Dimensioning the Elephant:
An Empirical Analysis of the IPv4 Number Market

1 September 2012

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Research funded by the Next Generation Infrastructure Foundation, the Netherlands

The elephant in the room

One of the most important but least-studied aspects of Internet policy is the emergence of a trading market for previously allocated Internet number blocks. Without unique Internet protocol numbers for the networks and devices attached, the Internet simply doesn't work. The original Internet Protocol standard, known as IPv4, specified a 32-bit numbering space, which provided slightly less than 4 billion unique numbers that could be used as addresses (Postel, 1981). A large part of that number space has already been handed out to organizations. The available supply is dwindling, and the Asia-Pacific region is already reduced to rationing its last /8 in tiny, 1024-address chunks, one to an organization, while the European region is only a few months from that status.

Recent market developments and policy changes by Internet number registries now allow organizations with more numbers than they want to sell them to another organization. In other words, a market for IPv4 numbers is now possible. This is a major change in the political economy of Internet governance. It is likely that the commercial forces unleashed will have far-reaching consequences for Internet businesses, users and governance institutions. In a related area, domain name registration, the emergence of a commercial market led to the growth of a domain name industry and major changes in policies and institutions, such as the formation of ICANN, the separation of registries and registrars and the new gTLD program.

After a highly publicized deal in which Microsoft bought Nortel's number assets in a bankruptcy proceeding, the reality of an IP number market can no longer be denied. But many in the Internet technical community still feel uncomfortable about it. One reporter with attitudes typical of the technical community, has predicted that "a functioning market won't form at all, or will break down very quickly after it forms" (van Beijnum, 2011). This is partly due to an ideological resistance to the commodification of a critical Internet resource, and partly due to their fears that an IPv4 market might delay or even prevent a migration to a new Internet protocol (IPv6). Either way, few wish to openly acknowledge the market's existence. Thus the topic of number markets brings to mind the phrase "the elephant in the room."

Moreover, the information we have about this elephant is fragmented and unsystematic. IP number allocation is controlled on a contractual basis by five separate regional Internet registries (RIRs). Each has different policies toward transfers, different registry databases, and different disclosure practices. It is difficult, therefore, to obtain a comprehensive picture of the emerging market for IPv4 number blocks. This recalls the old fable about the five blind men and the elephant, with each one having access to a small part of the body and none of them quite grasping the nature of the beast as a whole.

Based on this double-elephant metaphor, this paper tries to make a less than elephantine but much-needed empirical contribution to the literature on the economics and institutions of IP addressing. While several papers already discuss IP number markets in theoretical or policy terms, no one has actually compiled and analyzed the transactions themselves. This paper draws on the records of the RIRs to compile as much information about traded IP number blocks as possible, and then conducts some very basic analysis of stocks, flows and proportions to assess the nature of this emerging market and explore some of its implications for Internet governance. Although it is early days for IP number markets, the data we have gathered already seem to have interesting implications for certain policy issues currently being debated.

IPv4 number transfer policies

This section describes the policies the RIRs passed authorizing market transfers and the date they were passed. It also explains the significance of what are known as "legacy" or "historical" allocations in the emerging market.

Legacy number allocations

Prior to 1991, there were no RIRs with formal policies for allocating number resources, only a central registry known as the Internet Assigned Numbers Authority (IANA), run by USC's Information Sciences Institute (Cerf, 1990). Furthermore, upon receipt of number resources from IANA, organizations did not have to sign contracts governing their use. Conservation was not a major consideration in this early period. Universities, the U.S. military and major corporations involved in data networking projects received large allocations simply by asking for them, and many of them retain those allocations to this day. Organizations that received IP number blocks prior to 1991-1999[1] are considered "legacy" or "historical" holders, and their number holdings are usually not subject to RIR contracts created later. One of the key policy issues raised by the rise of an IP number trading market is whether these legacy holders have de facto property rights in their blocks, or need approval from RIRs to sell them.

IPv4 scarcity and the IPv6 transition

After the RIRs assumed responsibility for managing IP numbers, increasingly stringent conservation policies were applied (Hubbard, Kosters, Conrad, Karrenberg, & Postel, 1996). To receive an allocation one had to "demonstrate need," which meant providing the RIR with technical and confidential business information about how the requested numbers would be used. To gain new allocations one had to demonstrate a specific utilization level of one's existing allocation. In theory, numbers that were not needed were supposed to be given back to the RIR, which would then be able to allocate them to others. In practice, few number blocks were returned. Those holding number blocks had no incentive to return them, and the RIRs lacked the institutional capacity or authority required to take them back (Mueller, 2010). The combination of weak-to-nonexistent reclamation and the delegation of 40% of the IPv4 numbers to legacy holders regardless of need meant that despite the apparent scarcity of IPv4 numbers, there were many unused or underutilized number blocks (Mueller, 2008; Perset, 2007).

The standard refrain at this point is to say that the whole problem of IPv4 scarcity will go away because there is a new Internet protocol with an expanded address space. This is a half-truth, at best. It is true that Internet engineers were already concerned about the occupation of all IPv4 numbers in the early 1990s and that by 1998 they had developed a new Internet protocol, IPv6, with a gargantuan address space. But in one of the most fateful and questionable design decisions in the IETF's history, the IPv6 protocol was not made backwards compatible with IPv4. The lack of compatibility means that to implement IPv6, one must either abandon communication with everyone else running IPv4, or run both protocols at the same time. And running both protocols in parallel (known as 'dual stacking') does not actually reduce the demand for IPv4 numbers. So the migration from IPv4 to IPv6 does not involve an incremental reduction in the demand for IPv4 numbers as networks adopt IPv6. Rather, it involves

[1] The date varies because RIRs were established in different regions at different times. A North American organization that received address blocks in 1994 is likely to be a legacy holder, because ARIN wasn't created until 1997, whereas in Europe RIPE-NCC was established in 1991 and had a contractual governance scheme in place by 1994.

parallel growth of the IPv4 and IPv6 Internets until such time as a huge tipping point is reached, when almost everyone is running IPv6. Then, and only then, can the networks running IPv6 shut off IPv4 without losing access to a significant number of other networks. Then, and only then, will IPv4 number scarcity cease to be a factor.

Transfer policies as bridge (or roadblock?)

Once the Internet community noticed that the supply of unallocated IP numbers was nearing exhaustion (Hain, 2005) and that migration to the new IPv6 protocol still seemed years away (Colitti, Gunderson, Kline, & Refice, 2010; Dell, Kwong, & Liu, 2008; Elmore, Camp, & Stephens, 2008), it began to debate the merits of number markets. So controversial was the idea of trading address blocks that the terminology used by the RIRs studiously avoided explicit recognition that numbers would be bought and sold. They were called "transfers to specified recipients" or "transfers of allocations." Still, allowing organizations to sell IPv4 blocks to other organizations suddenly seemed not only reasonable, but unavoidable. Market transfer policies would, its advocates claimed, build a bridge to the future by providing incentives for legacy holders and others with underutilized allocations to make them available to companies that needed them. The rising price of increasingly scarce IPv4 blocks would encourage a gradual and economically rational migration to IPv6. Others feared that the bridge would be so successful at extending the life of IPv4 that it would become a roadblock on the path to IPv6. This debate is covered in other literature and will not be recounted here (Edelman, 2008; Hofmann, 2009; Lehr, Vest, & Lear, 2008; Mueller, 2008). Suffice it to say that in most regions market transfer policies were passed after long, rending debates. Table 1 summarizes the situation and contains links to the relevant policy documents governing market transfers.

Table 1: RIR market transfer policies

RIR	Transfer policy	Date passed
RIPE NCC (European region)	http://www.ripe.net/ripe/docs/ripe-553#-----transfers-of-allocations	12/ 2008
ARIN (No. American region)	https://www.arin.net/policy/proposals/2009_1.html	6/2009
APNIC (Asia-Pacific region)	http://www.apnic.net/policy/transfer-policy	2/2010
LACNIC (Latin Am. & Carib. region)	No transfer policy in place	
AFRINIC (African region)	No transfer policy in place	

RIPE-NCC, the RIR for the European region, was first to approve a policy authorizing commercial transfers of IP address blocks in 2008. Paragraph 5.5, "Transfers of Allocations", in RIPE's basic policy document authorizes market transfers. The RIPE NCC also runs a "Listing Service" that allows holders of IP address blocks to advertise numbers available for "exchange."[2] In North America a transfer market proposal sparked a highly contentious debate that ultimately had to be resolved via an emergency board intervention. ARIN, the RIR for the North American region, implemented a market transfer policy in June 2009, and also runs a listing service.[3] APNIC, which serves the Asia-Pacific region, was one of the first to propose a transfer policy, but debate and controversy prevented its adoption until February 2010. The other two RIRs have not yet authorized market transfers of IPv4 address blocks.

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[2] RIPE NCC Listing service: https://www.ripe.net/lir-services/resource-management/listing. As of August 1, 2012 it showed 4 /21s (8,192 numbers) available.

[3] ARIN specified transfer listing service: https://www.arin.net/resources/transfer_listing/index.html

Market and non-market transfers

We define *market transfers* as those transfers authorized by the new transfer policies listed above; or more generically as an agreement between separate organizations to transfer the registration of a specified number block from the holder to the recipient in exchange for money. Market sales are not the only way to transfer IP address allocations from one organization to another. Transfers also occur through mergers and acquisitions. RIRs have well-established policies governing the methods by which IP number block registrations held by an acquired organization are transferred to the acquiring organization. There are also specified methods by which organizations with multiple subsidiaries or business units, which might have different corporate accounts with the RIR, transfer number resources among themselves (internal transfers). We refer to internal transfers and transfers arising from mergers and acquisitions as "non-market'' transfers. In order to study the emerging transfer market, it is necessary to differentiate records of non-market transfers from records of market transfers. Some RIR data regarding transfers, notably APNIC, combine logs of non-market transfers and market transfers and do not differentiate between them (see Data and Method section below).

Data and Method

There is no single source of data about market transfers of IPv4 number blocks. This section describes how the authors cobbled together the data used in this paper, drawing on bankruptcy court records, RIR statistics, Whois records, and RIR lists of transferred blocks.

The IP address Whois is a database that shows the general public which organization is holding which IP address block(s). Each RIR operates its own Whois database. It provides a tool for network operators and others to discover which number blocks are allocated or assigned to which organization. Using web-based interfaces, one can type the name of an organization and see a list of the IP number blocks registered in its name, or one can type in an IP address and see which organization has registered the block containing it. It may also be possible for an organization to obtain "bulk access" to the Whois records of an RIR, which means that the entire database is downloaded and can be processed and analyzed automatically. At least one RIR also maintains a "Whowas" database, showing which organization held a number block at specified dates in the past.

The 3 RIRs with transfer policies take entirely different approaches to recording number transfers. RIPE publishes no information whatsoever about events that occur under its market transfer policy. ARIN publishes a list of *IP Address Blocks Transferred per NRPM 8.3.* The list, updated weekly, shows the IPv4 block numbers that have been traded using Section 8.3 of ARIN's Number Resource Policy Manual.[4] The list contains nothing but IP address block numbers; it does not specify the name of the seller, the date the seller registered the address block, the name of the buyer, the date of the transfer, the price, or anything else. Still, using the list of *IP Address Blocks Transferred per NRPM 8.3* in combination with ARIN's Whois and Whowas databases, one can determine the organizations involved, the date of the original registrations and the date of the transfer.

APNIC provides the most information. It maintains a public log of all IPv4 transfers that includes the name of the releasing organization, the name of the acquiring organization and the effective date of the transfer. The problem with the APNIC list is that it includes both market transfers and non-market transfers, and provides no basis for distinguishing between them. Utilization of this data, therefore, involved additional work to see if the organizations involved were part of a merger, or whether they were subsidiaries of the same corporation. In some cases no strong confirmation of the status of a transfer as non-market could be found. In those cases, the transactions were

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[4] ARIN NRPM, Section 8.3, Transfers to specified recipients.
https://www.arin.net/knowledge/statistics/transfers_8_3.html

presumed to be market transfers. It is possible that some of those presumptions are wrong, and that we slightly overstate the number of market transfers in the AP region.

The APNIC data is further complicated by the existence of national Internet registries (NIRs) in the region. The oldest and most organized NIR, JPNIC of Japan, also publishes a list of transfers between Japanese entities, which allows the same methods to be used as in the APNIC log. Fortunately Japan is one of the more active countries in the transfer market. In other cases, such as Indonesia, one sees a record of a transfer in the APNIC list, but the only party shown is the Indonesian NIR itself. These opaque transfers were discarded from our calculations, but there were only 3 of them and they did not involve large blocks. As noted before, RIPE NCC provides no public log of transfers of any kind. Because no market transfers appear to have been made in the European region, however, the lack of data does not affect this study.

Using the methods and data sources described above, we assembled a spreadsheet of all market transfers (including IP numbers transferred as a result of bankruptcy asset sales). Each row contains data showing the region, the IP address of the block traded, the name of the releasing organization, the name of the acquiring organization, the transfer date, the traded block's prefix, the original registration date of the block, the status of the /8 prefix according to IANA records (legacy or allocated), and the contract type (RSA or LRSA).

How to count IP number trades

In quantifying and analyzing IP number trades, three different units of analysis are relevant: the number of transactions, the number of blocks, and the quantity of IP numbers.

The most obvious metric is the total amount of IP numbers involved. This gives a good overall sense of the dimensions of the trading market. However, for reasons related to routing efficiency, no one sells or buys individual IP numbers; in that respect numbers should not be discussed as if they were homogenous, interchangeable commodities that come in single units.

IP numbers are almost always assigned and allocated in contiguous blocks of various sizes.[5] RIR policies dictate that the smallest block that can be traded is a /24, which consists of 256 unique contiguous numbers. The largest allocated block, known as a /8, consists of approximately 16.78 million unique contiguous numbers. Thus, it is also relevant to count and analyze the number of blocks involved in trades, while recognizing that blocks vary widely in total IP numbers. (Table 4 provides a list that maps the /X notation to specific quantities of IP numbers.)

Finally, one can count transactions. A single market transaction can involve one or more blocks. That is, organization A may hold 10 different IPv4 address blocks; it might sell all 10 of them to organization B in a single market transaction; or it might sell its blocks in two transactions, 6 blocks to B and the other 4 to organization C. Thus, the paper also examines the number of transactions. Generally if the same two organizations are involved in a transfer of multiple blocks on the same date, we count it as one transaction. We found evidence of what may be complicated three-party and four-party transfers of address blocks which may not meet these assumptions, but there are only a few of them.

[5] Based on technical aspects of routing and network management, one would expect larger contiguous blocks to command higher per-address prices than smaller blocks. Put simply, the larger the block of contiguous numbers a network has, the easier it is for a network operator to manage addressing and routing.

Testing whether addresses are routed

Our research also performs some analysis of whether traded address blocks were used before and after the transaction. The lookups were performed using a Python library written by Asghari called PyASN. It takes as input a BGP dump file first. The website Routeviews archives these dumps for many years. Using a script, the IPv4 address space was enumerated, and for each /24 IP block, an ASN lookup is performed using the Routeviews data. We tested at 6-month intervals from January 2010 to July 2012, inclusive.

The address market data

Summary statistics for the period from November 2009 to the end of June 2012 indicate that there were 85 distinct transactions, 208 distinct blocks traded, and a sum total of 6,362,368 unique IP numbers exchanged in the transfer market. There was minimal activity in 2009 and 2010, but in 2011 and 2012 the number of transactions, blocks traded and IP numbers began to increase rapidly (Table 2). If the data for the first 6 months of 2012 are extrapolated forward, the number of transactions would quadruple and the total IP numbers traded would increase by 7.5 from 2011 to 2012. Using the same simple extrapolation, the number of blocks traded would increase by 50%. If numbers continue to trade in the range of $9-11 per number, the market in 2012 will be worth about $100 million, and if it increases at the extrapolated rate, it would be worth about ¾ of a billion in 2013.

Table 2

Accelerating pace of market transfers of IPv4 address blocks

	2009	2010	2011	2012 (first half)	Total
# transactions	3	2	28	52	85
# blocks traded	8	3	113	84	208
# IP numbers	11,264	10,240	1,340,928	4,999,936	6,034,688

When *# IP numbers* is used as the metric, North American activity dominates the market, whereas if the metric is *# blocks* or *# transactions* Asia Pacific region is more active. Ninety-five of the 208 traded blocks making up 5,391,616 IP numbers were in the ARIN region, whereas 113 blocks totaling 971,000 numbers were traded in the APNIC region. The *# IP numbers* traded in the ARIN region is 84% of the total amount traded, whereas ARIN accounts for only 46% of the *# blocks*.

Perhaps the most surprising aspect of this data pattern is that *ARIN has not yet run out of IPv4 numbers.* At the end of July 2012, ARIN still had 52.6 million numbers available for allocation. The Asia-Pacific region, on the other hand, announced it had exhausted its inventory on April 15, 2011.[6] In other words, North American organizations are turning to the market for IPv4 numbers when they could get numbers from ARIN. While there seem to be more transactions in the AP region (52 out of 85, or 61%), they generally involve smaller blocks and thus a much smaller quantity of IP numbers in total. Like ARIN, RIPE-NCC still has numbers available; as of July 30, 2012, its website shows 27.38 million in stock. As noted before, while there have been some parties willing to list blocks for sale in the RIPE region, there have been no buyers.

[6] The story is a bit more complicated than that. APNIC retains its last /8 as a kind of emergency reserve, but offers no more than one /22 block (1,024 numbers) to any single entity, regardless of how many numbers it can prove that it needs. RIPE will adopt a similar policy when its supplies go down to its last /8 which is expected to occur in November 2012. See Huston (2012) for a more detailed analysis of the final stages of IPv4 exhaustion.

Table 3

Quantitative comparison of ARIN allocation and market allocation

	2009	2010	2011	1st half 2012
IP numbers allocation by ARIN	41,317,376	45,266,688	22,471,424	16,077,056
IP numbers transferred via market ARIN	11,264	8,192	1,150,976	4,221,184
Percent allocated via market	0.03%	0.02%	5.12%	26.26%

Not only is the market flourishing in ARIN's region, it constitutes a substantial portion of total allocations in the North American region. Table 3 shows the quantity of IP numbers allocated by ARIN in the normal way from 2009 to the first half of 2012, and compares it to the quantity of IP numbers allocated via market transfers. The data show that the quantity of IP numbers involved in market allocations went from 3.66% of administrative allocations in 2011 to 26.23% in the first half of 2012. If the quantity of numbers involved in market transfers in the ARIN region continues to increase at the pace of the last two years, market transfers could equal administrative allocations in 2013.

Table 4

Address blocks traded

/ Notation	Number of blocks this size traded	Numbers per block size	Total number of traded numbers per block size	Percent of all traded numbers
/8	0	16,777,216	0	0%
/9	0	8,388,608	0	0%
/10	0	4,194,304	0	0%
/11	0	2,097,152	0	0%
/12	2	1,048,576	2097152	33.0%
/13	1	524,288	524288	8.2%
/14	3	262,144	786432	12.4%
/15	4	131,072	524288	8.2%
/16	29	65,536	1900544	29.9%
/17	5	32,768	163840	2.6%
/18	4	16,384	65536	1.0%
/19	14	8,192	114688	1.8%
/20	27	4,096	110592	1.7%
/21	14	2,048	28672	0.5%
/22	20	1,024	20480	0.3%
/23	16	512	8192	0.1%
/24	69	256	17664	0.3%
Sum	208		6362368	

Table 4 breaks down market transfers by address block size. It shows that the old Class C (/24) address blocks are the most commonly traded, with 69 transferred blocks, but due to their small size, /24s account for a tiny portion of the traded address space. The old Class B (/16) blocks, which contain 65,536 numbers, are also popular objects for trades, with 29 of them changing hands. Twenty-seven /20s were traded as well. The /16 trades are 30% of the total traded address space. Overall, the 35 largest blocks that were traded, from /16 up to /12, account for 91.7% of all the numbers changing hands. Still missing from this picture is a /8, the largest unit of allocation. If and when one or more of those blocks trade, all the other trades will shrink to insignificance in relative terms.

The reallocation of legacy blocks

The blocks in play in this market are overwhelmingly comprised of legacy allocations. Of the 6.36 million IP numbers that have been traded, 5.62 million, or 88 percent, were classified as 'legacy' allocations in IANA or RIR records.[7] 5.65 million, or 89%, were from allocations made before the year 2000. All of the larger blocks sold (/15 and up) were legacy allocations, and 22 of the 29 /16s traded (76%) were legacy blocks.[8] All of the larger blocks sold (/15 and up) were legacy allocations, and 22 of the 29 /16s traded (76%) were legacy blocks. Further, while the releasing organizations are corporations of a highly varied type, ranging from equipment manufacturers to pharmaceutical firms to universities and research organizations to hosting companies, the recipients are almost entirely Internet access providers (both mobile and fixed), online service providers such as Amazon and Microsoft, smaller VoIP providers and telephone cooperatives, and hosting companies. This indicates that market transfer policies are succeeding in re-allocating the inefficiently allocated legacy blocks from entities with an unneeded surplus to growing Internet businesses that need them more.

Three of the larger trades of legacy allocations involved bankruptcies in which the address blocks were sold off to creditors as assets: Nortel, Borders[9] and Teknowledge. The other large legacy block transaction involved the pharmaceutical company Merck. In 1992 it was given a /8 (16.78 million numbers). From that original allocation it sold to Amazon two /12s (roughly 2.1 million numbers) early in 2012. Borders and Teknowledge sold off legacy /16s as part of their bankruptcy proceeding.

In March 2011, it was announced as part of Nortel's U.S. bankruptcy proceeding that Microsoft would be acquiring 666,624 IPv4 numbers from Nortel for $7.5 million. Microsoft bought 38 number blocks that had been accumulated at various times since 1989 by Nortel from IANA or from corporate acquisitions. Included in the package were sixteen /24s, four /23s, one /22, two /21s, four /20s, nine /16s, and one /17 and /18 each. A second tranche of Nortel IP numbers, sold as part of the Canadian bankruptcy process, went to Vodafone, Salesforce.com, Bell Aliant, and two smaller ISPs. The Canadian court has refused to release any information about the price of these transactions. The Teknowledge /16 sold for $590,000, or $9.00 per address.[10]

The Merck-Amazon deal was not a bankruptcy but a straight legacy transaction, so we do not know the price. But the transaction illustrates the market's success at moving IPv4 address stock from legacy holders with excessive allocations to expanding, network-intensive industries. According to our tests, both of the /12 blocks went from being unrouted (i.e., not used on the Internet) to publicly routed within a year of the transaction. It also shows that legacy holders not subject to the duress of bankruptcy can and do calibrate what they release into the market. Merck retained more than 14 million IPv4 numbers of the original /8 for itself; though it is a big corporation it is unlikely that Merck needs that many numbers. We do not know why they are withholding the remaining stock – it could be for its own future use, or because there are no suitable buyers, or because they are deliberately withholding stock as part of an attempt to get a better price later.

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[7] The two categories (allocations made before 2000 and 'legacy' allocations) do not match perfectly, but the difference amounts to about 1% of the total.

[8] The two categories (allocations made before 2000 and 'legacy' allocations) do not match perfectly, but the difference amounts to about 1% of the total.

[9] Some of the relevant court documents in the Borders case are available here: http://www.internetgovernance.org/wordpress/wp-content/uploads/Bankr.S.D.NY_.-2233_merged.pdf

[10] The court order approving the sale is available here: http://www.internetgovernance.org/wordpress/wp-content/uploads/Bankr.N.D.Cal_.-034022138232.pdf

Some policy issues

The previous material set out the basic parameters of the transfer market. Understanding and dimensioning that market is the main purpose of this paper. A solid empirical outline of the transfer market is intended to provide a stronger basis for discussion of the many interesting and important policy questions raised by the future of IP addressing. In this section, we introduce briefly some of those policy issues.

Why ARIN/North America?

One would expect market transfers to take place in APNIC's region, where the RIR has almost nothing to give out to applicants, and one would *not* expect to see a lot of market transfers in Europe, where the RIR still has unallocated numbers to give out. Both of those expectations hold up. But North America is the anomaly; its RIR, ARIN, has numbers to give – more than twice as many as RIPE – and lots of market activity. From a research standpoint, this is an interesting puzzle.

One obvious difference between the ARIN region and the others is the larger amount of legacy address space in North America. But the presence of legacy address space only explains why North America would have more *sellers*. It does not by itself explain why there would be *buyers* of those legacy holdings when there are still numbers available at ARIN.

In explaining this puzzle, the Microsoft-Nortel deal is especially revealing because the price is known. By paying $7.5 million, MSFT invested about $11.25 per IPv4 address. Using ARIN's fee schedule for numbers available in its free pool, Microsoft would have paid only $87,250 per year or about 13 cents per address per year in ARIN fees. To pay ARIN $7.5 million in annual fees, Microsoft would have had to hold the address blocks for 86 years, an unlikely eventuality (unless one believes that we will never get to IPv6 at all!). The disjunction between what MSFT paid Nortel and what it would have paid ARIN for perfect substitutes indicates that there are factors governing firms' economic calculations regarding IPv4 numbers that may not be obvious to casual observers.

The explanation for this puzzle, we believe, can be found in two policy factors. One is the large gap between the restrictiveness of ARIN's "needs assessment" policies when applied to its remaining free pool allocations and when applied to transfer markets. The other explanation lies in the disjunction between the *de facto* property rights enjoyed by legacy holders, and the far more limited use rights of non-legacy holders.

…To each according to his need

Much of the policy debate around market transfers centers on needs assessments. All the transfer policies in place require buyers of number blocks to justify their acquisition by showing that they "need" the numbers. The RIRs' conservation mechanism was based not on prices but on administrative-technical criteria, such as detailed data about the utilization of existing number blocks in their possession, as well as equipment orders or other indicators of investment in operations that required a certain amount of new numbers.

A critical policy issue in the IP number market is the role of administrative needs assessment in the market transfer process. Although market transfers introduce price signals and economic incentives into the allocation of IPv4 numbers, the commoditization of the resource is severely limited by the retention of needs assessment by all the RIRs. Data from ARIN indicate that in 2011, one third (33%) of all attempts to conduct market transfers via the 8.3 process were blocked or modified due to needs assessments. In 2012 the percentage was 28%. Need assessments thus restrict willing sellers from transacting with willing buyers in about 30% of the cases.

A key variable in the application of needs assessment is the time horizon employed. Proving that one "needs" X numbers tomorrow because one's network is overloaded is a fairly straightforward technical-operational calculation. Proving that one needs X numbers over the next three years in order to accommodate growth and/or implement new business plans is more like an investment decision than a network engineering decision. In free pool allocations, ARIN and the other RIRs have reduced the time horizon for needs assessments as the pool dwindles and exhaustion nears. For number applications from RIRs, the time horizon for demonstrating need is now only three months. To qualify for needs assessments in ARIN's 8.3 transfer process, on the other hand, the time horizon for assessing need was one year from 2009 – 2011, and was extended to two years from February 2012 on. Forward-looking companies that want to secure access to IPv4 numbers over a commercially relevant time frame would obviously opt for the transfer market over a free pool allocation – even if the apparent cost of the transferred numbers is much higher.

…The specter of ~~communism~~ property rights

There is another explanation for the existence of a market prior to the depletion of the free pool in North America. Transactions with legacy holders can provide buyers with more secure property rights – although this issue is still partially unsettled. The prominent role of legacy holders in the number market has raised important legal and policy questions about the legal rights of the transacting parties. If legacy holders have no binding contract with ARIN, they are not obligated to transfer their IPv4 number holdings via the Section 8.3 transfer policy. This means that legacy holders could transact with buyers regardless of whether the buyers can "demonstrate need." It would also mean that the buyers of legacy numbers would hold them free and clear of ARIN contracts, just as the seller did.

Fearing that such transactions would undermine its authority over a substantial portion of the IPv4 number space, ARIN has agitated to keep transfer market participants within its process. It has even gone so far as to publish advice in a bankruptcy law journal (Ryan & Martel, 2012). As it lacks any contractual leverage over legacy holders, however, it has had to grasp for other forms of influence over legacy sellers and prospective buyers. Specifically, it is attempting to use its control of the Whois database as a strategic lever. ARIN is now warning buyers of legacy resources that it will not update its Whois records to reflect transfers that take place outside of its 8.3 process. It is unclear what the effect of excluding transactions from the Whois will be. It could undermine the value of purchased number blocks, but only if their absence from the Whois prevented network operators from considering the buyer to be the legitimate holder of the block. This in turn might cause ISPs to refuse to route traffic to the affected number prefixes. On the other hand, it is possible that IPv4 number block buyers will discount this threat and purchase the block anyway. If the transaction involves a major, reputable corporation and a large block such as a /8 or /16, it is unlikely that the entire Internet would filter out the number block simply because ARIN didn't approve of the trade. If other ISPs routed to the "illicitly" traded block anyway, ARIN's database would lose its status as an authoritative, reliable guide to who holds which number blocks. Thus, ARIN's attempt to gain leverage over the transfer market through the use of the Whois database is like a game of chicken; if neither side gives in there could be a collision.

The MSFT-Nortel deal brought these issues to a head. In putting together their trade, Nortel and Microsoft, with the assistance of IP number brokerage firm Addrex, bypassed ARIN's 8.3 transfer process. Both the seller and the buyer transacted to exchange their property rights over the number resources in bankruptcy court. A last-minute intervention by ARIN, and private appeals to Microsoft, led to a compromise solution. Microsoft agreed to sign a special contract for legacy holders, known as a LRSA, and ARIN agreed that the transaction gave Microsoft the same de facto property rights held by the prior legacy holder, Nortel. The specific terms of the LRSA Microsoft signed have not been disclosed.

ARIN alleges that it performed a "needs assessment" prior to the Microsoft-Nortel transaction to ensure it was compliant with its policy. Others have disputed ARIN's claim, noting that ARIN intervened in the bankruptcy proceeding at the last minute and was in no position to prevent the transaction based on its needs analysis. The needs assessment, they believe, was simply a face-saving exercise to make it appear as if it was applying its policy and retaining some authority over legacy address transactions.

The evidence supports the more cynical view. By tracing the routing of prefixes, we can see which of the Nortel blocks Microsoft is actually using a year after the trade was approved. Under its Section 8.3 transfer policy, ARIN needs assessments are supposed to be based on a one year timeline. We find that as of July 2012, only 7 of the 38 Nortel blocks, totaling only 10,496 numbers, are now being routed by MSFT (See Table 5). Indeed, three of the larger /16 blocks transferred went from being routed to being *unrouted*. Thus, only 18% of the blocks involved in the Nortel - MSFT transaction were routed within a year of the transaction, and due to the withdrawal of the /16s from use there was a net *decrease* of 186,112 in the quantity of routed IPv4 numbers.

In what sense did Microsoft "need" these IPv4 numbers? From a technical point of view, it clearly did not need to put them into service within the short (one-year) time horizon contemplated by ARIN's policy. From an economic point of view, on the other hand, it makes perfect sense for a business with a market capitalization around $260 billion, the livelihood of which hinges very directly on Internet connectivity, to spend a paltry $7.5 million to secure long-term access to such a critical resource. Such a development could also raise concerns about the impact of IPv4 scarcity on smaller, less well-funded operators as the market becomes tighter.

Conclusions

The most important conclusion to be drawn from this analysis is the simplest: there is a thriving and growing market for IPv4 number blocks. This is a useful finding in and of itself. There were many who said that permitting trades of IPv4 numbers would fail to provide sufficient incentives for legacy holders and others to release their numbers. There were others who said that the whole issue was irrelevant because of the impending transition to IPv6. They believed that a market would never develop. The evidence so far indicates that both were wrong. Not only does the market exist, but from a policy standpoint it seems to be doing precisely what its advocates said it would do, namely provide access to additional IPv4 resources after the free pool is depleted, while reallocating number resources more efficiently by moving them out of unused or underutilized allocations and toward organizations who need them to grow.

An additional, partly unintended consequence of the transfer market has been to provide liberalized access to IPv4 numbers relative to the stringent needs assessment and documentation procedures required to get numbers from the RIRs. Companies have shown that they are willing to pay substantially more for IP number resources via the transfer market, if it allows them to extend their time horizon and/or avoid the needs assessment process. And at least one RIR (ARIN) has shown that it will scramble to modify its contractual arrangements to strengthen recipients' property rights in order to keep market participants from abandoning its contractual governance regime. Thus the market provides a check on ARIN's policy process. But due to the confidentiality of the needs assessment and contracting process, it also introduces an element of potential discrimination in the RIR's contracting process. It may be that there is one set of rules and contracts for smaller, less influential firms and quite another set for larger players whose defection from the ARIN regime might have a large impact. As technical needs assessments become less relevant, there is also the question of how a rising price for numbers will affect competitive entry into the market, and whether price manipulation through hoarding will occur.

It is too early to assess the impact of the transfer market on the migration to IPv6. However, given recent incremental growth in the adoption of IPv6 by some major online service providers and ISPs, it does not appear as if transfer markets are impeding the migration in any obvious way. The growth of IPv4 markets occurred simultaneously with what Huston (2012) has characterized as a "fourfold increase in the penetration of IPv6." Huston's research recognizes, however, that that rate of IPv6 adoption will not be fast enough to "avoid some of the major pitfalls associated with encountering IPv4 exhaustion." In other words, here again the market seems to be doing exactly what its advocates said it would do, namely provide a bridge over a period of scarcity that is of indefinite duration while Internet operators gradually come to terms with the costs and technical issues associated with IPv6 implementation, and wait for the great tipping point.

As noted at the beginning, introducing market forces and powerful economic incentives tends to produce institutional changes as well as changes in business practices. All of the transfer policies mentioned above are restricted to trades within the territory of a single RIR. As the market evolves, a huge gap is likely to emerge between available resources in one region and willing buyers in a different region. Specifically, as the home of most legacy resources, the North American region is likely to have more sellers and the faster-growing Asia-Pacific region is likely to have more buyers. The RIRs have already noticed this and have begun to develop policies for inter-regional transfers. Because these policies were not yet fully passed or implemented at the time this research was conducted, however, data about the results cannot be incorporated into this study. But the rise of inter-regional transfers raises questions about the continued viability of regional number registries, and may force us to consider a more integrated, global coordination mechanism and more globalized policies. It is time to stop debating the merits of IPv4 address markets; the issue now is how to make them work better.

Table 5: Utilization of Nortel blocks by MSFT

Entries in red indicate a change in the routing of a block by Microsoft. Trades took place in June and August 2011.

Block	Jan 2010	July 2010	Jan 2011	Jul 2011	Jan 2012	July 2012
131.253.1.0/24	ASN 19952	Unrouted	Unrouted	Unrouted	Unrouted	Unrouted
131.253.3.0/24	ASN 19952	Unrouted	Unrouted	Unrouted	Unrouted	Unrouted
131.253.5.0/24	ASN 19952	Unrouted	Unrouted	Unrouted	Unrouted	Unrouted
131.253.6.0/24	ASN 19952	Unrouted	Unrouted	Unrouted	Unrouted	Unrouted
131.253.8.0/24	ASN 19952	Unrouted	Unrouted	Unrouted	Unrouted	Unrouted
131.253.12.0/22	ASN 19952	Unrouted	Unrouted	Unrouted	ASN 8075	ASN 8075
131.253.16.0/23	Unrouted	Unrouted	Unrouted	Unrouted	Unrouted	ASN 23468
131.253.18.0/24	Unrouted	Unrouted	Unrouted	Unrouted	Unrouted	ASN 8075
131.253.21.0/24	Unrouted	Unrouted	Unrouted	Unrouted	Unrouted	Unrouted
131.253.22.0/23	Unrouted	Unrouted	Unrouted	Unrouted	Unrouted	Unrouted
131.253.24.0/21	Unrouted	Unrouted	Unrouted	Unrouted	Unrouted	Unrouted
131.253.32.0/20	Unrouted	Unrouted	Unrouted	Unrouted	Unrouted	ASN 8075
131.253.61.0/24	Unrouted	Unrouted	Unrouted	Unrouted	Unrouted	Unrouted
131.253.62.0/23	Unrouted	Unrouted	Unrouted	Unrouted	Unrouted	Unrouted
131.253.64.0/18	Unrouted	Unrouted	Unrouted	Unrouted	Unrouted	Unrouted
131.253.128.0/17	Unrouted	Unrouted	Unrouted	Unrouted	Unrouted	Unrouted
132.245.0.0/16	Unrouted	Unrouted	Unrouted	Unrouted	Unrouted	Unrouted
134.170.0.0/16	Unrouted	Unrouted	Unrouted	Unrouted	Unrouted	Unrouted
134.177.0.0/16	ASN 7099	ASN 7099	ASN 7099	ASN 7099	Unrouted	Unrouted
137.116.0.0/16	Unrouted	Unrouted	Unrouted	Unrouted	Unrouted	Unrouted
137.117.0.0/16	Unrouted	Unrouted	Unrouted	Unrouted	Unrouted	Unrouted
137.135.0.0/16	Unrouted	Unrouted	Unrouted	Unrouted	Unrouted	Unrouted
138.91.0.0/16	Unrouted	Unrouted	Unrouted	Unrouted	Unrouted	Unrouted
141.251.0.0/16	Unrouted	ASN 7099	ASN 7099	Unrouted	Unrouted	Unrouted
192.32.0.0/16	ASN 7099	ASN 7099	ASN 7099	Unrouted	Unrouted	Unrouted
192.48.225.0/24	Unrouted	Unrouted	Unrouted	Unrouted	Unrouted	Unrouted
192.84.159.0/24	Unrouted	Unrouted	Unrouted	Unrouted	Unrouted	Unrouted
192.84.160.0/24	Unrouted	Unrouted	Unrouted	Unrouted	Unrouted	Unrouted
192.84.161.0/24	Unrouted	Unrouted	Unrouted	Unrouted	Unrouted	Unrouted
198.49.8.0/24	Unrouted	Unrouted	Unrouted	Unrouted	Unrouted	ASN 8075
198.200.130.0/24	Unrouted	Unrouted	Unrouted	Unrouted	Unrouted	Unrouted
198.206.164.0/24	Unrouted	Unrouted	Unrouted	Unrouted	Unrouted	Unrouted
199.30.16.0/20	Unrouted	Unrouted	Unrouted	Unrouted	Unrouted	Unrouted
199.74.210.0/24	Unrouted	Unrouted	Unrouted	Unrouted	Unrouted	ASN 8075
199.242.32.0/20	Unrouted	Unrouted	Unrouted	Unrouted	Unrouted	Unrouted
199.242.48.0/21	Unrouted	Unrouted	Unrouted	Unrouted	ASN 8075	ASN 8075
204.152.140.0/23	Unrouted	Unrouted	Unrouted	Unrouted	Unrouted	Unrouted
205.174.224.0/20	Unrouted	Unrouted	Unrouted	Unrouted	Unrouted	Unrouted

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