics of innovation. The risks of innovation will always remain high, in the sense that very few new artifacts ever really catch on with a large consumer base. But the costs of failure are falling rapidly. Certainly, the possibility of fabricating complex objects anywhere in the world given a complete set of specifications poses threats to current systems of manufacturing and distribution. Decentralized manufacturing of objects means loss of control over the 'first sale' of an object, assuming the object can be completely duplicated. Consider the loss of profits claimed by designers of Gucci or Luis Vuitton handbags due to the proliferation of counterfeits. Sales of music CDs and movie DVDs continue to fall given the cheap and easy ability of anyone with an internet connection to download near-perfect copies. Imagine now the ability to truly reproduce any object in one's home using a desktop device hooked to a computer and the internet. The technology that is the dream of MNT researchers like Neil Gershenfeld will be a nightmare for the owners of IP. The losses currently faced by copyright holders will spread to patent holders as nearly any patentable object becomes easily copyable. Yet it is this same technology that promises to liberate the creative, innovative, and productive processes wielded now mainly by the already well-capitalized. It is this same technology that could alleviate poverty itself, bringing at least material wealth to every corner of the globe, overcoming barriers to ownership, such as costly materials, manufacturing, supply, and distribution chains. One-and-the-same technology is a terrible threat to the established economy, and the ultimate promise for a new one. What will that economy look like, and who will win the inevitable battle?

The advent of true MNT, and perhaps even some mid-range ‘micro-manufacturing’ phase involving desktop fabrication of objects with multiple materials (in some final, not-merely prototype form, for instance), means a transition from an economy that profits from scarcity to one in which scarcity is no longer an issue. While currently, prices in a free market settle into a state where margins for profit are available even to competing manufacturers in a market for a scarce good (because consumers cannot make the thing themselves, or because the thing is naturally scarce in some region), prices in a world in which anything can be made anywhere at any time (assuming available component materials) will fall inevitably toward zero. If prices for products will only fall, then we should consider the economic problems caused by a replicating-replicator-induced deflationary spiral, and whether such a technology is not only disruptive but also destructive. We need not evaluate models of supply and demand, nor bicker over the accuracy of such models, in a world in which items can be made at will by replicators capable of replicating themselves. Simply put, markets as they are currently construed would cease to exist, at least for things that could be made by such replicators. Perhaps the only surviving markets would be those by which designs or ideas for new things might be exchanged, something like an economy of types rather than tokens.

In a world of near perfect abundance, our economy would be radically different. Without the need for capital, only a few things would remain valued as scarce, including primarily creativity and land. Although anyone with the self-replicating replicator of the true MNT variety might make any object, *designing* new and useful things would likely still only be a skill that some subset of the population would have. Besides creativity, other human qualities necessary for services would remain in demand, as well as high-tech skill-sets associated with maintenance and repair of existing things. Land, too, will remain necessarily scarce as perhaps the last true rivalrous material good. Clearly, as we transition to an economy without scarcity of most if not all material goods, many will find their jobs disappearing, whole sectors of the economy will shut down, and the nature of production and distribution, as well as the nature of consumers and producers in general, will be altered forever. The structure of the last industrial revolution will be irretrievably lost, but what will be gained?

In a world with little to no scarcity, the definition of poverty will change, as will the definition of its opposite. No one will judge one’s wealth by the

number or quality of possessions, nor will individual possessions (except those, perhaps, with sentimental or historical value) be worth much at all. Rather the worth or value of objects will be only that value each user or owner affixes to the object, even where no more *market* value might exist. Let's assume such a future will come, and that the political and social hurdles that stand in its way are somehow bypassed or overcome. Many will question whether and how innovators will be rewarded for their inventions, or what incentive will remain for anyone to invent anything at all. Perhaps IP laws can be adapted to such a future in order to encourage continued innovation, and to give some reward to those who will still hold the (relatively) scarce, and thus valuable, trait called *creativity*. Can the legal institutions of patent and copyright, which many argue helped propel a fair amount of the innovation and wealth creation of the industrial and information revolutions, be adapted to the nanoware future, or even its intermediary forms involving some form of self-replicating replicators? How would this work? We can see how it will work by looking at the impact of IP on software and ICT, in which scarcity is not a driving economic force, and in which IP laws have been applied to varying degrees of success to create artificial scarcity.

Software and IP, a (Failed) Experiment in Inducing Scarcity?

As we have seen above, ICT and software have proven to be problematic for the application of traditional IP regimes. In many ways, both patent and copyright have failed either to achieve their principle aims of encouraging innovation or to successfully protect and reward authors or inventors. The failures have been both pragmatic and theoretical, and in the process, serious flaws in the ontology of IP have been revealed, as we have discussed in previous chapters and in more depth later in this book. The theoretical failures include conceiving of software as belonging to two previously mutually exclusive categories (copyright and patent); confusing algorithms with ideas and vice versa; inaccurate application of the categories 'abstract' and 'concrete'; overlap of the category idea with that of abstract; and misunderstanding of the natures of ideas and expressions. Practical limitations have been revealed in the failures of either copyright or patent to do what they are claimed to do: promote innovation, and reward authors and inventors for a limited time, after which the public is

rewarded by the invention or work of authorship's devolving to the public domain.

Practically speaking, neither patents nor copyrights tend to reward innovators, although technically that is what they were designed to do. Authors have only very rarely been the true beneficiaries of the patent and copyright systems historically, largely because of the mechanisms involved with publishing. The same has been true, more or less, for software. It is not necessarily the institutions themselves that are to blame (although as we'll see, there's plenty to blame on them), but rather the economics of seeking and enforcing protection with IP. Simply put, IP protection of the sort that matters is only really available for those with the capital to finance potential litigation, as well as the will to pursue their claims. Record companies, publishing houses, and large manufacturers can afford to both seek and enforce IP protection, and authors and inventors with little access to capital (before they 'hit it big', for instance, with some work of authorship or invention) might be able to afford to file for a patent, can afford certainly to copyright their works (as copyrights are free), but likely cannot afford to fight any litigation that might result due to someone's infringement or their own alleged infringement (or claims by others that their works are infringing). The history of IP litigation is replete with instances of the little guy getting steamrolled by the big guy. Chances are, if you are not rich, and you are an inventor or author who is challenged by a large publisher, designer, manufacturer, etc., then you will not have the fortitude to do what is necessary to win (even if legally you are in the right) unless you are willing to spend a great deal of money, take a great deal of time, and risk losing in court. The economics of litigation favors settlements forced by those who hold the leverage of capital, at the expense of justice. It is a rare person who has been wronged who can afford to pursue justice despite the cost and risks, on a matter of principle.

Authors and inventors who seek copyrights and patents are thus best advised to do so for leverage in some sort of sale of their work or the rights to their work. Publishing contracts (typically) for music and books favor the publishers first, who, after all, take the risk of expending their capital to make sure the works see the light of day. Royalties for authors who are not already established are scant, and all but the most token advances, rare. A patent is valuable for the inventor, if he or she works out a decent licensing deal (with the help of an expensive lawyer) and may make inventors

rich, but the risks of the marketplace ensure that very few ever do become rich, while corporations more easily pool the risks of multiple patents in the hopes that one or two will generate millions. The economic gamble for the small inventor, or unknown artist, is generally too great to take on the established publishing or manufacturing community, and the potential for reward too small to make it worthwhile.⁶ Patents are expensive to get, and very expensive to enforce, and so they too end up becoming the property of those who have more capital, less to lose, and the means to enforce them. While there are exceptional cases of garage inventors making it on their own, or garage bands becoming wealthy with 'indie' label contracts, these are exceptions to the rule. With the advent of ICT, specifically the internet, the economics of music publishing (and software as well) has changed irrevocably. Now, not only is it hard for laypersons with little capital to seek or enforce IP protection, but even those with sufficient capital now routinely fail to be able to contain the 'theft' of their IP.

Software was to be the ultimate medium for do-it-yourself inventors, opening up the means of production to anyone with creativity and a computer. Yet today, it remains the large content providers who routinely benefit from IP, whether its movies, music, or software. While the occasional Doom™ might come along as evidence of the ability of basement coders to make it big, the overwhelming number of dollars spent on software goes to well-financed software publishers who either generate code in-house or buy the IP of smaller companies or individuals. Now, given the rise in the popularity of P2P sharing of files, movies, music, and software are shared all over the world, reducing (theoretically) the number of first-sales that would ordinarily generate royalties due to IP. The risk is rising for those who could afford IP, and the rewards are falling.

The battle has also often devolved into technological warfare, as IP owners have sought at various times to prevent the 'theft' of their IP with technology. DRM, or digital rights management software and hardware, has been employed in various ways to prevent copying through technological means. Each time, however, similarly innovative hackers have devised mechanisms to thwart DRM. Some DRM has even allegedly harmed users' hardware, decalibrating hard drives or DVD drives. Money spent on new technologies to stop copying becomes cheaply and easily defeated within shorter periods of time, and users who buy pieces of hardware (like a computer, video game console, or DVD player) assert their right to use

the devices they own, and modify them as well, in any manner they see fit. The DRM arms race is an ever downward, tightening spiral, or game of cat and mouse, and the mice continue to win.⁷

IP has failed in ICT both theoretically (IP, as it exists, cannot fit ICT into its categories and principles neatly) and practically. It does not reward nor protect as it should, and the rate of practical failure appears to be increasing. But what of the other stated goal of IP, to encourage innovation? Despite the failures addressed above, is IP still working as sufficient incentive (perhaps due to poor gambling heuristics, or poor understanding of the current economics of inventing and authoring), such that innovation continues unabated, or is there a risk that innovation will slow in the face of IP's failure? Or have other mechanisms continued to fuel innovation even as IP fails?

Alternatives to IP and Innovation in ICT

As traditional IP has slowly failed in the ways described above, new forms of innovation and protection of IP have emerged. Some of these owe their origins to 'open standards' manufacturing projects dating back to the early 1900s, and others arose out of modern efforts, primarily in software development, to stave off the perceived deleterious effects of copyright and patent law on software coding.

Open source methods of innovation reveal the product and process from the outset to a community of developers (and sometimes users) in order to defeat certain negative effects of IP monopolies. The general notion is that the details of the product or process, when revealed to the community, encourage its use and improvement over time. Absent IP protection, users and developers of open source products need not fear any legal repercussions to improving the product or process, and over time a virtuous circle of use and improvement perfects the product or process to the benefit of all. In the early days of automobile manufacturing, a pseudo-open-source approach was adopted by the Motor Vehicle Manufacturers' Association which had created a 'patent pool' on the products and processes involved in members' automobiles. Members of the association could freely use the patents of other members without fear of litigation, allowing for each to innovate freely, freeing capital that might have been required to be set aside in case of litigation, and encouraging the improvement of parts and methods employed in their vehicles rather than paying lawyers to fight to hold and enforce patents.⁸

Open standards have been used for even longer in science and engineering. Units of measurement, standards of scientific and mathematical notation, and other community-based mechanisms that encouraged the spread of information without affixing ownership rights, all are progenitors of the modern open source 'movement'. Open source approaches to innovation, as well as to its precursor science's methods, have helped ensure that communities of researchers and developers can share their forward movement, collectively grow thereby, and even successfully commercialize products as a result without the necessity of monopolies 'far upstream'. The notion of 'upstream' and 'downstream' relates to the level at which a monopoly right might attach. Consider an elevator. The law of gravity is upstream while the particular mechanisms employed to use gravity to move an elevator up and down, in the particular configuration or a certain elevator brand, is downstream. There is a gradient in between the laws of nature and the exact mechanisms employed that is mid-stream, with certain features falling further upstream than others. For instance, the use of cables to attach a box to pulleys is probably further upstream than the particular ratio, the diameters of the pulleys, etc., used in any single elevator design. In many industries it makes sense to not seek patents too far upstream, and to rely either on open standards or patent pools. We see examples now in the development of open standards for video codecs (the algorithms by which video is digitized and compressed) for DVDs and internet. The same was true for videotape recorders and players. By keeping the standards for the encoding and replaying of data open, manufacturers of tape decks, and now of software that records or plays back video, create a virtuous circle by which their machines or software can interact with each other's, improving trust and increasing usefulness so that consumers feel free to buy the product. The use of proprietary standards can have the opposite effect.

The videotape standards war between Beta and VHS offers some lessons in the value of opening up standards, or at least liberal policies of cross-licensing. While Sony was slow to cross-license its video encoding standard to other manufacturers, JVC did so rapidly, increasing the number of VHS recorders and players on the market, and driving demand upward as the price of tapes fell. Users could risk purchasing any one of the VHS brands because their tape collections would play on any other manufacturer's VHS player, whereas a user who spent on Sony's Betamax would be forever stuck to a Sony machine. At first blush, open standards might seem like a poor

way to ensure profits. If Sony opens up its standards, or cross-licenses them liberally, it is only asking for competition, rather than locking in guaranteed profits due to an IP monopoly. But by locking up IP so far upstream, an inventor takes a huge gamble that the consumer base trusts them sufficiently to reduce the number of available options downstream. With all but the most respected or economically dominant manufacturers, this gamble is not worth the risk. Potential customers faced with locking in their choices so dramatically will choose another option, unless the product is valued for some other reason, or because brand loyalty is high enough to warrant giving up choices in the future. At the inception of a technology, especially, keeping standards open has proven to be a successful strategy. Only in the rarest of cases have innovators benefited by proprietary standards that remain closed due to IP where the technology monopolized is far upstream.

Open source or open standards dominated the early development of software. Early coders experimenting with writing software on shared servers at places like MIT and Stanford shared their code. ‘Hacker’ culture, out of which many of the leaders in the world of computers and software came, valued coding for its artistry and ingenuity, and improved upon each other’s products. Closed systems, not amenable to tinkering, were frowned upon. The machines were new, at least to those who later founded Microsoft,⁹ Apple, and other computer powerhouses, and freely tinkering with code, which was itself freely shared, proved the foundation upon which knowledge, skill, and innovation in software first began to spread. As Steven Levy details in his history of the early ICT era, *Hackers*, openness is considered a virtue, not just a practical necessity for innovation (at least far upstream). The heroes of the early days of software, who liberated the technology for everyday users and put computers in all our homes, turned at some point. Bill Gates stopped believing in the virtues of open source when he bought the kernel of what would become MS DOS, and modified it, working out licensing deals to put it in millions of new computers sold. It was protected then by copyrights and patents. Steve Jobs, who helped finance the early days of Apple by selling ‘blue boxes’ which could be used to hack phones to make long distance calls for free, became an IP believer when Apple took off. Current systems like OSX and the iPhone operating system are open to developers who wish to make code to run on top of them, but the code itself is not open to all.

Reacting to the commercialization of software, when licenses for some high-end products could range from the hundreds of USD to the tens of

thousands, hackers began to develop their own, free products and built new licenses to guarantee they would remain free. Richard Stallman was an early pioneer of creating free software equivalents of expensive protected software. Unix was one such expensive system. The GNU operating system (which recursively stood for 'Gnu is Not Unix') was a free alternative to Unix, but it came with a minor catch. To use GNU, you had to agree to the terms of the GNU license, called the GNU GPL, for GNU General Public License. Otherwise, GNU was free, and meant to be wholly compatible with its commercial cousin, Unix. GNU was built on the principles enunciated by Richard Stallman at MIT, and the GNU project was begun in 1983 and continues today. Stallman first quit his job at MIT in order to prevent MIT from claiming any IP rights to the project, and later published the *GNU Manifesto*, defining the goals and purposes of the free software movement.¹⁰

The GNU suite of software became widely known and used, especially on college campuses, in computer labs, and among hobbyists in the mid-1980s. It encapsulated the philosophy that code ought not to be owned, nor that the source code could or should be hidden from users (a compiled program you might buy at a store excludes the source code, so you cannot find out how it works, nor tinker with it to make it better). The Free Software movement, more or less begun by Stallman who remains a major influence in it today, is motivated by the 'hacker' ethic, according to which the things we make and use ought to be transparent to users, and available to tinkerers to improve upon and modify. As the GNU project evolved and eventually developed an operating system, word processing software, and numerous other applications, Stallman developed the first GNU General Public License, or GNU GPL. The GNU GPL is meant to ensure that the software distributed under it remains free, and that no one profits by reselling it, or by attempting to monopolize it through traditional IP law.

One might very well ask what business sense 'free software' makes. How can one *profit* from making things freely available at no charge? The free software philosophy argues that the community of users profits simply by having better software available, freely, and openly so that anyone can improve it. Indeed, recent surveys show that free software pervades business operations throughout the world, and large segments of the information backbone of large corporations, and the internet itself, run on free software. Tools like Apache (a major platform used for web servers), Linux, Mozilla

Firefox, Sun's OpenOffice (a complete competitor to Microsoft's Office suite), and numerous other applications are now available under 'open source' licenses.¹¹ Open source is an offshoot of the free software movement, and has adopted many of the core institutional tools of the GNU GPL, but has also developed business credibility, and a devoted user base which pays, often, in various ways to use these otherwise free (and still open) tools. The movement toward open source has helped both legitimize and commercialize, yet keep software coding open. Because of the commercialization and adoption by large corporate entities like Sun Microsystems, Stallman has publicly opposed open source and continues to advocate free software. Nonetheless, a growing number of software projects, at every level of complexity and with varying degrees of commercial success, are now committed to calling themselves open source projects.

Importantly for our purposes, open source has begun to move out of the realm of software and computers into methodologies for delivering other goods as well. A critical difference between the free software paradigm and open source is that under the open source philosophy, people are entitled to profit from open source products, if only in limited ways. For instance, companies like Red Hat, which offered services surrounding its version of Linux (an open source operating system), built its business model on the provision of services and products *on top* of the free operating system it sold (Red Hat has since merged with another Linux-based system called Fedora). Sun Microsystems, as mentioned above, has a complete competitor to Microsoft's Office™ suite called OpenOffice. Hewlett Packard has been achieving some success by offering engagements with companies building upon the installation of open source software. The margins they are realizing, and the savings that the companies they contract with achieve, are part of their value statements.¹² So how can one profit on top of a product that is free? By changing the nature of the transaction – by charging not for the product, but for some *service*, or by selling some proprietary version apart from a free version.

Open source projects have shifted the conception of value away from goods to services, and have proven to support the proposition that creating products out in the open, without worrying about locking up the IP, can spur both innovation *and* profits if done right. Open source is also the model behind some of the home-grown fabrication projects discussed earlier. Can open source spur both innovation and profitability for nanowares in this

transitional mode toward MNT, and how would an economy flourish and grow in such a transitional phase, or in a true MNT future if open source prevailed?

Innovation and Growth: Profiting without Scarcity

Why do people innovate? Why do certain people wake up one morning and decide to create something new and useful, or to delve into some hitherto unknown aspect of nature to figure out why some physical phenomenon happens and how? Why do some people choose to make up stories, or songs, or make paintings or sculptures? One theory is that all of these activities occur because all of these creative impulses lead to profit. Part of the profit *now* achieved from each of these activities and products now stems from the monopoly rights afforded by IP regimes. Proponents of existing, traditional IP regimes argue that without them, the rate of innovation and growth experienced in the past 150 years would not have been possible. Let's assume this is the case, just for the sake of argument. Perhaps because of the nature of industry and the innovations that drove it since the industrial revolution, monopoly rights helped to buffer the risk of developing infrastructures for both manufacturing and delivery of new products, and thus encouraged large scale, expensive capitalization of new discoveries and inventions as eventually profitable consumer technologies. Although there is nothing but correlative evidence to support this hypothesis, and no *causal* necessity to it, and many economists disagree regarding its historical accuracy, let's assume for the sake of the rest of this argument that it is the case. The question remains: Even if IP was necessary for innovation and growth during the industrial age, is it necessary now, and will it be necessary for the *next* postindustrial age in which nanowares predominate?

Let's examine the possible reasons why IP might have been necessary to growth and innovation for the past 150 years and extrapolate. One argument for IP's necessity has been expressed above: the cost of investment in the research and infrastructure for the development, manufacture, and distribution of a new product *requires* some legal protection by way of a guaranteed monopoly for some period. The monopoly rights afforded by copyrights and patents ensure that, should a product or work of authorship prove to be in demand, then the public benefit conferred by their provision is rewarded by some term in which no one else may market the work or

receive profits from first sales. In return, the monopoly right is set to lapse at some point, but in the near term, authors and investors are encouraged to take the risk, expend the costs associated with the design, production, and distribution of the work, and so innovation is encouraged and invention rewarded.

The manner in which works have traditionally been produced, both aesthetic expressions (the subject of copyright) and utilitarian ones (the subject of patent), has perhaps warranted the assumption that IP is necessary to encourage risk involved in innovating. After all, publishing a book, making a movie, designing a computer, or any new device, all required a great deal of money, especially if one wished to not only create the object, but place it into a crowded stream of commerce. Part of the reason for the expenses involved has been scarcity, which, as we have discussed a bit already, helps drive the prices of goods in a market. These forces are the familiar ones involved in the law of supply and demand. Consider books: while books were once hand-lettered by monks (a service that was itself rare producing even rarer products) the advent of the printing press made the service of book printing and thus the product less rare. Prices fell. Over time, the cost of printing books fell, driven in part by computerization in the latter half of the twentieth century. But physical book prices and the costs of setting up the infrastructure for printing and distributing books in profitable numbers are still driven by scarcity, even as the prices have fallen, and the margins have increased due to technologies like ‘print on demand’. Printing a book still requires a press of some sort (even if it is a machine that can print and bind complete books on demand). Books also require paper. These physical necessities are necessarily scarce, as all physical goods are. Even replaceable goods like food and paper, which can be grown in theoretically limitless quantities, will always remain scarce because at any one time there is only a limited amount of the good available for use. The same is true for all traditional modes of production of both aesthetic and utilitarian goods. Beyond the cost or scarcity of the creativity involved in the design of some good, there are always some scarce products involved in the manufacture and delivery of the final product into the stream of commerce.

ICT changed all of this with the convergence of software and the internet – the perfect, frictionless delivery device for theoretically never-scarce goods. Software now suffers almost none of the scarcity issues of other industries, and essentially the only cost involved in the production of a

new product is the creativity and time involved in coding. As we have seen with successful open source products, even these 'costs' can be provided essentially 'for free'. Innovators in ICT recognized rather early on the value of openness upstream, and even downstream, in promoting innovation where capitalization is not an issue. With ICT goods, research, development, and distribution no longer created expenses that needed to be recouped through monopoly rents. As we have seen above, even in the manufacturing of physical, scarce goods, forgoing IP upstream is often a rational choice for innovators and entrepreneurs who seek market penetration without the costs associated with IP disputes or potential disputes. For ICT innovators especially, given the decrease (ordinarily) of scarcity and thus costs of capitalization for design, development, and distribution, open source solutions have often proven to make sense. They reduce the costs, and lubricate the development cycle, providing input by a community which also aids in distributing the work. They also build consumer trust and loyalty.

The fact is that innovation still occurs in a climate in which free alternatives to commercial products compete equally. The fact also is that the industry remains profitable. The software industry is thriving, even as other media and manufacturing industries suffer. The gross profit margins in the software sector most recently ranged around 75 percent.¹³ This is a significant margin, partly due to the fact that the amount of capitalization required in this sector is lower than in hardware industries, as discussed above. These margins, and the fact that more companies are realizing the value of their sales can be acquired in *services* as much as in products, continue to argue the case for providing at least some of the sector's new products and innovations in software under an open source model. For the same reasons, innovating in nanowares might similarly argue for and prosper from an open source model.

With MNT, and perhaps as transitional forms of nanowares become perfected, scarcity will continue to decline in importance. Without scarcity controlling the provisioning of materials, infrastructure, or distribution, marginal costs associated with design, development, and distribution will similarly fall. At some point, as true MNT is perfected, the assembly of any item at any place in the world will be as cheap and easy as downloading a piece of software. The costs associated with the invention of a thing will depend upon the *value of the creativity* involved, and little more. Of course, creativity will remain scarce, as will services associated with the design

and distribution of *types*, rather than tokens. It seems likely that those involved in the creation of the transitional forms of nanotech described earlier, and who remain active in promoting the science involved in true MNT, recognize that the goal of ending scarcity as a physical impediment to well-being requires open source development at the inception of the technology. Fab Labs, RepRap, Fab@Home, and similar projects are all currently open source. As opposed to HP's 3D printer, which is proprietary and relatively costly, the open source alternatives being developed are accessible for general consumption. They are also open and subject to improvement by the community of users. Competition among the various projects is continually pushing costs down and improving the systems available. People are even making money with these systems, as they do in other open source industries, by selling their services in building open source fabricators for those who prefer not to buy them used, or to make them themselves. What might the economy of MNT look like? We might be catching glimpses of its form by examining the current landscape in the ICT sector, and watching micro-fabrication evolve as it has.

Capitalism without Capital

One direction those who are pursuing MNT might pursue is the path of the *status quo*. Developers could well file for patents on their products, and pursue stronger enforcement so that physical goods don't become the next heavily pirated object on peer-to-peer networks. This path will be expensive for developers, ensuring that only large corporations who typically can take the risks associated with patents and their costs will dominate the innovative landscape of this new technology too. It seems likely that many innovators pursuing these technologies have already soundly rejected that path, judging by the proliferation of open source, grassroots development projects. Artificial scarcity by means of IP would clearly clog the innovative pipes upstream, and slow the promise and progress of these technologies early on. Some might fear that without strong IP, and with free copying, sharing, and improvement of individual innovator's ideas, capitalism as we know it will cease. Capitalism is built, after all, on the specialization of trades, scarcity of goods, and the invisible hand of supply and demand directing rational pricing in free markets. Without scarcity, prices would seem to always trend toward zero, and thus profit margins would likely cease to exist.

But this is likely not going to happen if we can fairly extrapolate from the model of ICT. Specialization will continue at the creative stage of product design. Improvements to existing designs require human ingenuity, and services surrounding the provision of software will be similarly important (and maybe even more so) with physical goods and their complicated relations among moving parts. People will still pay others for doing things they cannot themselves do, even where they need not pay for no-longer scarce physical objects. New, improved objects will always be in demand, and those who can design or improve things will be similarly in demand. Finally, the need for profits will slowly come to be reduced, even as profit margins continue to climb (because of the low costs of nonscarce goods). Innovators are also consumers, and as prices for goods fall, so too will the need to accumulate capital.

The transition will no doubt be difficult, and economists might rightly worry about the deflationary effect the growing lack of scarcity would have on individual and world economies. Some things, however, will always remain scarce, including both land and creativity. Creativity will be the fuel of the nanoware economy, and educating people in the creative and productive uses of both transitional forms and true MNT will be highly valued. The services that we provide each other will similarly remain valued, and valuable. Perhaps food will be replicable via MNT, and some are seeking ways to use synthetic biology as a shortcut to alleviating scarcity of food and energy, but during the transitional phase as we move toward real MNT, land, food, and the services associated with providing basic needs will remain scarce. Of course, the end of scarcity itself remains the noble goal of converging technologies, and the scenarios and arguments made here are only outlines. But we can see in ICT, and in the early stages of the nano-now, that this potentially disruptive technology can be both profitable and revolutionary at once, if we embrace the best in our creative abilities, and learn lessons from our recent past.

Case Study

Nanowares in the Market

Many of those who are actively pursuing a nanotech future are focusing on achievable results that will presumably aid the

development of a true MNT infrastructure. Specifically, the ability to construct identical copies of the same object, not at the nanoscale, but at a useable ‘meso’ scale, delivers some of the same promise of MNT. This is why this book considers such ‘micro-manufacturing’ to belong on a spectrum called *nanowares*. It is a transitional phase, and it is happening now.

Mass production has been the model for corporate success in the marketplace of physical goods. In order to produce and distribute goods at a scale that can produce profit margins deemed to be sufficient, factory-driven mass production has been more or less universally adopted as the best model. While this model has arguably worked well for consumer goods whose market demand is great, it means necessarily that products which enjoy only a niche market have had to seek smaller scale manufacturing solutions. Until recently, such solutions were hard to come by. In the past decade, however, it has become possible to have niche manufacturing done by contract, especially by competitively priced Chinese manufacturers.

But this model too is vulnerable, and costly, and does not solve the problem of distribution infrastructures. Cheaply made, small lots of factory-fabricated goods made in China still need to be shipped, either back to the designer who ordered them or to the eventual customers. One solution is to take yourself, as the designer, out of the supply chain, and to make the goods where they are wanted – by the customer, essentially. This is the ultimate goal, of course, but it will be a while before RepRap or Fab@Home bots are able to accomplish this technically. Meanwhile, some are attempting to enter the market with some of the institutional infrastructures they think will underlie the coming home-fabrication revolution. Two concurrent trends, sometimes intertwined, are precipitating the nanoware future: micro-manufacturing (by which we mean manufacturing on a smaller scale than that done with traditional factories, and with custom-sized runs) and distributed or decentralized production.

While Fab Labs are enabling the easier, cheaper design and prototyping of products, micro-manufacturing and distributed production allow for bypassing problems associated with capitalizing

Case Study: Nanowares in the Market (continued)

large production runs, warehousing large lots of goods, and cheapening the supply chain. Reaching markets is another story, and companies that are producing small lots of goods are being aided by websites like <http://www.etsy.com>. Etsy enables producers of goods to find customers who are specifically interested in custom-made, one-off products. Customers can also custom-order goods made to their specifications from producers willing to tailor-make them (<http://www.etsy.com>; another similar site is <http://ponoko.com>). Most of the items available are handmade by artisans, but the success of this marketplace suggests that manufacturers of limited-run items can find alternative markets without significant capitalization. eBay also stands as an example of a marketplace that serves the emerging trend of micro-manufacturing. The costs of entry to internet-based, mail-order marketplaces are low, and margins for products can be increased without increasing unnecessarily the costs of the products themselves. Even large companies are choosing micro-manufacturing as an alternative to large production runs and warehousing, and a number of infrastructural, trade-oriented solutions are becoming available. Micro-manufacturing online is a major portal to products, associations, and a network of those involved in this emerging trend (<http://www.micromanu.com/>).

Another approach is to distribute the type rather than the tokens, and companies like Arduino are doing this, in a sense. While Arduino (<http://www.arduino.cc/>) manufactures and distributes copies of the Arduino microcontroller (it manufactures them at its plant near Milan, Italy, using a small, 'pick and place' micro-controlled robot), it also distributes the complete set of instructions for making its micro-controllers, billing its product on its site as 'Arduino is an open-source electronics prototyping platform based on flexible, easy-to-use hardware and software. It's intended for artists, designers, hobbyists, and anyone interested in creating interactive objects or environments'. Arduino is consciously financing with its profits the total distribution of the manufacturing infrastructure. It is also creating an institutional infrastructure, having adopted a

form of the Creative Commons license for use in the distribution of the complete set of manufacturing instructions used to reproduce its controllers. Everything it makes is open source, and hobbyists, serious inventors, and others who envision the total decentralization of production are adopting its tools and similar models to enter the market cheaply, without any supply chain at all. Even while anyone can download the plans and make the final product themselves, and even improve upon it, Arduino profits from orders of completed boards, or parts that can be ordered by those who wish to assemble the product themselves.

Another approach is being taken by Bug Labs, which sells open-source based modules, a sort of preassembled, hardware app toolset, that can be assembled into new devices according to the consumer's desires (<http://buglabs.net>). Even while the Bug Labs parts are all based upon open source components, the company can profit by selling preassembled parts. A community of users share their 'bug' based inventions, and more people order the parts, driving a virtuous cycle.

These various efforts at creating new technological precursors to true MNT fit firmly within our inclusive category of *nanowares*, and the institutional approaches being undertaken to accommodate them are indicative of the inadequacy of current institutional approaches to the merger of hardware and software. It is not surprising that a prevalent model being used to both encourage and protect emerging nanowares is an open source one. These efforts are geared toward devising means to distribute, ultimately, not tokens but types. Ideally, eliminating the supply chain necessary for a final innovation will be one of the critical achievements of nanowares. IP law as we know it cannot protect this sort of exchange, nor is it clear that it would encourage innovation, although it might best ensure monopolistic ability to control prices and assure profits. Patent law prohibits the reproduction of a thing, and copyright protects the reproduction of non-'thing' expressions. Micro-manufacturing solves the problem of capitalizing and warehousing large lots of things, and is a step toward nanowares, but distributed production,

Case Study: Nanowares in the Market (continued)

by which the types themselves are reproduced at the point of purchase, is cheaper, more efficient, and arguably truly a nanowares phenomenon.

In the examples above, the ongoing conundrum remains profiting. Arduino distributes production completely when it distributes its full specifications on an open source model, but cannot profit from that distribution via patent, not if they wish to keep the product itself open. The value statement for keeping the ultimate product open is that, by so doing, users have actually improved it. They still also profit from sales of the (now improved) product to those who would rather not construct it themselves, or who purchase the parts from Arduino, and then do the final assembly. So while Arduino's open source platform is earning them profit, they still have not merged profitability into an infrastructure for distributing the types rather than tokens. Bug Labs is reasonable middle-ground, leaving open all of the parts, and distributing them at a profit (even while leaving the parts themselves amenable to copying by being open). Bug Labs's value is in providing the service of delivering an underlying infrastructure for further innovation. They also profit by maintaining a community of users whose growing interest and expertise in improving the parts and infrastructure may tip over into a profitable hardware version of Apple's App Store.

The alternative to each of these approaches would be to develop some sort of licensing scheme that would be modeled after current IP, but that could accommodate the distribution of types, and maintain monopolistic control over the tokens produced at the purchase side, and yet keep the purchaser from violating the prohibition of reproduction. Patent law's current prohibition against reproduction would require each purchaser of a type to get such a license so that the construction of the token would be legal. It seems likely that this approach will be tried as the trends of micro-manufacturing and distributed production become more popular, and their value statements increase. The result would be something like an End User Licensing Agreement (EULA) for hardware, much like those we currently agree to when installing software.