New perspectives on the IPv6 transition

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Abstract

Despite it being more than a decade old, and nearly two decades since the problems with IPv4 were first identified, IPv6 still has not diffused significantly through the Internet. Policies advocating market forces to promote IPv6 diffusion are widespread, and thus this paper examines IPv6 adoption from the perspectives of Hotelling's economics of exhaustible resources and the economics of permit markets, concluding in both cases that significant IPv6 diffusion will not occur until after the IPv4 address space is exhausted. This outcome is not desirable, and therefore new policy alternatives must be debated.

Keywords:

IPv6, policy, technology diffusion, exhaustible resources, permit markets.

Introduction

> "The problem of address scarcity is as severe for the Internet economy as the oil shocks and gasoline shortages of the 1970s were to the industrial economy" (Mueller, 2008).

The above quotation paints a dire picture for the Internet, and by extension for economies in which the Internet is currently, or expected to be, a critical piece of infrastructure. The core of the problem is that IP addresses – which are to the Internet what telephone numbers are to the telephone network – are fixed in number and rapidly running out. The date at which exhaustion will occur is currently projected to occur is between 2011 and 2012 (IPv4 Address Report, 2009), at which point future growth of the Internet will be constrained.

The vast majority of previous literature surrounding this issue has focused on technological aspects. This paper departs from this pattern and investigates the problem from the perspective of economics. The remainder of the paper is structured as follows: first, a brief orientation to the history and background of the problem is provided. Second, current obstacles to a solution are discussed. This is followed by an application of two different economic theories to the problem. Finally, the paper finishes with discussion and conclusions.

Background to the problem

All computers connected to the Internet need a unique IP address. The protocol currently used as the basis for Internet communications is Internet Protocol version 4 (IPv4), and the addresses in use today are thus referred to as IPv4 addresses.

Although IPv4 addresses are typically expressed as four numbers separated by dots, they are actually a single, 32-bit number. Thus, a total of 2^{32} – approximately 4.3 billion – possible addresses exist. This is clearly inadequate given a global population of approximately 6.8 billion people and rising, many of whom still do not have individual access to the Internet but are likely to want it.

There were warnings about the eventual exhaustion of the 32-bit IPv4 address space even before the massive wave of commercial Internet adoption that took place during the mid-1990s. RFC 1287, issued in 1991, describes routing and addressing as "the most urgent architectural problem, as it is directly involved in the ability of the Internet to continue to grow successfully".

Classless Inter-Domain Routing[1] (CIDR) was developed during the 1990s as a medium-term measure to slow the rate at which IPv4 address space was depleted, thus extending the useful life of IPv4 to the projected dates mentioned above. CIDR tackled supply by enabling more flexible address allocation policies and thus minimising the proportion of wasted – allocated but unused – addresses. Today, CIDR is universal and there are now few gains to be made from further improvements to address supply.

Meanwhile, Network Address Translation[2] (NAT) tackled demand by allowing a single address to be used to connect an entire network, where previously a single address had been required for each device on that network. The introduction of NAT has introduced technical problems for a wide range of protocols and services, which in turn has led to the development of a range of "workarounds"[3]. Unfortunately, none of these are universal and each introduces its own problems.

Nevertheless, NAT is now the *de facto* means for connecting networks to the Internet and further impact on demand is unlikely. While implementing multiple NAT systems, sometimes called "layered NAT", could in theory be used to reduce demand for IPv4 addresses, this is not a desirable solution to future address shortage as it compounds the problems NAT introduces.

Concurrently with the development of CIDR and NAT, a new version of Internet Protocol – IPv6[4] – was developed as a long-term solution to the problems with IPv4. IPv6 was officially standardised in 1995[5], followed by an updated version in 1998[6]. The principal advantage of IPv6 is that it has a much larger address space – 128 bits, as opposed to IPv4's 32 bits – and this provides an extraordinarily large number of addresses: 3.4×10^{38} addresses, or 6.7×10^{23} addresses for every square metre of the Earth's surface. Indeed, it has been said that this is sufficient for a unique address for every grain of sand on Earth (Wiljakka, 2002).

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[1] CIDR was standardised in 1993 by RFC 1518 and RFC 1519.

[2] NAT was standardised in 1994 by RFC 1631. NAT is typically used with private IP address space specified in RFC 1918.

[3] The most common workarounds are NAT-PMP (NAT Port Management Protocol), TURN (Traversal Using Relay NAT), STUN (Standard Traversal of UDP Through NAT) and ICE (Internet Control Exchange).

[4] The jump from version 4 to version 6 can be explained as version 5 (IPv5) had already been created as an experimental version to test media streaming features (c.f. RFC 1190 and RFC 1819).

[5] See RFC 1883.

[6] See RFC 2460.

Nevertheless, it is now at least 18 years since the initial warnings about IPv4 address space and more than 10 years since the final version of IPv6 was published, and yet IPv6 adoption is still negligible (Domingues *et al*., 2007; Joseph *et al*., 2007). Indeed, a projection based on current trends anticipates that 80% diffusion of IPv6 could take between another 8 and 22 years (Elmore *et al*., 2008). Of course, trends can change and such projections may thus prove to be inaccurate; however, such projections do show that there are still significant barriers to IPv6 adoption. The following section examines these in more detail.

Current barriers to IPv6 adoption

Hovav *et al.* (2004) proposed the Internet Standards Adoption (ISA) model, which describes individual adoption decisions in terms of how useful the technology is to the organisation and how conducive the organisations's environment is to adoption. Both usefulness (UF) and environmental factors (EC) can be high or low, leading to the 2×2 matrix shown in Figure 1. Given the almost complete lack of adoption of IPv6 to date, it is clear that almost every organisation is firmly within the Status Quo quadrant.

		Conduciveness of environment to adoption of a/the new standard (EC)	
		Low	High
Usefulness/need of features of new standard (UF)	Low	**Status quo** *Stay where you are*	**Replacement** *Implement but with no new features – use like the old technology*
	High	**Coexistence for best use (*niche*)** *Implement with some but not all features, and support both in the transition*	**Full implementation** *Implement new standard with all of the features*

Figure 1: Models of Internet Standard Adoption
Source: Hovav *et al*. (2004)

That IPv6 is not perceived as useful is hardly surprising. Technologically superior features of IPv6, such as improved security, mobility and Quality of Service (QoS), do not offer the same level of advantage over IPv4 that IPv4 offered over its predecessor (Huston, 2007) – the benefits are primarily long-term rather than immediate (Bohlin and Lindmark, 2002), and the belief that there is no business case for IPv6 is widespread (Roberts, 2009). Indeed, the primary benefit of IPv6 – a vastly expanded address space – is not relevant to organisations that already have sufficient IPv4 address space and have no immediate need for expansion. Further, the impending IPv4 run-out is not likely to occur until approximately 2011-2012 – very soon from a "whole of Internet" point of view but far enough into the future to be less worrying for individual firms concerned only with their own networks. Thus, rightly or wrongly, it is unlikely that most organisations will perceive IPv6 as useful.

The current environment for IPv6 is also extremely unconducive to adoption. IPv4 is ubiquitous, and this would create high drag, inertia and conversion costs should an organisation decide to adopt IPv6 (Bohlin and Lindmark, 2002; Hovav *et al*., 2004). Further, most organisations have little access to IPv6 skills and experience (c.f.Warfield, 2003; Dell *et al.*, 2007) and there have also been few monetary incentives or opportunities for sponsorship available in most countries.

Even in the albeit rare case where an organisation might fall in the coexistence, replacement or full implementation quadrants, the opportunities to obtain an IPv6 connection from an Internet Service Provider (ISP) are extremely limited. As at January 2009, there were only 44 ISPs or similar organisations worldwide that provide native IPv6 services to their customers, 14 of which were in Japan.

Country	Companies	
Japan	NTT Communications	JENS
	KDDI	Media Exchange
	IIJ	Freebit
	Nifty	Plala Networks
	Dream Train Internet	OnDemandTV
	Powerdcom	Softbank
	Japan Telecom	Japan Sustainable Community Centre
Germany	Easynet	Space.Net
	IDKOM Networks	SpeedPartner
	Individual Network Berlin	TAL.DE Klaus Internet Service
	rh-tec	Titan Networks
USA	Epik Networks	Lava.net
	Citynet	Spectrum Networks
	ipHouse	Transaria/Cutthroat Communication
UK	Claranet	Entanet
	Andrews and Arnold	Goscomb
	Bogons	
Switzerland	Cyberlink	Init Seven
	Jaguar Network	Nexellent
France	Jaguar Network	Proxad / Free SAS
	Nerim	Wanadoo France
Italy	ITGate	Panservice
Ireland	Airwire	
Canada	Epik Networks	
Ukraine	NetAssist	
Finland	Nebula	
Estonia	Linxtelecom	
Netherlands	BIT	
Australia	Internode	

Table 1: ISPs offering native IPv6 to customers
Source: SixXS (2009), IPv6Style (2009)

The majority of these providers do not have a significant market share and therefore it is presumed that they are capable of only limited capacity. Indeed, only seven of the world's biggest (by revenue) 21 telecommunications companies are IPv6 ready (Ladid, 2008), and only two of those – NTT and KDDI – have retail IPv6 offerings. Thus, it is reasonable to conclude that although native IPv6 services do exist, they are extremely rare and that IPv6 is not yet significantly diffused.

Consequently, any organisation unwilling or unable to connect to the small number of native IPv6 providers must either implement protocol translation systems such as NAT-PT (Network Address Translation – Protocol Translation) and NAPT-PT (Network Address Port Translator – Protocol Translation)[7] in order to connect their own IPv6 network to IPv4 service providers, or pass IPv6 traffic through IPv4 "tunnels" to IPv6 tunnel brokers elsewhere on the Internet[8]. Protocol translation still faces a range of technical challenges (Vogt and Perkins, 2008), and both tunnelling and protocol translation impose extra costs and degrade performance and are thus likely to be considered unacceptable for important or critical services. Consequently, it remains difficult – if not impossible – to put forward a business case for IPv6 adoption.

Economic perspectives of IPv6

Clearly, initiatives to promote update of IPv6 have largely not succeeded, a fact which may well be due to an almost complete absence of relevant theoretical or empirical research. Despite a reliance on market economics to promote the diffusion of IPv6 in many countries, there have been only two serious discussions to date of the economics of IP.

First, Bohlin and Lindmark (2002) considered the individual firm's incentive to invest in IPv6 and view the issue as an example of the Boiteux problem, in which the decision to invest in maintenance of an existing system appears rational when considering local issues, but is irrational when one takes in the global perspective. Thus, individual firms continue to invest in stop-gap measures to extend the life of IPv4; however, this is inefficient when one considers the Internet as a whole.

Second, Mueller's (2006) examination of IP addressing policy concluded that there is significant room for variation and called for further research to identify optimal address policies. However, any effort to introduce change has been blocked by the existing policy regime.

Thus, economies around the world are increasingly reliant on a global communications network that is fast reaching a point at which further growth will be problematic. Despite being a major economic issue, economic analyses of the transition from IPv4 to IPv6 are almost non-existent. To help rectify this situation, this paper now turns to such an examination in which two approaches are considered: the economics of exhaustible resources and the economics of permit markets.

Economics of exhaustible resources

Economic analysis of exhaustible resources is not a new discipline; there is extensive literature on the subject from Hotelling's (1931) ground-breaking paper to the present day. The study of exhaustible resources typically has tended to focus on natural resources, particularly minerals and energy, but can be applied to any exhaustible resource. Considering IPv4 address space as an exhaustible resource which is being

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[7] NAT-PT and NAPT-PT are defined in RFC 2766.

[8] Much of the literature on transition technologies for IPv6 provides discussion of dual-stacking. It is noted here that this is no longer relevant, as the shortage of IPv4 address space now renders it infeasible to run IPv4 in parallel with IPv6.

depleted in much the same way as the world's oil reserves are being depleted gives a valuable insight into any transition from IPv4 to IPv6 under market forces.

The essence of the Hotelling's analysis – now known as the "Hotelling Rule" – is that efficiency and competitive market forces will result in an increasing scarcity rent of an exhaustible resource that is equal to the interest rate. In other words, increasing scarcity of a resource contributes to increasing market price. Eventually, the market price of the exhaustible resource reaches the backstop price, and the backstop technology (Nordhaus, 1992) becomes more economical[9].

In monopolistic situations, production is equal to demand at the current market price. If the net price rises too slowly, production shifts forward due to increased demand, leading to earlier exhaustion. Similarly, if the net price rises too quickly, the producer is inclined to keep its resources in the ground to maximise return (Solow, 1974).

This is exactly what is happening in the case of IPv4 addresses. The market price of IP addresses cannot be observed because there is no IP address market. As Mueller (2006) observes, government agencies are not subject to market forces, so actual prices for IP address allocation – levied indirectly through other fees, but effectively the price one must pay to obtain address space – almost certainly do not reflect the price that would be obtained in an IP address market. The artificially low price thus promotes increased consumption of IPv4 addresses.

It is also possible to see evidence of economics of exhaustible resources in the "production" of IPv4 addresses. The monopolistic "producer" of IPv4 addresses is the Internet Assigned Numbers Authority (IANA), which is operated by the Internet Corporation for Assigned Names and Numbers (ICANN) and is responsible for the global coordination of IP address space allocation. The IANA allocates IPv4 addresses to the various Regional Internet Registries (RIRs) according to their needs. RIRs in turn allocate address space to Local Internet Registries (LIRs), which are effectively customers and are usually Internet Service Providers (ISPs).

Address allocation policies typically prevent stockpiling of addresses and require the LIR be able to demonstrate a need for the address space. In other words, the production of IPv4 addresses is done in response to demand, just as Hotelling's analysis of exhaustible resources predicts.

If one accepts that demand for IP addresses will continue to expand at roughly exponential rates[10], and if one accepts that IP address space consumption obeys the

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[9] It has been argued by some that for this reason, "exhaustible resources" are never actually exhausted. In the case of IPv4 addresses, depending on the address allocation policy that prevails at the time it may be that the market price does not reach the backstop price, but there may be administrative difficulties in obtaining new addresses. In other words, it may be that the administrative burden for obtaining an IPv4 address will be more costly than that required for obtaining an IPv6 address.

[10] Exponential growth in the Internet has been true historically and is likely to continue in the future as more and more devices are designed with Internet connectivity in mind; Internet-capable refrigerators, security systems, air-conditioners and television set-top boxes are all available today, and the range of devices with an Internet connection will continue increasing in the future. Further, new technologies that are still in their infancy, such as sensor-webs, or which do not yet exist at all, will require still more addresses. When one considers these technology trends, combined with an increasing global

Hotelling Rule, it follows that significant uptake of IPv6 will not occur until IPv4 address space becomes more expensive than IPv6 address space. However, given that the "market price" of IPv4 address space is artificial it may well be the case that it never reaches the backstop price, in which case IPv6 uptake will only begin when IPv4 address space is completely exhausted, as illustrated in Figure 2. In any case, economic theory of exhaustible resources predicts that meaningful IPv6 diffusion does not commence until the point where further IPv4 deployment ceases, resulting in a sudden – as opposed to gradual – transition.

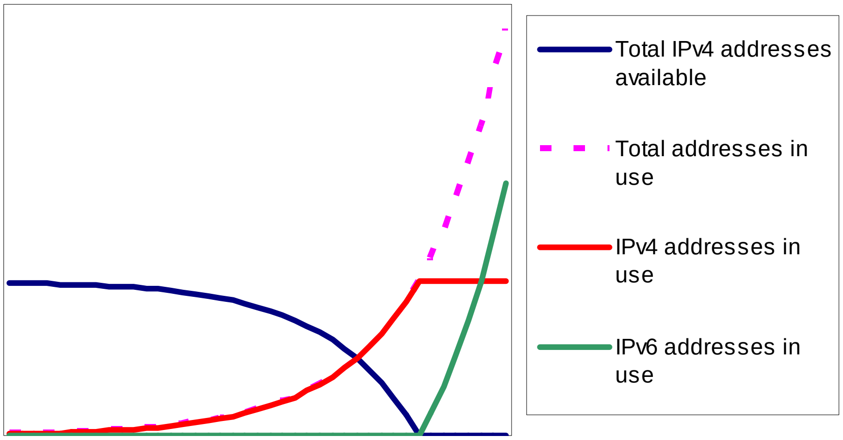

Figure 2: Predicted IP address trends after the economics of exhaustible resources

This model assumes that IPv6 addresses can be directly substituted for IPv4 addresses, albeit at a higher cost; however, this assumption may be incorrect. Roberts (2009) revealed that in the event of IPv4 address space exhaustion, most organisations plan increased use of NAT, while very few would adopt IPv6. If this eventuated, deployment of new services and Internet diffusion in developing countries would be significantly constrained.

Regardless of which of these two scenarios one regards as more likely, neither is desirable. While the latter case has obvious disadvantages – the inability to serve new markets and offer new services – the former case is also undesirable. To conduct the inevitable IPv6 migration only as a response to the complete exhaustion of IPv4 address space would be a risky strategy as the inevitable time pressures in such a situation would lead to *ad hoc* and unplanned actions. Indeed, serious problems with interoperability may result in a fragmented Internet if the transition to IPv6 is not properly managed, posing significant reliability issues for critical infrastructure (SIFT, 2007), and likely significantly higher cost of conversion than if the process was able to be planned in advance (Klensin, 2002).

Permit markets

Permit markets have been increasingly used as a means for environmental regulation, particularly since the 1980s. Issues such as carbon trading, regulating water

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population, much of which is still not yet online but will be in future, it is clear that demand for Internet addresses may run into the tens – if not hundreds – of billions.

consumption, sustainable fisheries, regulating the taxi industry, the phasing out of leaded petrol, limiting the emissions of chlorofluorocarbons and sulphur dioxide have all been subject to various schemes around the world, although not all schemes are alike. They are designed to meet specific objectives and will have varying rules concerning permit pricing, allocation and subsequent trading, and are subject to a variety of different monitoring and enforcement regimes.

Since it is impossible to connect to the Internet without an IP address, these can be considered analogous to a permit to connect to the network. There are a fixed number of "IPv4 permits", and IP address allocation policies typically prohibit on-selling or subletting of addresses; thus, IP addresses are analogous to non-tradeable permits. Indeed, non-tradable permits can be conceptualised as a method for allocating a scarce resource (Leffevre, 2005), and this objective is an explicitly stated policy goal of the RIRs and is recommended in RFC 2050.

Current policy is that IPv4 addresses are technically free and in practice require only the payment of a nominal annual membership fee to the RIR and to be able to meet the most basic of eligibility criteria – essentially to be able to demonstrate a need for the address space. As long as IPv4 permits continue to be allocated on this basis, firms will continue to have very little motivation to adopt IPv6 – in fact, it is likely that they will remain more motivated to continue using IPv4 due to network effects.

Assuming this policy does not change, firms will continue to use IPv4 address space until it is completely exhausted, after which point they will have no choice but to adopt IPv6 or to restrict the number of connections to the Internet. Of course, this is how permit markets are intended to operate – a maximum number of permits is decided upon that allows an industry to function while restricting the impact of negative externalities to a satisfactory level. The only significant difference with IPv4 "permits" is simply that the maximum number is determined by the technology rather than by the consideration of externalities.

The exhaustion of the IPv4 address space will lead to the creation of scarcity rents for IPv4 addresses. At this point – if it has not already been addressed – it should be decided whether to auction IPv4 addresses or whether they should continue to be allocated freely. The only difference between these two options is that in the latter case the extra revenue is collected by the firm, while in the case of the former that revenue goes to the taxpayer (Cramton and Kerr, 2002). It is generally accepted that auctioning permits is superior to free allocation (Boemare and Quirion, 2002).

As well as pricing it may be desirable to allow the trading of IPv4 permits, as cautiously recommended by Mueller (2006), thus effectively transforming IPv4 addresses into tradeable permits. If issues concerning address aggregation can be adequately addressed, allowing IPv4 address trading would seem to be potentially advantageous for a number of reasons.

First, it is extremely unlikely that a central entity that issues non-tradeable permits will have access to enough information to allocate permits in a way that yields the greatest benefit (Howe, 1996). It is thus extremely unlikely that the IANA, RIRs, and so on can effectively judge which applicants for IPv4 address space will use addresses in ways that maximise public benefit.

Second, non-tradeable permits tend to be static and unresponsive to changing social values (Howe, 1996). This is evident in the way IPv4 address space has been allocated – many address blocks that were inefficiently allocated early in the development of the Internet remain with the original applicants, resulting in large amounts of allocated but un-used address space.

Third, non-tradeable permits imply that a consumer cannot benefit directly from trade even if there are opportunities to reduce consumption of the regulated resource[11] (Vollebergh *et al*., 1997). Thus, even if an organisation could reduce their use of IPv4 address space, there would be little incentive to do so.

In contrast, permits move to applications with the highest value in competitive markets in which trading is allowed (Montgomery, 1972). Indeed, this is true regardless of whether permits are auctioned or issued for free. When permits are issued for free and permit trading is allowed, total expenditure on permits is equal to the cost of the permit system objective, i.e. the cost of emission control or restricting fishery catches to sustainable levels (Montgomery, 1972), or managing the transition to IPv6 in the current context.

If IPv4 addresses were allocated free of charge but were allowed to be traded, any expenditure on such trades would equal the cost of restricting the (IPv4) Internet to a maximum size. However, the US and Canadian experiences in allocating cellular licenses in the 1980s, in which there were many frivolous and speculative licence applications (McMillan, 1995), suggests that the current first-come-first-served approach to allocation would not necessarily be the most appropriate. Thus, if address trading were to be allowed, auctioning may be a more appropriate method for initial IPv4 address allocations.

A counterargument to allowing the trading of IPv4 addresses is that trading permits may not obtain the maximum value from a resource if there are high transaction costs (Stavins, 1995), which may apply to the case of IPv4 address space. The effort involved in renumbering networks – as would be required by trading IPv4 addresses in a market – is immense. Further, trading IPv4 addresses could result in a highly fragmented IPv4 address space, leading to backbone routing performance problems. This paper thus seconds Mueller's (2006) call for further research into the technical implications of such trading.

A final consideration is that tradeable permits can be inequitable if the poor are forced to sell their permits to the rich in order to fund their own development. Thus, it can be argued that permit trading consolidates the power of the rich (Leffevre, 2005). Thus, any policy to allow trading of IPv4 address space would need to include measures to minimise this outcome (through initial address allocations, for example).

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[11] In other tradeable permit markets – emissions trading, for example – selling of permits can be a source of additional capital before relocating to another country where such permits are not required, negatively affecting the effectiveness of the permit system (Vollebergh *et al*., 1997). However, in the case of IPv4 addresses such trade would be pointless since the IPv4 address "permit market" is global: it is not possible to simply move to another country where IPv4 addresses are unnecessary.

The impact of different market-based instruments on technology diffusion is subject to only limited agreement. Some contend that auctioning permits also results in greater diffusion of alternative technologies than other instruments (Milliman and Prince, 1989, 1992), while others argue that taxes provide greater incentive (Denicolò, 1999; Keohane, 1999). Jaffe *et al*. (2002: 53) review the literature and decide that "unambiguous exhaustive ranking of instruments is not possible on the basis of theory alone"; indeed, each case needs to be considered on its own merits.

Figure 3 illustrates two possible scenarios for IPv6 diffusion through the lens of the economics of permit markets. It is likely that significant IPv6 diffusion will not commence until IPv4 exhaustion is reached. At that point a range of trajectories are possible, depending on the policy that is adopted at that point – whether IP address trading is allowed, and whether IPv4 addresses are taxed, auctioned, grand-fathered or freely allocated on a first-come-first-served basis. It is assumed that the maximum demand for IP addresses would not exceed exponential growth, but that different policy frameworks will yield different levels of diffusion.

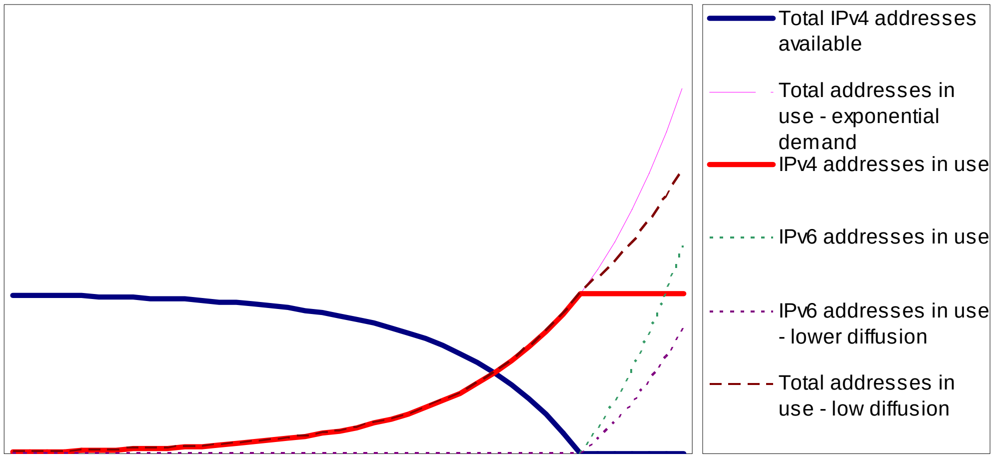

Figure 3: Predicted IP address trends after the economics of permit markets

This is clearly a similar result to the previous analysis based on the economics of exhaustible resources and is undesirable for the same reasons.

Discussion and conclusions

The analysis above suggests that a safe and effective transition to IPv6 will not occur if current policies do not change. Relying on market economics will only yield significant IPv6 diffusion after IPv4 exhaustion has already occurred, and may additionally lead to constrained Internet growth. These outcomes would be exactly the opposite of what the OECD states is necessary:

> "Deploying the newer IP version 6 address blocks is necessary to enable growth in use of the Internet. But making the switch is difficult and it takes time and resources as well as a commitment by all stakeholders, including governments" (OECD, 2008: 3-4).

The OECD's explicit reference to the role of governments is a reminder that it is governments that set the policies that will shape the transition to IPv6. The point of such policies must surely be to ensure that the scenarios described above do not occur. Policies that rely on market forces have largely failed due to the discrepancy between the need to support IPv6 at a national level and the lack of a business case at the organisational level.

Perhaps because it is an economic approach, there has been widespread support for the use of government buying power to stimulate the market. Such policies have been endorsed, for example, by the OECD (2007) and the Australian government (Lundy, 2008). This is similar to the policy pursued in the US, where it was announced in 2005 that federal agencies must support IPv6 by June 2008.

However, exploiting buying power alone seems unlikely to be successful for two reasons. First, the implementation of this policy in the United States gave federal government organisations three years to make the transition and yet many still did not meet the deadline (Kerner, 2008). Given the difficulty such organisations had in meeting a mandatory three-year deadline, it is difficult to envision successful IPv6 diffusion within a similar or shorter time-frame in other countries when IPv6 is only encouraged and not mandatory.

Second, even if government agencies do manage to adopt IPv6 in a similar time-frame, it is still unlikely that this will lead to widespread diffusion: the American experience has been that despite the mandatory IPv6 capability on government networks, enterprise adoption in non-government organisations still remains extremely low (Kerner, 2008).

Alternatively, the use of appropriate economic incentives could tip the balance in favour of IPv6; however, such a move could involve the use of public money and it is therefore unlikely that such policy would be adopted without a clearly stated public benefit. Dell *et al*. (2008) argued that this situation necessitates the development of a "national interest case" in order to facilitate government action, rather than relying on business cases driving adoption decisions within individual organisations. Similarly, Bohlin and Lindmark (2002) identified a need for policies to be based on a global view.

A third option is public policy that mandates its adoption, as has been the case in South Korea, where policy IT839 – officially launched in 2004 – requires the use of IPv6 by 2010. A principle argument against mandating standards is that this forfeits the benefit that can be obtained from competition in research and development. This argument is strong in cases where standards are immature and technologies are still emerging; however, IPv6 is mature and universally accepted as the standard that will inevitably replace the incumbent IPv4 as the basis for Internet communications. Further, earlier adoption of IPv6 would not prevent taking advantage of later improvements to the standard, just as organisation that have been using IPv4 for decades are able to implement recent improvements to the standard.

Mandating standards is ideologically uncomfortable for many, yet there are numerous examples where technologies have been mandated with success. For instance, many countries around the world have mandated the adoption of digital television and the

European mandate of digital telephone standards via the European Telecommunications Standards Institute (ETSI) is widely regarded as one of the great successes of telecommunications policy in Europe, while the North American approach in which the market was allowed to determine digital telephony standards is widely regarded as a policy failure (Gandal *et al*., 2003).

To only seriously consider a single policy option is to equip oneself with the proverbial hammer that makes everything look like a nail, yet debate of the alternatives to current IPv6 policy is characterised by an almost deafening silence. There are undoubtedly many other options to be discussed, and this paper therefore calls for an urgent and vigorous debate of new policy ideas.

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Appendix – RFCs

The following RFCs are referred to in this paper, and can be accessed from http://www.ietf.org/rfc.html.

RFC	*Title*	*Date*
1190	Experimental Internet Stream Protocol, Version 2 (ST-II)	October 1990
1287	Towards the Future Internet Architecture	December 1991
1518	An Architecture for IP Address Allocation with CIDR	September 1993
1519	Classless Inter-Domain Routing (CIDR): an Address Assignment and Aggregation Strategy	September 1993
1631	The IP Network Address Translator (NAT)	May 1994
1819	Internet Stream Protocol Version 2 (ST2) Protocol Specification – Version ST2+	August 1995
1883	Internet Protocol, Version 6 (IPv6) Specification	December 1995
1918	Address Allocation for Private Internets	February 1996
2050	Internet Registry IP Allocation Guidelines	November 1996
2460	Internet Protocol, Version 6 (IPv6) Specification	December 1998
2766	Network Address Translation - Protocol Translation (NAT-PT)	February 2000