

Technology: Infrastructure Software

United States

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"Hello everybody... I'm doing a (free) operating system (just a hobby, won't be big and professional...)."

—Linus Torvalds, creator of Linux, from the first Internet announcement of Linux on August 25, 1991. Even he initially underestimated its potential.

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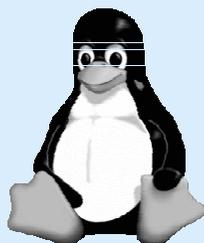
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Tux, the Linux Penguin
Official mascot of Linux
(creator: L. Ewing)

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Fear the Penguin. Linux-on-Intel appears likely to emerge as the dominant platform in corporate data centers. This paradigm shift should have significant implications for a broad range of enterprise IT vendors. Our handbook highlights key themes and offers an initial framework for investing in Linux's emergence.

The rise of Linux should have significant consequences for IT vendors

In our view, Linux has evolved into an enterprise-class operating system that we believe will have a significant and lasting presence on the IT landscape. Its continuing emergence will likely cause considerable changes in the enterprise IT vendor ecosystem.

Most see enterprise Linux as an "edge" story; we see it in the data center

Many observers confine Linux's enterprise opportunity to the market for low-end "edge" servers such as file, print, Web, and e-mail servers, but we are confident that the technical developments and market forces are in place for it also to become the dominant O/S on the higher-end servers of the enterprise data center, where mission-critical functions are run and the lion's share of IT spending occurs. In particular, we believe that enterprise customers will use Linux primarily to take advantage of lower-cost, higher-performance Intel-based servers and avoid technology lock-in situations. As a result, we believe the Linux-on-Intel model will displace the existing paradigm of premium-priced proprietary systems based on Unix operating systems and RISC processors.

No magic bullet for Linux investing—use the "open stack" as a framework

We do not believe that there is only one company that will succeed with Linux. Rather, we believe the positive impact will be spread over the vendors in an "open stack" of technologies that Linux facilitates. We believe the emergence of Linux will most directly benefit independent PC semiconductor companies (Intel and AMD) and Intel-based server businesses (Dell) while having a mixed impact on proprietary systems companies (Hewlett-Packard, IBM, and Sun Microsystems). It should also benefit "open" infrastructure software vendors such as BEA Systems, BMC Software, Oracle, and Veritas at the expense of infrastructure software companies with proprietary solutions, though it may negatively affect overall software pricing at the same time. Although we believe that Red Hat is well on its way to establishing a definitive standard for enterprise Linux, we also believe it is primarily a service provider and that it should be valued as such.

Certain trends could accelerate adoption of Linux

We believe Linux's emergence is likely to follow the more measured pace of server hardware upgrade cycles and will not occur within the short time frame many envision. However, trends such as server consolidation and wider deployment of J2EE-based computing models could significantly accelerate rates of adoption, while slow support from packaged application vendors could be the key drag on the time frame for Linux's continued emergence.

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Fear the Penguin—Linux changes enterprise computing

In our view, Linux has evolved into an enterprise-class operating system that will have a significant and lasting presence in the IT landscape, and its continued emergence will cause considerable changes in the enterprise IT vendor ecosystem. We believe its strongest effects will be seen in the corporate data center, where we see a shift occurring toward Linux-on-Intel servers away from the current paradigm of proprietary Unix-on-RISC systems. This paradigm shift should have significant implications for the enterprise computing market and for a broad range of vendors in both hardware and software.

Linux is a technology that is only now beginning its move into the enterprise. As such, many issues surrounding the emergence of Linux are only beginning to surface and be understood, and some issues have yet to be uncovered. With that in mind, we have created this Linux handbook to begin to frame what we believe are the relevant questions surrounding Linux's emergence in the enterprise, and, where possible, provide our views on the most likely answers.

The Linux handbook

The purpose of this handbook is fourfold:

- To present our conclusions on the emergence and timing of Linux as a viable enterprise operating system.
- To explore the implications for key vendor groups.
- To propose an initial investment framework for investors to use, while highlighting the as-yet-unanswered questions.
- To provide context on the rise of Linux and a more in-depth exploration of its value proposition.

The Linux opportunity is large and growing

We believe that the pieces are in place for a widespread move in the enterprise from platforms based on proprietary Unix operating systems and RISC processors to Linux-on-Intel-based systems. In our view, this will occur because Linux:

A move to Linux-on-Intel appears to be a compelling value proposition for CIOs.

- **Allows enterprise IT departments to reduce hardware expenditures** by moving off costly proprietary Unix/RISC-based systems and onto more cost-efficient Intel-based hardware, without sacrificing the dependability required in the data center. We believe this is the primary driver for Linux's emergence in the enterprise.
- **Provides a familiar Unix environment that allows for an easy transition** from existing proprietary Unix platforms, particularly by enabling re-use of existing code and skills and well-understood infrastructure and systems management solutions.
- **Frees IT customers from being locked into expensive single-vendor hardware and software stacks**, giving them freedom to choose from best-of-breed software and hardware products. This creates a more "open" technology stack where vendors compete on the basis of price and functionality rather than their control of platforms, which benefits customers.

We believe these factors combine to make a move to Linux-on-Intel a very compelling value proposition for CIOs. Accordingly, we believe that Linux will be widely adopted in the enterprise and will have the most significant impact on the data center, where the majority of enterprise-computing dollars are spent and where high-priced Unix/RISC systems currently dominate. In the process, we believe the emergence of Linux will affect companies throughout the entire enterprise computing landscape.

The O/S is a crucial piece of technology, making Linux's emergence significant

A great deal of attention has focused on the emergence of Linux, primarily because, as an operating system, the technology sits at the junction of hardware and software and has the potential to affect companies in both markets. At its most basic level, an operating system (O/S) is the first layer of software that sits atop computing hardware and is a shared piece of software required by applications to run on the specific underlying hardware. The core function of the O/S is to provision and schedule processing capacity and memory for specific tasks. As operating systems have evolved, they have also begun to take on additional functionality not directly related to their original role, and functions like network and systems management have been added to many operating systems. O/Ss in enterprise environments have also taken on additional functionality to meet the needs of enterprise users, with higher-level functions added to increase scalability and dependability, such as enhanced I/O (input/output) capabilities and multi-system clustering, fail-over, and load-balancing functionality.

As a result of their role in connecting software to the hardware that it runs on, operating systems like Linux are a key piece of technology in software development. New applications are written to use the application-programming interface (API) of a specific O/S, which is the set of commands that an O/S provides to give programs access to its functionality. This technological element has had a key business impact in the enterprise computing landscape, as enterprise systems vendors have often

used their O/S-specific API as a lever to build and maintain their customer base for hardware and software. In effect, **integrated systems vendors and independent O/S vendors have been able to use the API as a vendor-specific standard, one that makes it difficult for customers to move off the platform once they have begun to use applications that are written for that particular API.** This aspect of application development has led to a phenomenon called vendor “lock-in” that has been prevalent in the past and is critical to understanding part of Linux’s appeal in the enterprise.

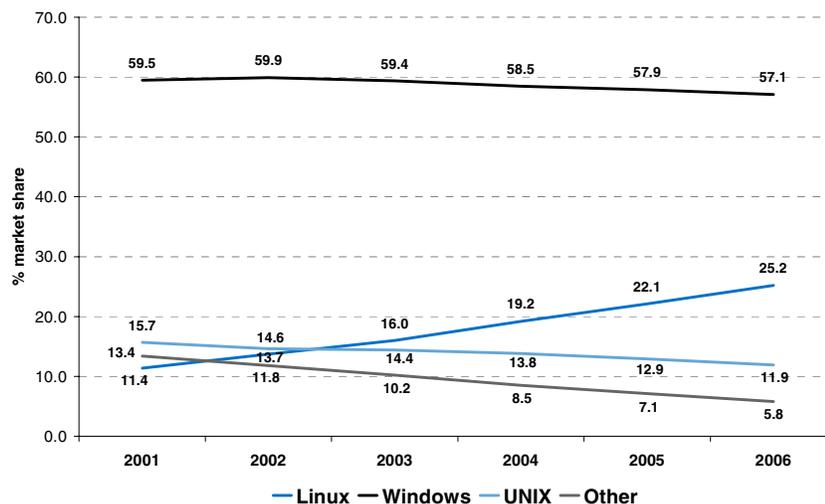
It is important to note that, functionally, Linux is an operating system like any other, with no specific technical advantages. Instead, the key differentiator for Linux lies in the fact that it is an “open-source” O/S, meaning that it is not the proprietary property of any company, and any party can use and/or contribute to its source code and use its APIs. This is a model that has not existed to this point in the enterprise computing market and has significant implications that we explore further throughout this report.

Market-share data begin to suggest a sizable opportunity

According to IDC forecasts, shipments of servers running Linux will significantly outperform the growth of the overall market and take market share over the 2001-2006 time frame.

Although we do not believe that Linux shipment data can completely account for the spread of the open-source O/S, given its free availability outside normal enterprise distribution channels, we do believe that it helps put the opportunity for Linux in the enterprise into context. In a recent report, IDC forecasts a worldwide server system shipment CAGR of 13.9% through 2006 (from 4.3 million shipments in 2001 to 8.2 million shipments in 2006), but estimates that **shipments of servers running Linux will grow at a 33.6% CAGR (from 11.4% of total server shipments in 2001 to 25.2% in 2006), with all other classes of operating systems declining in share.**

Exhibit 1: Estimated operating system share through 2006, by server shipments
Linux grows in share to 25.2% of the total server market in 2006 while all other O/Ss decline



Source: IDC report, “Worldwide Server Market Forecast Update, 2001-2006,” November 2002.

Although Windows is cited as the leading server operating system, it primarily functions in the lower end of the server market (in markets for e-mail, file, Web, and print servers). We believe Linux’s largest opportunity is higher up in the market in the data center,

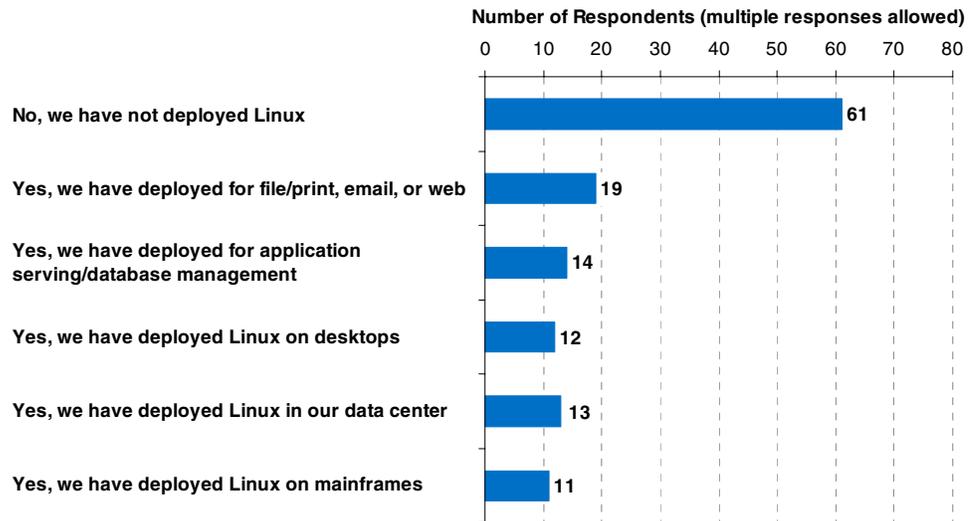
which is generally defined as the servers on which higher-end, mission-critical enterprise applications and databases are run. We believe Linux can continue to take market share from Unix and will displace it in the data center (Unix is shown declining from 15.7% of the market to 11.9% by 2006); see Exhibit 1. **If anything, we believe there is upside to these numbers for Linux and that the trend toward Linux and away from Unix will accelerate through the end of the decade**, with Linux continuing to take share from other server operating systems and becoming the dominant operating system in the data center over that period.

Our more qualitative IT spending survey reinforces the overall growth story...

Our November 2002 IT Spending Survey also suggests that adoption of Linux in the enterprise is not a vision of the future—the beginnings of such a move are already being seen today. The survey found that 39% of respondents had currently deployed Linux in some capacity within their IT departments, with deployments of Linux spread relatively evenly throughout the enterprise. The same proportion plans to increase the use of Linux over the next year (Exhibits 2 and 3), indicating that a base of early adopters co-exists with an entrenched camp of users who are either unacquainted with Linux’s benefits or are waiting for it to prove itself in the enterprise first before even considering it for use.

Exhibit 2: Of 100 respondents, roughly between 10 and 15 use Linux in any given area of the IT infrastructure

question: Have you deployed Linux in your company? If so, where? Mark all that apply



Source: Goldman Sachs November 2002 IT Spending Survey.

Exhibit 3: A healthy but not overwhelming proportion plans to increase use next year.

question: Do you plan to increase your company’s deployment of Linux in the next year?

Yes	39%
No	60%
Unsure	1%

Source: Goldman Sachs November 2002 IT Spending Survey.

...but it also suggests that Linux is beginning to surreptitiously enter the data center

Although the majority of corporations still appear to view Linux as a nascent technology that is not yet enterprise-ready and some have already ruled out its use, our survey also suggests that Linux-on-Intel is beginning to gain a foothold in the data center. In the IT Spending Survey, 16% of respondents stated that they have plans to deploy Linux-on-Intel in the near future in their data center. In addition, 19% of respondents are in the process of considering it for data center use (Exhibit 4). Similarly, our checks indicate that Wall Street IT departments, which are generally leading-edge adopters of new technologies and a leading indicator of IT trends, have made Linux an area of focus, and many have begun to deploy Linux or explore it for use on their data center servers.

Exhibit 4: Beginning to gain a foothold in data centers, but still much room to grow

question: Have you considered using Linux on x86-servers in your data center?

Yes, and we have plans to implement it in the near future	16%
Yes, we are in the process of considering it	19%
Yes, but we have ruled it out	12%
No, we have never considered it	53%

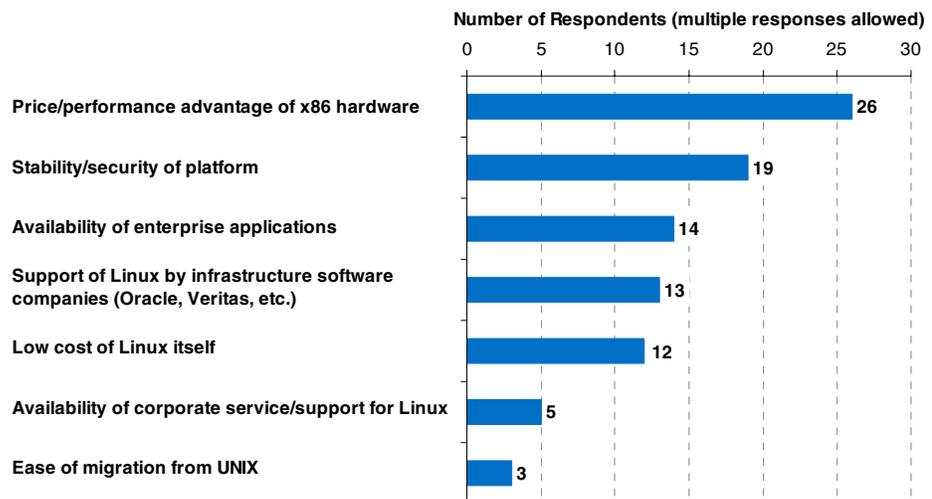
Source: Goldman Sachs November 2002 IT Spending Survey.

Respondents who chose Linux in the data center cited the price/performance advantage of Intel-based hardware over traditional proprietary RISC-based servers and the stability and security of Linux as primary drivers for that choice (Exhibit 5).

This reinforces our view and corroborates much of the anecdotal evidence we have heard from companies, which have found that they can move from traditional RISC-based servers running proprietary versions of Unix to Intel-based servers running Linux and significantly reduce hardware expenditures without sacrificing dependability.

Exhibit 5: Drivers for data center adoption are price/performance and dependability

question: If you are considering or planning to implement Linux in the data center, what factors led you to consider its use there?



Source: Goldman Sachs November 2002 IT Spending Survey.

Sink-or-swim time for vendors up and down the IT stack

We believe that the Linux operating system, together with cost-efficient Intel-based hardware, will change the enterprise data center. We believe this combination will displace the paradigm of proprietary Unix O/S and RISC processor-based systems that currently dominates the data center. This fundamental shift in platforms should have far-reaching implications for software and hardware vendors up and down the enterprise computing stack. Below we discuss the implications for the following key vendor segments:

- Independent software vendors likely to benefit longer term.
- Incumbent operating systems vendors likely to see increased competition.
- Pure-play Linux businesses emerging, but more as service providers.
- Hardware businesses rooted in Intel-based architectures should benefit significantly.
- Systems vendors likely to face new challenges, with a clear Linux strategy becoming critical to ongoing success.

ISVs should realize a number of significant benefits from Linux's emergence

We believe the adoption of Linux in the enterprise will, in general, positively benefit independent software vendors (ISVs) over the longer term, as Linux introduces a number of changes to the software market.

First and foremost, because Linux is not controlled by a single platform vendor and will most likely be standardized across different hardware platforms, we feel its adoption in the data center will provide a more standardized platform for software development and deployment and begin to mitigate the effects of the vendor “lock-in” that had previously existed. In the “lock-in” model that has prevailed in enterprise computing, certain vendors that control the platforms on which software is run are able to charge premium prices for proprietary “integrated” stacks of hardware and software products that force customers to tie their software and platform buying decisions together. The emergence of Linux works to change this situation by providing a standardized, open platform that separates hardware and software purchasing decisions from one another. This will be a boon for the ISVs that have traditionally competed against integrated platform and software vendors like IBM and Microsoft, as they will now be able to compete on a level playing field without confronting the additional factor of inertia of locked-in customers.

A second benefit for ISVs is the ability to contribute to the development of Linux itself. Because the source code for Linux is freely available and can be modified by any party that wishes to, ISVs are for the first time able to contribute to the development of the platform on which their products run. This can be contrasted to the situation that ISVs faced in working with platform vendors and their operating systems to implement features in the O/S that would allow for certain functionality of their products. Although software vendors could attempt to work together with the platform vendor to implement the desired features in the O/S, ISVs received no guarantees that the desired features would be included. Even when the ISVs convinced the platform vendor of the need for the feature, they are left to wait until the next release of the O/S to see the feature implemented. With Linux, ISVs have been actively working through the development process with Linux vendors and the open-source community to implement changes

themselves, leading to a more rapid return on investment for ISVs and, more important for the market, an increased amount of functionality in products for users.

Finally, we believe that the emergence of Linux will benefit ISVs because it keeps the enterprise based on a Unix operating system as opposed to a Windows-only environment, even as the server hardware moves more to Intel-based solutions.

Before the development of Linux as a viable enterprise O/S, many believed that a move to Intel-based hardware would result in a corresponding move to Windows in the enterprise data center, as Windows had traditionally been the only O/S available for Intel-based hardware. Such a move would benefit Microsoft and other software vendors whose products have traditionally written for Windows and would hurt many current leading enterprise ISVs, which have primarily built their products around Unix-based systems. However, if Linux becomes the dominant O/S on Intel-based platforms in the enterprise data center, its similarity to the Unix systems currently prevalent in the enterprise means that the platform landscape for ISVs will not shift significantly, which should benefit the current leading enterprise ISVs.

However, the negative impact of lower pricing also should be considered

The emergence of Linux could also prove to be a negative for the software industry in general, as its success could lead to a proliferation of open-source models in other areas in software, which could drive down pricing in each of those areas. (We

discuss areas that are more likely to see an outgrowth of open-source solutions in the “Other opportunities” section of this report.) In general, open-source software solutions have succeeded in functions that are widely used across many users, have a technical user base, and are used in technically focused applications (such as operating systems and Web servers). In these cases, the user base often overlaps with the potential developer base for an open-source solution, resulting in a situation where users of the technology also are familiar with its uses and shortcomings and have the skills and know-how to improve on it. In cases where the motivation also exists to work together with other knowledgeable users to create their own open-source versions of the technology, open-source solutions result and work to drive down prices for similar, proprietary technologies. The Web server is one example of an area where the proliferation of a common open-source solution (Apache) has worked to completely commoditize the market and drive down pricing.

Incumbent operating systems vendors likely to see more competition

We believe that Linux will not take away market share from Microsoft in its traditional markets; however, it is our view that it will hamper the movement of Windows into the enterprise data center, an area Microsoft has only recently begun to target for growth. We focus in this section on Microsoft, the leading independent operating systems vendor. As the other major enterprise O/S vendors are the Unix systems of the integrated enterprise systems vendors, we consider the impact on them in a separate section of this report.

Because Linux and Microsoft vie in the same market of operating systems for Intel-based hardware and because Linux provides an easier migration path off current Unix-based deployments, **we believe that enterprise IT departments that choose to move off existing Unix/RISC systems onto Intel-based hardware will invariably choose Linux**

as their operating system for that hardware. This shift will limit Windows' market opportunity in the data center for both its operating system and its applications that run on that platform. (Some have speculated that Microsoft might consider migrating some of its server-based applications to Linux in order to broaden its opportunity; however, this appears unlikely at this stage.) At the same time, we also believe that Linux is unlikely to take away much of Windows' current installed base, for precisely the same reason that Windows is unlikely to grab a large share of the Unix installed base—it is difficult to migrate from Windows to Linux or any other Unix, a factor that allows Microsoft to continue to build on its installed customer base. **It is also possible that Linux, by providing a lower-cost alternative to Windows in the market for Intel-based servers, could exert pricing pressure on enterprise versions of Windows.**

Although much mainstream attention has been paid to Linux as a replacement for Windows on the desktop, the operating system has yet to gain much real traction in this area. Initially, this was attributed mainly to the fact that Linux, with its original command-line interface and high learning curve, was too imposing for the average user. As more Windows-like graphical desktops for Linux like the KDE and GNOME environments have come to the fore, more attention has been focused on there so far being no adequate replacement for Microsoft's other dominant platform, the Office productivity suite. The Office suite is the main set of applications used on desktop machines in the workplace today, and its file formats have effectively become a standard in the computing world. As Microsoft has no plans to offer a Linux version of Office and as Office-compatible alternatives for Linux like Sun's StarOffice are often found wanting by many users, we believe the current lack of a widely accepted, fully Office-compatible productivity suite is the main factor keeping Linux from achieving traction on the enterprise desktop. **As a result, we do not believe that widespread displacement of Windows on the desktop is likely in the near term.**

At the same time, Linux on the desktop could see growth through a completely different avenue. We have heard of government agencies in Europe that are using Linux clients for e-government initiatives (particularly kiosks), where the only need of the desktop is to use a browser to connect to a series of e-government applications written with pure Internet-based thin-client technologies. In cases like this, no Microsoft Office products were being utilized, and there is no real reason for the client to be Windows-based. As a result, Linux desktops are being chosen in these instances primarily for their cost advantage.

Pure-play Linux vendors emerging, but more as service-providers

In terms of companies that focus on the Linux O/S itself, **we believe that the only viable pure-play Linux vendor is Red Hat, the market leader with more than 50% of worldwide market share.** The company has been the driving force behind Linux's growth as an enterprise O/S and has gained significant traction in the enterprise. This is primarily the result of its introduction of the Advanced Server version of Linux, the first enterprise-ready Linux distribution, and through its aggressive efforts to build partnerships around the product. The UnitedLinux consortium of Linux vendors (Conectiva, SCO Linux, SuSE, and Turbolinux) offers a comparable enterprise Linux distribution that is built on a single standard. However, while the Linux kernel (base O/S functionality) that both the Red Hat Advanced Server and UnitedLinux enterprise

versions are based on is standardized through a process centrally controlled by Linus Torvalds (the inventor of Linux), each enterprise distribution includes specific and differing extensions to the kernel that are specific to those versions, making them incompatible with one another for enterprise data center purposes. Software certified on one version is not assured of running on another. Thus, in effect, Red Hat and UnitedLinux are currently in a race to establish an enterprise “standard” for Linux.

We believe that Red Hat’s head start both in getting its product on the market and in forging partnerships with leading enterprise computing vendors has given it a significant lead in deployments and mind share that has in effect given the company the de facto enterprise Linux standard. We believe this gives Red Hat an advantage that UnitedLinux vendors will be hard-pressed to surmount.

At the same time, Red Hat and all other pure-play Linux vendors face the difficult proposition of carving out a business model around an open-source product that, by definition, does not allow them to protect the intellectual property and R&D dollars they have invested in it. As a result, it is very difficult to directly profit from Linux itself, and the value of a establishing the standard for a freely available technology is still open for debate. **Given these issues, we believe it is difficult for these vendors to build true, high-margin software businesses from the development, marketing, and sale of enterprise Linux products, even if they are able to brand the de facto standard. However, we do believe that Red Hat has found its niche and has built a sustainable model for itself as a service provider of software updates and system management solutions through its Red Hat Network (the true value-add it sells to customers with Advanced Server-based subscription) and should be valued as such.** In addition, the impressive array of vendors that Red Hat has partnered with to certify on Advanced Server is another differentiator, as customers have shown a willingness to pay for the assurance that any certified packaged software they run on Advanced Server will run without problems.

Hardware business models built on Intel-based architectures stand to gain the most

We believe that the primary driver for Linux adoption is the ability of companies to drive down IT costs by using Linux as the platform to take advantage of the price/performance advantage of Intel-based systems (see Exhibit 6). This may result in a server market that has characteristics more like the current PC market than the traditional enterprise server market. In addition, a standardized O/S across hardware built on the same processors also should result in less differentiation between companies and their products and more competition on price. Accordingly, **a transition to Linux in the enterprise data center will most likely strongly benefit the makers of Intel-based hardware, which includes both producers of the processors themselves and vendors whose servers are built around those processors.** These vendors have not had much of a presence in the enterprise previously, particularly in the data center, and stand to gain the most market share and revenue. Thus, we believe that the vendors that stand to benefit the most are independent processor manufacturers Intel, which has realized the potential that Linux has for its business and has heavily funded and supported Linux efforts, and, to a lesser extent, Advanced Micro Devices (due to its relative lack of OEM relationships). We also believe Linux will strongly benefit Intel-based server OEMs like Dell, which is the only

major enterprise server vendor whose entire product line is Intel-based and whose low-cost model will likely be a major selling point for enterprise buyers.

Exhibit 6: Intel-based server model contributes to significant price/performance lead over proprietary systems
results of TPC-C benchmark for comparable 8-processor servers available in the 12/00 to 12/01 time frame¹

Price/Performance Rank	Vendor	System	Processor Type	Price (\$)	Performance (unit: TpmC)	Price/Performance (\$/TpmC)	Database	OS	Date of system availability
1	Dell	PowerEdge 8450/900 DC	Intel Pentium III Xeon 900 MHz	\$591,071	69,901.74	8.46	Microsoft SQL Server 2000 Enterprise Edition	Microsoft Windows 2000 Datacenter Server	11/15/2001
2	Dell	PowerEdge 8450	Intel Pentium III Xeon 700MHz	\$495,610	57,014.93	8.70	Microsoft SQL Server 2000	Microsoft Windows 2000 Datacenter Server	1/15/2001
3	HP	HP NetServer LXr 8500	Intel Pentium III Xeon 700MHz	\$435,038	43,046.55	10.11	Microsoft SQL Server 2000 Enterprise Edition	Microsoft Windows 2000 Advanced Server	3/1/2001
4	NEC	Express5800/180Rb-7	Intel Pentium III Xeon 900 MHz	\$682,724	52,671.30	12.96	Microsoft SQL Server 2000 Enterprise Edition	Microsoft Windows 2000 Advanced Server	9/30/2001
5	HP	HP Server RP 7400	HP PA-RISC 8600 550MHz	\$1,065,085	60,366.82	17.64	Sybase Adaptive Server Enterprise 12.0	HP HP-UX 11.00	12/1/2000
6	IBM	IBM eServer pSeries 660 Model 6M1	IBM RS64 IV 750MHz	\$2,462,401	105,025.02	23.45	Oracle 9i Enterprise Edition 9.0.1	IBM AIX 4.3.3	9/21/2001
7	Bull	Bull Escala PL800R	IBM RS64 IV 750MHz	\$2,668,861	105,025.02	25.41	Oracle 9i Enterprise Edition 9.0.1	IBM AIX 4.3.3	9/26/2001
8	Bull	Bull Escala Epc 810 c/s	IBM RS64-III 500MHz	\$2,508,189	66,750.27	37.57	Oracle 8i Enterprise Edition v. 8.1.7	IBM AIX 4.3.3	5/28/2001
9	IBM	IBM RS/6000 Enterprise Server M80 c/s	IBM RS64-III 500MHz	\$2,523,482	66,750.27	37.80	Oracle 8i Enterprise Edition v8.1.7.1	IBM AIX 4.3.3	3/20/2001

Source: Transaction Processing Performance Council Web site (<http://www.tpc.org>).

¹ Goldman Sachs Research notes:

TPC-C is a measure of total system price/performance for database transactions administered by the Transaction Processing Performance Council. 8-way servers were chosen by Goldman Sachs Research as the systems for comparison because they are generally used only in data centers and are the traditional strength of the proprietary systems vendors. As no 8-way Unix/RISC systems were submitted for testing in 2002 and price and performance change rapidly over time, we have only included results from the Transaction Processing Performance Council's published results in the 12/00-12/01 time frame, to provide a more comparable sample of systems available to customers at one time (Intel-based systems have begun to come in with more attractive price/performance results in more recent tests). Note that the proprietary Unix/RISC systems, while lagging in price and price/performance, still produced better total overall performance. Part of this can likely be attributed to their use of 64-bit processors; servers built with Intel-based 64-bit processors will become more common over the next year.

TPC-C measures total system price and performance (both hardware and software), and the benchmark does not call for standardization of the software used across different brands of hardware. As such, it is difficult to use these results to categorically show that Intel-based hardware is the sole source of the price/performance advantage here, as the contributions of the software to both price and performance cannot be separated out. However, the large disparity in price/performance between the Intel-based systems and the proprietary systems provides a good indication that the hardware model contributes greatly to the advantage for the Intel-based servers, as does the fact that the four Intel-based servers in the benchmark (produced by a variety of vendors) came in at the top four spots. In addition, while part of the price/performance advantage for Intel-based systems comes from the lower price point and differing performance of MSFT SQL Server versus Oracle or Sybase, in all cases, the total cost for each of the systems in this comparison is still dominated by the hardware costs and performance is also generally more of a function of hardware. To provide a rough approximation, substituting Oracle 9i and its price point (approximately \$170,000 greater than MSFT SQL Server) on the Intel-based machines would result in a price/performance of approximately \$10.88/TpmC for the top-ranking Dell and \$14.06/TpmC for the HP NetServer LXr 8500, still appreciably better than the UNIX/RISC machines. However, it is important to recognize that this is a very rough approximation, as it makes the imprecise assumption that performance does not change in switching the DB.

The Intel-based servers in this comparison are running on Windows, as Windows was the only choice for Intel-based systems in the 12/00-12/01 time frame used for comparison. Linux has only recently added support for 8 processor systems and could not be used on 8-way systems submitted for the TPC-C benchmark during this period. However, for reasons outlined in this report, we believe Linux will be the main platform that enterprise IT departments will use going forward to take advantage of the price/performance advantage of Intel-based servers in the data center.

Systems vendors face new challenges but are defining Linux strategies

The corollary of the argument above is that the companies we believe will be most adversely affected by Linux are the traditional enterprise systems vendors like Sun, IBM, and Hewlett-Packard, which are the main purveyors of the Unix/RISC paradigm that Linux-on-Intel displaces in the data center. Exhibit 7 lays out the vendor-specific Unix operating systems and RISC processor architectures that these companies have used to build their proprietary solutions and tie customers into their platforms (RISC stands for Reduced Instruction Set Computing, which is a design principle underlying most high-end processor architectures). Of the traditional systems vendors, we believe the company likely to be most affected by the emergence of Linux will be Sun, which has only begun to articulate a clear strategy for Linux and whose entire business model has, to date, been built around the sales of the premium-priced proprietary Unix/RISC-based servers that Linux will ultimately displace. Overall, while the effects of Linux on the market are not completely clear-cut, we believe the emergence of Linux-on-Intel is more likely to result in a decrease in total server revenue for all the traditional systems vendors, given that Linux-on-Intel will (1) likely drive down price points much lower than those typically seen for more premium-priced Unix/RISC systems, due to both the price/performance advantage of the platform and the fact that customers using Linux will be able to increasingly pit vendors against one another on the basis of price, and (2) allow additional competitors to enter the market, as the barriers to entry into the enterprise server market will now be much lower.

Exhibit 7: Proprietary systems solutions of traditional enterprise systems vendors
different vendor-specific Unixes and RISC processor architectures have proliferated over time

Enterprise Systems Vendor	Proprietary Unix	RISC processor architecture
Hewlett-Packard	HP-UX	PA-RISC
	OpenVMS	Alpha
	Tru64	
IBM	AIX	POWER
		RS64
Sun Microsystems	Solaris	UltraSPARC

Source: Compiled by Goldman Sachs Research.

However, while Linux poses challenges, it will also create new opportunities. The emergence of Linux-based hardware platforms may create the potential for a larger addressable market and greater market share for some of these vendors, as the emergence of a Linux-centered market less balkanized by proprietary solution stacks means that companies can more easily begin to take share from one another than ever before, and the best solutions will be more likely to succeed. IBM, Hewlett-Packard, and, to some extent, Sun have diversified their businesses beyond their original hardware roots and have also clearly begun to account for the emergence of Linux in their business models. They have also thrown their support behind Linux to varying degrees and have all developed Intel-based servers running on Linux. For example, IBM has, in many respects, taken a leading role in the emergence of Linux in the enterprise, with more than 250 IBM developers in IBM's Linux Technology Center developing both applications for Linux and contributing to the development of Linux itself. The company is an advocate of Linux in all areas of enterprise computing, claiming a sizable number (about 4,600) of Linux customers across

every server platform and application line and porting Linux to many of its hardware lines (including traditional mainframe and RISC platforms, in addition to its newer Intel-based lines).

The other systems vendors have also realized that Linux will emerge in the enterprise in some form and have moved to embrace it to varying degrees. Hewlett-Packard has increased its focus on its relationship with Intel and its Itanium processor line (which HP helped develop) and has centered much of its server strategy on that architecture. In turn, the company has also been a strong proponent of Linux across its server lines.

In an interesting twist, HP has also ported its proprietary HP-UX Unix operating system to the Itanium line of processors, a move that would seem to give HP customers one of the main benefits of Linux—the ability to use a dependable enterprise Unix O/S on top of more cost-efficient Intel-based hardware—without having to migrate to a different O/S. However, as this situation keeps customers locked into HP’s proprietary platform when they now have an option to move to an open platform like Linux on the same hardware, we believe that this is primarily an interim solution for customers that use packaged applications not yet available on Linux. Given our belief that most major packaged applications will soon be ported to Linux and the relative ease of migrating from proprietary Unix systems to Linux, we believe that, in both this specific situation and in general, customers will tend to migrate to Linux when using Intel-based hardware.

Sun has also recently begun to embrace Linux and has released an Intel-based edge server, but it has mainly pushed Linux as a technology for lower-end edge functions and for the desktop (it also has plans to release a low-cost Linux based workstation). In addition, the company has begun to offer its own distribution of Linux, based on Red Hat’s product. However, the company has stated that it does not believe Linux is a data center technology and will continue to focus on its proprietary Solaris-based solutions in that area for the time being.

Experience in complete enterprise solutions may be continued advantage

Although we believe that most current systems vendors are likely to be hurt more than they are helped by Linux, additional factors could mitigate the negative impact. The central question that remains to be answered is whether Linux can commoditize the market for servers to the extent that Windows has commoditized the market for PC hardware, given that enterprise computing needs place heavier demands on vendors than do the demands of the PC market. Because most desktop applications do not come close to maxing out the resources of a desktop PC, performance is less a factor in PC purchases and price is the primary differentiator for hardware, resulting in the more commoditized market. It is less clear that this will completely be the case with servers, where customers consider factors like performance and service to a greater extent than desktop purchasers do.

Traditional systems vendors’ extensive experience in providing complete enterprise solutions for customers could continue to provide an advantage for these companies in a world with Linux, in four ways:

- With servers, performance is not only a function of the power of the processor itself, but also results from the supporting hardware infrastructure that vendors build into

their systems. These companies are likely to be able to transfer much of the knowledge and technology they have developed for their proprietary systems to their Linux-on-Intel-based systems. In doing so, they may be able to differentiate more on functionality than price, as their systems may have better overall performance than the products of server vendors that are only now entering the market. For example, traditional server companies like IBM and Hewlett-Packard currently have an edge in using their existing knowledge to offer large Intel-based multiprocessor systems (16 processor and above). In most cases, newer entrants have chosen to stay away from the technological hurdles of these systems and have chosen to focus on the mid-tier. Dell, in particular, has chosen to limit itself to 8-way servers and below for the time being, as the company believes that, given the price/performance of Intel-based hardware and newer technologies like database clustering, 8-way or smaller servers using Linux will be able to fulfill the majority of data center needs.

- Given enterprise IT buyers' strong emphasis on vendor support, the traditional enterprise system companies' experience in providing support to customers could give them an advantage over newer entrants that have not previously provided those types of services.
- Although Linux is a relatively new entrant in the market for enterprise operating systems, the proprietary Unix operating systems from the enterprise systems vendors have for years been providing the higher-end features like clustering, fail-over, and enhanced I/O that enterprise users require. These companies have been able to continue to add to and refine those features, while Linux is only beginning to implement the basic functionality. Although we believe Linux has made great strides and is enterprise-ready in its current form, it may turn out that the functionality gap between these enterprise O/Ss and Linux will take longer to bridge than many realize, to the benefit of the traditional system vendors that own and use those O/Ss.
- For the highest-end functions that demand top levels of performance or extra functionality from a single system, these vendors may be able to include proprietary hardware optimizations in their system architectures that raise system performance or add differentiated functionality. In doing so, it is possible that they would only provide access to this hardware functionality through their own proprietary OS/s. In this case, companies could conceivably continue to offer integrated proprietary systems that customers will show a willingness to buy, as the performance or functionality they can offer cannot be matched by other vendors. For example, Sun's N1 initiative, in which it is building specific features into its hardware and Solaris O/S to allow for pooling and sharing of resources between systems, can possibly be viewed in this light. Although the company is partnering with non-systems vendors for some N1 functionality, it has not to date discussed sharing the base N1 technology with other systems vendors. If successful, N1 could give Sun a more attractive proprietary feature for its Unix/RISC systems that may differentiate it in the more Linux-centered market we see emerging and continue to drive sales of its proprietary system stack. However, in general, we believe that the value proposition of Linux-on-Intel is very attractive and that higher-end applications requiring greater levels of performance will occupy a smaller part of the data center market. Accordingly, while proprietary systems may continue to rule in these areas, we believe the addressable market will be smaller and Linux will be a force in the rest of the market.

Fundamental drivers in place, but pace of adoption unclear

Widespread adoption of Linux in the data center will be primarily driven by the rate of server hardware replacement cycles. Trends such as server consolidation and adoption of J2EE-based application server architectures could accelerate the rate of Linux adoption, while a continued lack of support from packaged application vendors could serve as a drag.

Strong support from key vendors has increased enterprise visibility and viability

Although the operating system itself has been in existence since 1991 and a brief flurry of prominent IPOs around Linux in 1999 sparked initial interest in the technology, it is really only developments over the past three years that have laid the groundwork for a move by Linux into the enterprise market (see Exhibit 8). The support of key software, systems and hardware vendors has both spurred interest in the potential of Linux in the enterprise and worked to make the open-source operating system more “enterprise-ready.” These developments include:

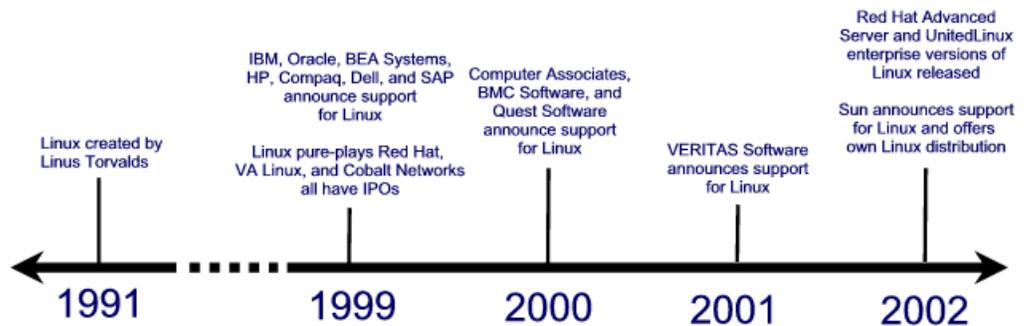
- Support for Linux by key infrastructure software vendors such as Oracle, Veritas, and BEA Systems.
- Continued technological development of enterprise versions of the Linux operating system itself, led by Red Hat and its Advanced Server product.
- Support for Linux by systems vendors such as IBM, Hewlett-Packard, and Dell.

The developments in these three areas have put all the necessary pieces in place for Linux to realistically be considered a full-fledged enterprise operating system, in our view.

Although Linux has been in existence since 1991, the pace of companies announcing support for Linux has increased significantly in the last three years.

Exhibit 8: Enterprise Linux timeline

increased vendor support has driven interest



Source: Goldman Sachs Research.

Still, adoption is likely to follow the slower pace of hardware replacement cycles

At the same time, these developments have led to a steadily building “hype curve” that has given many onlookers the impression that accelerated adoption of Linux in the

enterprise is just around the corner. However, in our view, adoption of Linux in the enterprise market will not take place at the rapid pace many expect, particularly in the data center. **We believe that the adoption of Linux by corporate IT departments instead is more likely to closely track the more measured pace of server hardware replacement cycles (generally recognized as spanning three to four years), as the main benefit of adopting Linux is the lowered hardware costs associated with Intel-based hardware.** Thus, while we believe that Linux's value proposition will lead to its widespread use and that Linux-on-Intel will become the dominant platform in the data center, we also believe most companies will not look to realize its benefit until the time comes to upgrade their existing systems.

However, this process could be slower than expected, given the glut of excess server capacity that currently exists from the IT spending bubble of the late 1990s and because it may take a number of "replacement cycles" for a full switchover to occur. It is likely that a large percentage of more conservative IT buyers will choose to stick with their existing platforms and only begin to switch to the Linux-on-Intel paradigm after seeing the clear benefits that early adopters realize in previous cycles. This sentiment is backed up by the results of our IT Spending Survey, in which there was a direct correlation between the 61% of respondents who had not yet deployed Linux and those who did not plan to increase their deployments of Linux in the next year, indicating the existence of a base of early adopters and a larger number of more conservative buyers who have not even considered Linux. We believe that, despite the clear benefits of moving to Linux on Intel-based hardware, **most mainstream CIOs will need to see Linux prove itself among early adopters before considering it for deployment.**

However, emerging trends could act as strong accelerators

At the same time, we believe the recent trend toward server consolidation and the continued adoption of J2EE thin-client architectures could serve as drivers for companies to replace or add to existing server hardware in advance of typical replacement cycles. These trends could accelerate the adoption of Linux significantly above the normal rate of hardware upgrades.

1. Linux's role in server consolidation efforts could serve as driver

Server consolidation efforts have emerged as a result of IT departments' desires to lower the total cost of ownership for the large number of servers that currently exist in most companies. The process generally involves moving functions previously run on their own separate, underutilized servers onto a single higher-performance, higher-capacity machine; for example, a number of file, print, and Web servers could be moved off independent machines and consolidated onto a single physical server. In doing so, companies are able to cut down on the number of physical boxes in the data center and lower administration costs, cut down on hardware maintenance contracts (which are generally signed on a per-box basis), simplify maintenance, and decrease the physical resources required to house and run multiple servers (including floor space and power).

More specifically, the availability of higher-performance, lower-cost Intel-based server hardware has increased interest in server consolidation, as the greater price/performance of these machines allows functions to be moved from a number of lower-performance machines onto partitions of a single higher-performance server. This,

in turn, allows companies to take advantage of the lower attendant maintenance and administration costs. Similarly, **companies have also begun to take advantage of IBM's port of Linux to its mainframe hardware for server consolidation** (as the source code to Linux is freely available, it is not limited to Intel-based hardware and can be adapted to any hardware or processor architecture). In some cases, organizations have moved simpler data center functions such as file, print, and Web servers off dedicated Unix machines and onto Linux partitions on the mainframe. We believe the cost-effectiveness of purchases of new mainframe hardware for the express purpose of server consolidation is questionable. However, the use of Linux partitions on mainframes does allow companies to extend the life and usefulness of existing mainframe hardware by employing unused processing power for functions that traditionally have not been run on the mainframe, while taking advantage of the benefits of consolidating servers into a single machine.

Given the current proliferation of Unix systems and their use for a number of functions and purposes in the enterprise, **companies may begin to use Linux on higher-performance/ lower-cost Intel-based hardware (and, to a lesser extent, on existing mainframe hardware) as a platform for server consolidation**, as the ease of migration from existing Unix systems to Linux plays a role in simplifying the consolidation process. Given the current economic climate and the hard look that many companies are taking at their IT budgets, the trend toward server consolidation has the potential to accelerate adoption of Linux beyond the constraints of the hardware replacement cycle, as companies weigh the total expected savings of the lower future maintenance and administration expenses against the upfront fixed costs of replacing existing server hardware with new deployments for consolidation and find that the trade-off favors immediate consolidation.

2. Move to J2EE server-based architectures could also hasten adoption

Another trend that could accelerate Linux adoption beyond the constraints of the hardware replacement cycle is a continued move to thin-client, server-intensive architectures, particularly those built on J2EE-based application servers. Such a model places more of the processing burden on the server than in current client-server architectures and implies an increase in the amount of server hardware deployed in the data center, which could increase the rate of server hardware deployments as these new Internet-based applications come online. Although the adoption of these new architectures has been slowed by a depressed IT spending environment that has inhibited deployment of new technologies, we believe widespread adoption of thin-client computing models will pick up together with a turnaround in IT spending; recent data points from BEA Systems and IBM have been positive on this front.

We believe that the use of J2EE application server-based architectures, in particular, favors Linux-on-Intel as the underlying server platform and that increased rollout of these architectures could accelerate adoption of Linux. J2EE-based application servers run on top of Java virtual machines, a technology that adds a "platform independent" component to the O/S by creating a standardized interface for software across hardware platforms and O/Ss that supplants the O/S-specific API. Programs are written to the J2EE application server rather than to a specific O/S; thus, a program can be run across different hardware platforms and O/Ss without being

rewritten. The application server platform also takes on many of the higher-level functions that have traditionally been rolled into the operating system, such as clustering and fail-over, returning the operating system to more of its original role as the interface between software and hardware.

The use of J2EE application servers allows applications to be portable across operating systems, which, importantly for Linux, lessens the importance of the choice of the underlying hardware and operating system. Such an environment begins to commoditize both the hardware and operating system to a greater extent, which favors the price/performance advantage of Intel-based hardware. The choice between Windows and Linux in this case is less clear, as the migration issues that are a key factor in Linux's advantage over Windows in the current data center models are mitigated by the use of platform-neutral J2EE application servers. However, at the same time, we believe it is more likely that customers will choose the option that they believe to be more familiar and dependable and drift toward the lowest-cost operating system when using J2EE application servers, which would seem to favor Linux over Windows.

Key risk to Linux adoption timeline could be slow rollout of applications for Linux

One of the most commonly cited barriers to Linux adoption in the enterprise is the current lack of packaged enterprise applications available for the platform. Most major application vendors have yet to officially announce their support for Linux; to date, SAP is the only major packaged applications vendor to do so. In our view, given that both the hardware and software infrastructure for running applications on Linux are in place, more and more customers will see Linux as a more viable option and will seek to realize the economic benefit of moving to Linux, and this customer demand will lead major application vendors to begin to port their products to Linux. In addition to being a boon for customers, this will also likely work to greatly increase the market for Linux systems. As the majority of application deployments on Linux are currently for in-house-developed custom applications, the continued rollout of widely used packaged enterprise applications on Linux should work to expand its addressable market in the enterprise.

Also, to some degree, packaged application vendors are partially constrained by their infrastructure software vendors (such as ORCL, BEAS, VRTS, IBM, SUNW, HPQ, etc.) as to which underlying operating systems they can target. The good news is that all these vendors have announced support for Linux and, in most cases, all their products will be fully available on Linux by mid-2003, paving the way for an ensuing increase in packaged application support.

However, as the introduction of packaged applications for Linux is both a sign that demand is reaching critical levels and a driver of increased adoption of Linux as a platform, **a prolonged delay in the rate at which packaged enterprise application vendors port their offerings to Linux could have a material impact on the rate of Linux adoption in the data center.**

The open stack: a framework for Linux investing

In the end, we do not believe there is a single “magic bullet” investment in the emergence of Linux, given that its effects in the data center are not confined to a single company. Instead, we believe that gains from the use of Linux will be spread over a group of companies, and the way to begin to look at the possible beneficiaries of Linux’s emergence is to consider the companies that make up the complete open software and hardware stack that Linux plays a large part in enabling.

Our definition of the open stack is one in which purchasing decisions about software and hardware can be made separately from one another. Linux enables this by providing a standardized and non-proprietary platform for software that can be used across any type of hardware, allowing customers to choose software and hardware on the basis of best fit for price or purpose.

Traditionally, companies like IBM and Microsoft have used their proprietary hardware and/or O/S platforms as the means to lock customers into their entire stacks of solutions. Linux facilitates an open stack that essentially prevents platform lock-in.

Exhibit 9: Examples of open-stack solutions likely to benefit from emergence of Linux

Functions	IBM Stack	MSFT Stack	Linux-based Open Stack
Application Server	WebSphere	Internet Information Server	BEAS
Development Tools	WebSphere Studio	Visual Studio	BORL / RATL
Host Security			SYMC / NET
Integration	WebSphere	Biztalk Server	TIBX / WEBM
Identity Management	Tivoli		VRSN / NETE
Network Security			CHKP / ISSX
Portal	WebSphere	SharePoint Portal Server	PLUM
Presentation Mgmt	WebSphere	Internet Information Server	BEAS
Relational DBMS	DB2/Informix	MSFT SQL/Server	ORCL
Software/System Testing			MERQ
Storage Management	IBM Total Storage	NT/Windows 2000	VRTS
Systems Management	Tivoli	MSFT SMS Server	BMC / CA
Transaction Management	CICS, MQSeries	MSFT Transaction Server	BEAS
O/S	OS390/OS400/AIX	Windows NT/2000	Linux (RHAT)
Hardware	IBM hardware	Intel-based	Intel-based

Source: Goldman Sachs Research.

As a result, while Linux can be used together with any type of hardware, we believe the primary driver for its emergence is the desire of customers to use it in conjunction with cost-efficient Intel-based hardware. Accordingly, we believe its emergence will most distinctly benefit PC semiconductor companies like Intel and Advanced Micro and Intel-based independent hardware vendors like Dell, as these companies stand to gain the most market share in such an environment. We believe the emergence of a Linux-centered open stack will have a more mixed impact on proprietary systems companies (Hewlett-Packard, Sun, IBM), which are adapting their business models to account for Linux but will be negatively affected by the displacement of their proprietary systems businesses by Linux-based platforms.

The emergence of Linux should also benefit “open” infrastructure ISVs such as BEA Systems, BMC Software, Oracle, and Veritas Software at the expense of infrastructure software companies with proprietary solution stacks, as software companies in an open-stack world can compete directly on the basis of price and functionality, rather than on control of platforms. However, an unknown for these companies is that widespread acceptance and adoption of Linux may lead to the emergence of open-source models in other areas of software, which may negatively affect overall software pricing. In addition, though we believe that Red Hat is well on its way to establishing a definitive standard for enterprise Linux and stands to gain from its emergence, it is primarily a service provider, not a traditional software company, and we believe it should be valued as such.

Advances in technology and server market data are key milestones to watch for

Investors can look to a number of key indicators to gauge the development and continued traction of Linux in the data center, including:

- Increased packaged application development for the Linux platform.
- Indications that Intel-based servers are increasing their share of total server revenues.
- Continued development of Linux to support multiprocessor configurations above and beyond its current eight-processor limit.
- Introduction and wider acceptance of newer 64-bit Intel-based servers.

Announcements of support for Linux from leading packaged application software vendors will serve as an indicator that demand for Linux is reaching critical mass among customers and, at the same time, serve as a driver for increased adoption of Linux platforms. However, as stated previously, slow uptake of Linux by these vendors could serve to hinder Linux adoption.

Similarly, continued indications that Intel-based servers are increasing their share of server revenues should, in part, indicate that Linux-on-Intel is gaining traction in the higher end of the enterprise. Gartner estimated that, in 2000, Intel-based servers accounted for 84% of shipments but only 35% of revenue, indicating that Intel-based servers dominate the low-end market but have little presence in the high-priced mid-tier and high-end markets. This number has trended upward, with Gartner now predicting that Intel-based servers will surpass proprietary RISC-based servers in revenues for the first time in 2003. Although the correlation between this number and Linux adoption is not direct, because some of these higher-end server shipments will use Windows or other O/Ss, we believe that this provides a more reliable broad-brush approximation than attempts to directly size the Linux market, as Linux’s freely available nature may make it more difficult to track its adoption through either vendor revenues or vendor product shipments.

More important, we believe that Linux is the main facilitator for the move to Intel-based servers from Unix/RISC platforms in the higher-end data center segments of the market and that an increasing majority of higher-end Intel server deployments will be on Linux in the future. Accordingly, we believe tracking the rise of high-end Intel servers will provide a good proxy for tracking Linux adoption in the data center.

On the technical front, the perception that Linux does not scale as well as other operating systems in terms of support for large, multiprocessor configurations has been a factor that seems to have kept enterprise CIOs from considering Linux for use in high-end data center deployments. Although we believe that different clustering technologies may have the potential to mitigate some of the need for large multiprocessor systems (later in this report we offer a more in-depth discussion of this topic), **continued development of Linux itself to support multiprocessor configurations above and beyond its current eight-processor limit should lead more CIOs to consider Linux and its value proposition in the data center.** As this is one of the most oft-cited shortcoming of enterprise Linux and because of the resulting focused development efforts on this front from enterprise computing companies and the Linux community, we believe Linux should continue to scale up in this way and should continue to add support for larger numbers of processors over the next two years.

Similarly, the introduction and continued development in the next year of servers based on newer, more widely supported 64-bit architectures from Intel (Itanium 2) and AMD (Opteron), coupled with prior announcements about Linux support of these platforms from both system vendors and Linux providers, will likely provide the marketplace with viable Intel-based 64-bit systems that will work with Linux. In general, we believe 32-bit processors (Intel-based processors' current sweet spot) will be all that is necessary for the vast majority of current functions. However, the release of these 64-bit servers running Linux should work to address another technical concern that has lingered in the minds of CIOs, namely that Linux does not support the 64-bit processors that are generally required to address the vast amounts of memory needed to raise the performance of large, high-end databases.

Other opportunities raised by emergence of Linux

Just as Linux raises many questions from an investment standpoint, it also raises many questions for, and opportunities in, surrounding technology areas. Obvious areas that will need to develop in tandem with the Linux O/S include security and systems management solutions, both to ensure that Linux is and remains enterprise-ready and because Linux itself can provide new solutions in both areas. The success of Linux also opens the door for other open-source software solutions; storage seems a likely next sector for open-source solutions to address.

Linux security is perceived as good, but management is still fairly new

As security concerns become increasingly prevalent in enterprise IT organizations, we believe that the security of Linux will be increasingly scrutinized. While Linux is often perceived as more secure, it is not necessarily any more or less secure than any other operating system straight out of the box. In general, customers are still faced with the same basic security issues, namely configuration issues, patch and version control, and monitoring how many and which network services are running. However, we feel some interesting features of Linux are worth noting from a security perspective.

- First, the open-source nature of the platform results in many developers reviewing the code base to look for potential flaws and submit patches where appropriate. This institutionalized peer review has resulted in relatively high reliability thus far. However, as we would expect from a fairly new operating system, flaws are being discovered and several new viruses, such as the SlapperWorm, that particularly target Linux have emerged over the last several months.
- Second, government initiatives promise to further increase the security of Linux. In December 2000, the National Security Agency (NSA) released its Security-Enhanced Linux (SE Linux) in an attempt to push security enhancements back into the Linux development community. SE Linux includes mandatory access control by confining the actions and domain of a given process to only the needed resources, functionality that is not found in other conventional operating systems.

Opportunities exist in management and high-security instances

The movement toward using Linux in more mission-critical areas of the IT environment increases the security management requirements. Immediate response to newly discovered security flaws is necessary, and customers will likely expect vendors to provide patch updates and support as issues arise. Given the nature of Linux and the proliferation of Linux vendors, this may provide an opportunity for companies that can manage the security across multiple vendors and O/Ss. In addition, for particularly security-sensitive customers, there appears to be an opportunity for vendors to take advantage of the open-source nature of Linux and enhance the O/S to produce specialized versions of Linux that have been hardened for high-security environments.

Systems management opportunities also exist in dealing with higher rate of change

Linux is gaining a reputation for simplifying the management and administration of servers in enterprise organizations, in part due to the features and nature of the operating system itself. The stability of the operating system and the generally rapid availability of bug or security fixes generally lead to less downtime to reboot or update the system. In addition, in cases where bugs are discovered and are a result of a specific system configuration, administrators can modify the operating system themselves to suit their needs or can lean on the open-source community to aid them in finding a solution. However, as fixes are generally available in real time as they become available, rather than being subject to the release schedule of a single company, additional complexity around managing the higher rate of change in the system is introduced into the systems management equation, one that has not previously existed to this extent with other platforms. **As such, the monitoring, alerting, diagnosing, and fixing of the system becomes more dynamic, and the need grows for systems management tools that can deal with the more fluid makeup and real-time nature of the Linux O/S.**

The success of Linux opens the door to other open-source software solutions

The emergence of Linux could show that open-source products can work in the enterprise and lead to the proliferation of open-source solutions in other software areas. We believe that if open-source solutions do move into new arenas, they will slowly work their way up the computing stack from the O/S and stay mostly in the domain of technology-focused infrastructure software. The next area of software we would look to after the O/S and Web server would be storage software, which is similar to the operating system in that it is a set of low-level technical solutions that manage computing resources and has a base of technical users with the skills to contribute to development. In addition, vendors that are proponents of Linux's development, such as Red Hat and IBM, have motivation to add this type of functionality to Linux itself to broaden its appeal to corporate users and have license to do so given Linux's open-source nature. Another area that has already seen the emergence of start-ups focused on building enterprise versions of open-source solutions is the intrusion detection area of security, where an open-source solution called Snort has emerged. Companies such as SourceFire have been funded to develop a more enterprise-ready version around the open-source technology.

We would monitor the storage sector closely to gauge the spread of open-source solutions into other software areas.

However, domain-specific software unlikely to follow this trend

On the other hand, industry-specific solutions like supply-chain management solutions or human resources applications require more non-technical domain-specific knowledge to implement and have user bases that do not have the technical skills or motivation to create their own solutions. In these cases, a software solution is not just about the technology itself but also about business processes that it works to enable, and writing a solution to address the problem requires intimate knowledge of both areas. Here, the user base with the knowledge of the business processes does not overlap much with the technical developer base, and the software vendors that currently possess the combination of business-process know-how and technical knowledge have little incentive to go open-source. **As a result, we believe that as one goes up the software stack, from technical infrastructure software products to more business domain-specific packaged applications, open-source solutions are less likely to emerge and pricing will remain intact.**

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Linux's enterprise emergence

Enterprise system vendors traditionally have developed their own enterprise O/Ss

A great deal of attention has focused on the emergence of Linux, primarily because, as an operating system, the technology sits at the junction of hardware and software and has the potential to affect companies in both markets. At its most basic level, an operating system (O/S) is the first layer of software that sits atop computing hardware and is a shared piece of software required by applications to interface with the underlying hardware. The core function of the O/S is to provision and schedule processing capacity and memory for specific tasks. As operating systems have evolved, they have also begun to take on additional functionality not directly related to their original role, and functions like network and systems management have been added to many operating systems. O/Ss in enterprise environments have also taken on additional functionality to meet the needs of enterprise users, and higher-level functions have been added to increase scalability and dependability, such as enhanced I/O (input/output) capabilities and multi-system clustering, fail-over, and load-balancing functionality

In their role in connecting software to the hardware that it runs on, operating systems are a key piece of technology in software development. New applications are written to use the application-programming interface (API) of a specific O/S, which is the set of commands that an O/S provides to give programs access to its functionality. This technological element has had a key business impact in the enterprise computing landscape, as enterprise systems vendors have often used their O/S-specific API as the lever to build and maintain their customer base. In effect, **systems vendors have used the API as a vendor-specific standard that makes it difficult for customers to move off the platform once they have begun to use applications that are optimized for that particular API.** This aspect of application development has led to a phenomenon called vendor "lock-in" that has been prevalent among enterprise systems vendors in the past, and critical to understanding part of Linux's appeal in the enterprise.

Unix is a generic term for enterprise O/Ss produced by systems vendors **Historically, vendors of enterprise systems have created their own proprietary operating systems designed to run on their own server hardware.** Although the term Unix is often thought to describe a single, unified operating system, the Unices currently in use are actually a family of independent operating systems that stem from a single 1971 Bell Labs creation. Although the different proprietary Unix systems originate from the same original source code and nominally share the same APIs, the internal mechanics of these systems have evolved separately, and the APIs have also evolved to take advantage of platform-specific features and optimizations. As a result, software written for one flavor of Unix will not necessarily run on another.

Software and hardware combination created vendor "lock-in" situation **Traditionally, these operating systems have served to both optimize the performance of the underlying hardware and provide for the vendor "lock-in" described above.** Before the advent of independent application software vendors, many systems vendors provided the entire enterprise technology stack; companies that are

thought of today as mainly hardware vendors provided both the computing hardware as well as applications that ran on their hardware and operating system. Enterprises that chose to use one company's hardware were also effectively forced to run their applications and their version of Unix, leading to a "lock-in" situation. Once customers were locked in, these systems vendors were able to charge a substantial premium for their complete solution.

The 1990s saw the rise of independent software vendors (ISVs) that produced applications that ran on multiple versions of Unix. These applications began the process of permitting enterprises to mix and match their hardware and O/S vendors with their application vendors; no longer were corporations forced to purchase the hardware and O/S produced by the vendor of their applications. However, ISVs were faced with the prospect of modifying and certifying their software for use on each of the platforms and also continued to face the prospect of competing with the inertia of the "locked-in" installed base of the integrated vendors. Customers also found themselves locked into platforms once they had written and bought software for use on them.

Linux is an open-source Unix that has had little enterprise presence

The Linux operating system is the brainchild of an individual, Linus Torvalds, who, as a graduate student at the University of Helsinki in 1991, sought to write his own version of Unix that would work on Intel's x86 hardware architecture. Although Mr. Torvalds was responsible for most of the initial development, the development process was soon opened up to users across the Internet, and the code base of the operating system came to be licensed under the GNU General Public License (GPL).

Under the GPL, the source code for the Linux kernel must be open, meaning that it must be made available, without cost, to be examined and modified by the public.

Developers who wish to improve on a piece of open-source code covered under the GPL or who wish to use pieces of GPL code in their own programs must also cover that work under the GPL, ensuring that the work remains in the public domain. This agreement has been a boon for the Linux technology itself, as it has allowed members of Linux's far-flung developer "community" to inspect and improve the code as they see fit; it has been one of the fundamental factors in the development of Linux to this point.

Although the licensing of Linux under the GPL means that anyone is free to modify the operating system itself or create and sell customized compilations of the O/S, the source code for those customizations is required to be freely available for download without charge. As such, while the GPL does not mandate that Linux must be "free software" in a monetary sense, its open nature makes it nearly impossible to protect any intellectual property invested into Linux itself and, as a result, to profit from work on the O/S. As the terms of this licensing agreement made the payoff for contributing to the Linux development process unclear to most corporations, the O/S has mostly remained the domain of a core group of hobbyists and academics who donated their time to improve on the world's most advanced free and public operating system, and enterprise and consumer adoption have been slow.

On the enterprise level, Linux, having been pieced together from the work of individual, far-flung programmers, has also until recently been viewed by IT decision makers as unreliable and of questionable origins. Technically, the O/S also lacked support for a variety of features required for enterprise-level computing, including

security, scalability, and centralized support. In addition, in the late 1990s, while the O/S was maturing, CIOs were under little pressure to rein in costs and were gladly paying the premium prices enterprise systems vendors were demanding for their complete system solutions, giving them little motivation to consider the economic proposition that Linux offers. **Thus, until recently, little attention has been paid to the use of Linux in the enterprise.**

Linux has been confined to its core community and the edge of the enterprise landscape

Linux is just now beginning to gain traction in the core of the enterprise and has had little penetration into the home user market. As a result, a relevant question is, where is Linux actually being used today? Linux's current installed base can be split into two constituencies:

- 1. The core Linux community is a knowledgeable group of users in the academic and technical communities and similarly technically savvy home hobbyists.** Linux can be found on the desktops of many of these users, and is used as the platform for a wide variety of functions, from desktop machines to personal Web servers to platforms for government-funded academic research. The ability to modify and customize both the kernel source code and the makeup of the components included with the operating system to their own tastes, for their own uses, is often something that these users find attractive, and this is the user group that most actively contributes to the development of the open-source operating system. Other factors that have led to the widespread adoption of Linux in these communities include its low cost and the similarity of the user-interface and application programmer interfaces (APIs) of Linux to the Unix systems on which many of these users have been trained, which makes the open-source operating system even more attractive to this group of users.
- 2. The "edge" of enterprise.** Linux has also gained a great deal of penetration into the world of enterprise computing, but has mainly been limited to the "edge" of the enterprise landscape. We would define the edge in this context in two distinct ways:
 - At the "edge" of individual companies' IT architectures.** When Linux's penetration into the enterprise is discussed as only beginning, it is generally accepted to mean that the O/S does not yet have much of a presence in the data center, the high-powered servers that serve as the platform for the back-room functions that drive many businesses. Although it is true that Linux has not yet gained much traction in that market, **Linux has a significant presence in the IT structures of many companies; however, that presence is limited to mostly non-mission-critical functionality such as file, print, e-mail, and corporate Web servers.** Because functions like e-mail and Web serving are services that users all over the Internet want, they have been widely deployed by members of the Linux community and have demonstrated their benefits. Thus, because Linux has already established its credentials as a stable and economical choice in these areas outside the enterprise community, corporate IT managers see little risk in deploying Linux for those same purposes within the enterprise and have adopted it in larger numbers.

- **Throughout companies that are on the “edge” of the traditional economy.** Although Linux is just beginning to gain traction with CIOs of traditional corporations, it has long been deployed in pure-play e-commerce companies that rely on technology as the basis for their business. Google and Inktomi, the two leading Web search engine companies, are examples of pure e-businesses that use Linux together with commodity Intel-based hardware to run the computing functions that form the basis of their businesses. The search engines, Web crawlers, and Web servers that combine to give Google and Inktomi their search capabilities are all run on Linux. Other high-profile e-business companies that have recently chosen to move their technology from Unix-based systems to Linux include Amazon, VeriSign, and E*TRADE. With these companies, the software run on their servers form the basis of the business, and these tech-savvy companies are choosing Linux as the platform on top of which to run their most mission-critical functions.

Higher-end Intel-based enterprise servers are a relatively new development

Against this backdrop of proprietary Unix systems and vendor lock-in in the data center and the maturation of Linux outside the core of the traditional enterprise, **higher-end servers using processors based on Intel’s processor architectures (including those produced by Intel rival AMD) have slowly have begun to gain traction within enterprise computing.** This has been a relatively recent phenomenon, driven by Intel and hardware vendors like Dell that have traditionally focused on the desktop and low-end server markets and that now wish to expand their addressable market upward into the data center, where RISC-based servers have dominated. The initial opportunity for these companies is immense in this market; Gartner estimated that, in 2000, Intel-based servers accounted for 84% of shipments but only 35% of revenue, indicating that Intel-based servers dominate the low-end market but have little presence in the high-priced mid-tier and high-end markets. That this number has trended upward, with Gartner now predicting that Intel-based servers will surpass RISC-based servers in revenues for the first time in 2003, shows the beginnings of a move toward Intel-based servers throughout the enterprise.

Although these servers generally provide greater performance at a lower price than the hardware sold by traditional enterprise systems companies, they have been limited in terms of the operating systems that run on them. Historically, these servers have run primarily on Microsoft’s Windows NT and Windows 2000 enterprise operating systems, and have found use in deployments of e-mail, print, and file servers. However, Microsoft has not attracted many enterprises to deploy their mission-critical enterprises applications on the Windows platform, due to perceptions about the dependability of the platform and the difficulty of moving from existing Unix platforms to Windows. Thus, because Intel-based technology has traditionally been wed to Windows, enterprise Intel-based servers have been taking only marginal market share from Unix vendors as the platform for the more mission-critical functions run in the enterprise data center.

Enterprise versions of Linux have only recently been created

As the market for Intel-based enterprise servers began to take shape, commercial vendors of Linux distributions like Red Hat, which had traditionally focused on the

consumer and small-business markets, began to see an opportunity for Linux as an enterprise operating system. In their view, Linux could leverage the advances in the Intel-based hardware that it had traditionally been written for to extend its reach into the enterprise data center, a market where proprietary Unix systems dominate. However, Linux had traditionally been targeted at the individual or small businesses and lacked many of the features required by enterprise users, such as high levels of dependability and scalability. As the traditional Linux developer community had scant interest in developing Linux for enterprise use, Linux vendors, in particular Red Hat, took the lead in the development of many of the required features. In the process, the company also entered into partnerships with a number of established enterprise vendors like Oracle, Dell, and Veritas, which had begun to grasp the opportunity that Linux in the enterprise presented to them and realized the opportunity they had to contribute to the development of the platform itself. As a result of these efforts, Red Hat released a fully featured enterprise version of Linux, called Advanced Server, in May 2002.

Provides the benefits of an expensive Unix while running on inexpensive hardware

As the rise of Intel-based enterprise servers and enterprise versions of Linux are relatively new developments, the spotlight has only recently focused on the potential in the enterprise of the Linux-on-Intel-servers model. Because of the novelty of Linux's open-source model, popular attention has focused on the fact that, as a freely available operating system, Linux has the potential to bring down IT expenditures on operating systems. Although we believe this is part of Linux's attraction, **we believe the fundamental reason for enterprise interest in the Linux O/S is that it provides an avenue to significantly bring down hardware expenditures.** Linux now offers a previously unseen combination: a non-proprietary enterprise-ready Unix that can also be used on Intel-based servers and has APIs that are in many ways identical to those already in use in the data center. Linux offers enterprises a relatively easy way to migrate mission critical applications from their previous Unix platforms onto a dependable operating system, one that, in turn, allows them to take advantage of the significant price/performance benefit of hardware built with Intel-based processors.

A closer look at Linux's value proposition

Recently, several high-profile product announcements around Linux by leading companies like Oracle, Veritas, and IBM, coupled with the release of more enterprise-focused versions of the operating system itself, have placed the spotlight squarely on Linux's move into the enterprise. Although many have attempted to position the story as Linux's continued penetration into the edge of the enterprise, we believe the real story with Linux is its emergence and possible domination within the computing landscape in the data center, generally defined as the mid-tier and high-end multiprocessor servers used as platforms for a variety of mission critical enterprise applications and databases. The data center is also the area of the IT infrastructure where the largest expenditures occur.

In our view, the real story with Linux is its emergence and possible dominance of the computing landscape in the data center.

Fundamentally, the story behind Linux's rise in the data center is not about the technology itself; instead, it is about what the use of Linux in the data center enables corporations to do. Namely, the three main factors that we believe will drive the continued ascent of Linux in the data center are (1) the cost savings that the use of Linux allows in server hardware expenditures, without a corresponding drop-off in system dependability, (2) the ease of migration from existing Unix platforms to Linux, and (3) the freedom of choice and economic advantage that Linux allows by breaking the product lock-in that is common in the current server computing environment.

The current situation in the data center: dependability is the foremost concern

Currently, the foremost concern for CIOs and IT decision-makers in purchasing decisions in the data center is dependability. For the purposes of this report, we define dependability as a single term that encompasses those traits of a system that allow it to approach the holy grail of the data center: the ability to boot up a functioning server in a back room and never touch it again. Traditionally, the definition of dependability has included a number of different distinct qualities, which are generally included with other qualities under monikers like "the -ities" or the "abilities." These include:

- **Stability:** CIOs are very concerned with how stable a platform is and how often and for how long they can expect their systems to crash for in a given year. The stability of systems is often measured in the number of "9s" a system can provide you with, which measures the percentage of total possible uptime a system can provide. For example, a system providing "two 9s" stability will be up and running for 99% of the year (which is equivalent to approximately 3.7 days of total downtime a year), while a system with "five 9s" stability can be counted on to be up and running at least 99.999% of the year (equivalent to a maximum of 5 minutes of total downtime a year).
- **Security:** Another aspect of dependability is the vulnerability of a system to attacks from hackers or viruses that can bring down corporate IT systems. Recent high-profile cases like the Nimda and Code Red viruses and denial of service attacks on a number of well-known e-commerce sites have highlighted the extent to which the lack of security of IT systems can affect the economics of corporations in general.
- **Manageability:** Manageability includes a number of different concepts that allow for easier administration and troubleshooting of systems in the data center. The

availability of easy-to-use, fully featured management tools can allow IT workers to quickly make changes to systems or troubleshoot crashes, reducing the amount of downtime needed to update or fix a system.

The traditional trade-off in the data center: dependability versus economy

Traditionally, corporate IT decision-makers have placed a high premium on the dependability of the servers in their data centers, as the economic cost to the company of server downtime can far outweigh any cost savings in software or equipment. This preference has been hard-coded into the economics of the data center, as the traditional choices for systems to use in the data center have generally forced buyers to choose between dependability and improved price/performance. Within this framework, enterprise IT decision-makers have generally shown a willingness to pay a large premium for safeguards against any system downtime. In the current landscape in the data center, which we describe below, **proprietary Unix/RISC servers have generally come out ahead when purchasing decisions have been based on these criteria,** and, as such, these systems currently dominate the market in the data center.

Mainframes: high dependability but lower price/performance

At one end of the spectrum of data center computing choices lie mainframe computers, vestiges of 1970s computing models that are still used, and are in fact prized, for their superior stability. The stability these systems can achieve is not the result of any inherent advantages of the mainframe computing architecture; rather, the stability of mainframes is mainly derived from their prolonged existence on the computing scene, which has provided ample time to iron out all the kinks in their implementations. However, these systems command extremely high prices relative to the performance they deliver and require somewhat specialized knowledge to maintain and administer. More important, mainframes do not interoperate easily with current client-server architectures, and many of the more recent packaged applications widely used in industry have not been written to work on mainframe architectures. As such, mainframes mainly exist in the enterprise to run legacy custom-developed applications whose stability and usefulness have given companies little incentive to move to newer architectures; however, mainframes have not traditionally been a viable choice for companies rolling out newer programs, due to the prohibitive cost of the hardware and issues with interoperability and portability.

Wintel servers: attractive price/performance, but dependability a concern

At the other end of the spectrum lies servers based on the “Wintel” model: systems using the Microsoft Windows operating system on top of server hardware based on the x86 architecture that originated with Intel. **While Microsoft on the operating system side, Intel and Advanced Micro on the processor side, and Dell, Hewlett-Packard, and IBM on the server side have made the data center a recent focus for these systems, they have not yet gained much traction in the high-end computing landscape.** This is primarily for two reasons. First, and most important, **despite the strides Microsoft has made in the area, there exists a perception among most CIOs that Windows has not yet achieved the dependability of other enterprise-targeted operating systems.** This has hindered adoption of Wintel servers, as the dependability of a server

is mainly determined by the operating system used to run it, while the price/performance characteristics of a system are mainly determined by the hardware platform. Thus, while Intel-based servers have the advantage of offering the best hardware price/performance combination on the market, the Windows operating system that the hardware has traditionally been wedded to has gained a reputation (deserved or not) for lagging in dependability in comparison to its competitors.

Second, because Microsoft and the Intel-based hardware vendors have only recently begun to target the data center, most companies currently have already developed and optimized applications for the Unix systems that are currently in use. Because these programs are based on completely different APIs (application programming interfaces, or the set of commands that an operating system allows software developers to use in their programs to access its resources) than those that Windows provides for programmers, they cannot be easily adapted for use on Windows without significant rewriting of the code. This fact, combined with the perceptions about dependability that surround the enterprise versions of Windows (Windows NT Server and the newer Windows 2000 Enterprise and Data center server products), has given CIOs little incentive to move from the Unix systems they use in the data center to Wintel systems, despite Intel-based servers offering a significantly cheaper price/performance proposition than either mainframes or Unix/RISC-based servers.

Thus, despite Microsoft's continued strides in tailoring its operating systems to the needs of the enterprise customer and its dominance in the desktop computer market, they have not yet been able to leverage that dominance into success in the enterprise market. This is true even though, if given a choice, many IT managers would prefer to run the same Windows systems they run on their desktop systems throughout their companies, to ease the administration and maintenance burden by standardizing on a single vendor's platform. However, the perceived instability of enterprise Windows and the difficulty of porting existing applications to the platform have hindered the acceptance of Windows in the data center and have, as an extension, also slowed corporate deployment of high-end Intel-based server products.

Current price/performance and dependability leader: Unix/RISC servers

In between mainframes and Wintel machines lies the true dominant player in today's enterprise platform landscape: high-end RISC-processor-based systems running proprietary Unix operating systems. These systems, produced mainly by IBM, Sun, and Hewlett-Packard, mirror mainframe systems in that they have been architected with the needs of the enterprise data center in mind, and they have been built with dependability as their foremost concern. While not quite reaching the dependability benchmark set by time-tested mainframe systems, their advantage over mainframes is that they have also been built to the specifications of today's client/server architectures and are thus more easily interoperable with today's systems and applications. In contrast, mainframes represent a different paradigm of computing in which all processing is performed on the mainframe rather than shared between the client and server, and many modern packaged applications are either not available for use on mainframe-based systems or must be specially redesigned for use with mainframes. In addition, the Unix/RISC systems have a distinct price and performance advantage over their mainframe counterparts and, while generally less attractive on a price/performance basis

than Wintel systems, provide superior dependability compared with those systems. **Because of this relatively superior combination of price, performance, interoperability, and dependability, proprietary Unix/RISC server systems have become the de facto systems standard in enterprise data centers.**

Linux does away with traditional trade-offs, while providing an easy migration path

Given the current situation in the data center, we believe Linux will eventually become the dominant operating system in this market for two reasons.

First and foremost, Linux completely changes the economic paradigm that currently exists in the data center. **The use of Linux allows IT organization to, for the first time, combine cheaper Intel-based hardware with a dependable, fully featured Unix operating system, one that is similar to the Unix systems they are already using. The use of Linux also disrupts the current platform “lock-in” situation that drives up prices and limits product choice.**

Second, **Linux’s similarity to the Unix systems currently in use in the data center, both in terms of its APIs and management skills and tools needed to administer it, provides for a relatively pain-free migration path from current Unix/RISC platforms to Linux/Intel.** Thus, we believe that the use of Linux no longer forces CIOs to choose between dependability and affordable hardware. In doing so, Linux creates a nearly irresistible economic proposition, one that can be easily realized in the data center due to the ease of Unix-to-Linux migration.

CIOs would rather deploy Intel-based hardware in the data center

All other factors being equal, CIOs would tend to choose a cheaper Intel-based server from any of a number of vendors over a single vendor’s proprietary RISC system. However, all other factors have not been equal in the data center, as different operating systems for different server systems have forced CIOs to either pay a premium for the superior dependability of the proprietary Unix/RISC systems or use cheaper Intel-based hardware but possibly risk greater system downtime. Linux gives IT departments an operating system originally tailored to Intel-based architectures that provides dependability on par with that of the various proprietary Unix systems. **We believe Linux is the missing piece that makes all other factors equal when choosing hardware in the data center and gives IT departments access to cheaper Intel-based hardware without sacrificing dependability.**

Linux’s open-source, Unix-like nature contributes to its dependability

At first glance, it would seem oxymoronic that an operating system originally developed by an amorphous “community” of programmers could be just as dependable as one developed in the controlled environment of a software company. **However, in what is quickly becoming the mainstream view of Linux, having the source code for the operating system available to so many programmers is actually a benefit.** The ability to easily examine, update, and modify the code base brings about the dependability that makes Linux attractive in the data center, as anyone from the community can check the code for errors and submit a fix. In addition, though any party is free to add extensions to the kernel (core functionality) of Linux, the development

process and release cycle for the standardized Linux kernel is tightly controlled by Linus Torvalds himself. Enterprise versions of Linux fold in additional extensions on top of the Torvalds-regulated kernel that are written both by the larger Linux community and by various enterprise IT vendors, are based on versions of the O/S that include only components that have generally proved to be stable and secure, have longer release and update cycles, and undergo additional centralized testing, all to provide customers with enterprise levels of dependability.

In terms of day-to-day administration of the systems, **the operating system's similarity to the Unix environments that it replaces is an advantage, as Unix administrators' skills and many tools that are already in use are easily transferable to the new environment, with little retraining required.** This situation can be contrasted with the scenario that confronts Windows as it attempts to penetrate the data center. There are fewer administrators with experience managing Windows in the data center, for the simple reason that it has not had a significant presence in that sector of the enterprise.

CIOs can now take full advantage of the economics of Intel-based servers **Thus, because Linux offers a dependable operating system that works with Intel-based servers, it does away with the price/performance-versus-dependability trade-off that traditionally led corporations to choose proprietary Unix/RISC systems.** In doing so, it enables corporate IT departments to now fully take advantage of the lower hardware costs of Intel-based systems in the data center, which comes as a result of two main factors. First, the Intel-based processor market is based on a high-volume, hardware-vendor-neutral business model pioneered by Intel that has led to significant cost efficiencies in the production of chips. That, combined with competition in the processor market between Intel and AMD, has dramatically brought prices down for the chips and allows these vendors to offer performance comparable to (or even better than) the proprietary RISC processors from Sun, IBM, and HP/Compaq, at lower cost. Second, because the Intel-based server market is built on top of Intel's vendor-neutral processor business model and sits underneath the vendor-neutral Windows and Linux O/S strategies, the servers offered are more interchangeable and less differentiated than those produced by the different proprietary Unix/RISC vendors. As a result, the market for Intel-based servers is more commodity-like, with buyers having the upper hand in the market and having greater flexibility in their product choices. As a result, customers can more easily pit vendors against one another and hardware makers are forced to compete more on price, bringing the cost of Intel-based systems down even further.

Gets rid of lock-in: Linux is truly an open-stack operating system

The use of Linux in the data center also presents another economic advantage to IT buyers: it breaks the product lock-in that often results from using the solutions of proprietary platform vendors. In the past, one-stop vendors offered an integrated, top-to-bottom solution of both the platform (the hardware and/or the operating system that the software runs on top of) and the software itself, with the software written to work only with their proprietary operating system APIs. Because the platforms were based on closed architectures (meaning that the inner workings of both the hardware and software were not available to other companies), the integrated vendors could use their intimate knowledge of features that only they could access to offer software products that were

“optimized” for their platform. Features were also built into the individual pieces of software to optimize them for use with one another.

Once locked into such a tightly integrated stack of technologies, customers often found it uneconomical to move to other platforms and unproductive to move to software solutions from third parties that did not integrate as well into the vendor’s stack as the vendor’s solution. This would lead to a self-perpetuating cycle in which companies would choose to stay on a vendor’s platform because the software already in use was part of the optimized stack and where they would also continue to use the software stack because the platform was already in place. ISVs competing in the same horizontal software markets as the integrated vendors encounter this type of inertia, effectively limiting their available market.

The use of Linux does away with this situation and allows for a truly open stack of independent products in which choices of software and hardware products can be separated from the choice of O/S. Linux uniquely provides for this, for two reasons. First, Linux is an open, independent technology that is not exclusively linked to any hardware platform and is governed under the GPL, which states that the Linux source code is always available to any party that wishes to use it. As no one can claim ownership of the Linux technology, the operating system cannot be exclusively used to the advantage of any one party. All Linux APIs are available for use by any piece of software, and any features added to Linux are available for use by any company, meaning that companies cannot leverage the platform itself or proprietary knowledge of closed features to provide an advantage for their software products. Second, because Linux can be adapted for use on any hardware platform (it is not limited to Intel-based architectures) and has a standard set of APIs, it provides a truly portable operating system that can provide an open, standard interface for software across all types of hardware. Applications can be written to a single platform, without regard to the underlying hardware that the O/S is tied to, and hardware decisions can be based more on need and cost rather than on compatibility with software.

The result of the use of Linux in the data center is that no single company can unilaterally leverage the Linux platform to the benefit of its products. In effect, as Linux continues to gain prominence, it levels the playing field for companies developing software and hardware for the data center. Software companies can develop for the Linux platform and can be assured that their programs will work across different types of hardware and that no other parties can derive any exclusive benefit from the platform. New hardware companies can enter the enterprise server market using standardized Intel-based processors and Linux as their O/S and introduce innovation in other areas. In such an environment, companies must compete solely on the pure economic and technological merits of their products. This is another positive for corporate IT buyers, as they are then free to choose best-of-breed solutions solely on their own merits, rather than having their choices dictated to them by the platform they choose to use.

The ease of migration also favors a move from Unix to Linux

In light of the economic advantages and freedom from lock-in that migrating to Linux allows companies to realize, the fact that a proprietary-Unix-to-Linux migration is surprisingly painless is another factor that favors the move. A number of factors contribute to this, including the ease of porting programs written for proprietary

Unix systems to Linux. This is because Linux and most proprietary Unix systems are nominally based on a common standard interface called POSIX. Thus, while Unix systems (including Linux) have evolved separately and have grown to include many specific features not found in other flavors, programs written for a POSIX-compliant Unix can generally be ported to Linux or any other Unix relatively easily, with companies needing to check for any platform-specific optimizations and functions in their code before recompiling it into a program that will run on Linux. In the current enterprise landscape, there has been little motivation to migrate from one Unix to another, as the proprietary systems were generally similar in price and performance and the benefits provided by any migration were most often outweighed by the costs. However, we believe Linux's value proposition and the access it provides to the price/performance advantage of Intel-based hardware is great enough to provide the motivation to make the migration.

Migration from Unix to Linux can be contrasted with the situation that occurs when CIOs choose instead to move from Unix to Windows in order to take advantage of the advantages of Intel-based hardware. Because Windows is based on an entirely different set of interfaces called the Win32 API, all legacy custom Unix applications must be extensively rewritten to allow them to work on Windows.

Unix-to-Linux migration is also made more palatable by the similarity of the skill set and tools for administering Linux servers to those used to administer current Unix systems, while the skills and tools for administering Windows differ greatly. We believe that as more and more CIOs realize the relative ease of migration from a proprietary Unix to Linux, it will remove another barrier to Linux's adoption and facilitate a greater move from Unix/RISC servers to Linux/Intel machines in the data center.

We believe this ease of migration from Unix to Linux is a factor that many studies of total cost of ownership have not accounted for completely. The cost of running and maintaining a Windows server may currently be slightly lower than that of running a Linux server when both systems are brought online from scratch. However, we believe that it is important to also factor in the costs, described above, that a transition from Unix to Windows entails when compared with a Unix-to-Linux migration. We believe these costs are significant and, as most existing companies will find themselves migrating functions from Unix-based systems when moving to Intel-based platform, it is a factor we believe is important to consider.

Support of key vendors is also a factor for enterprise customers

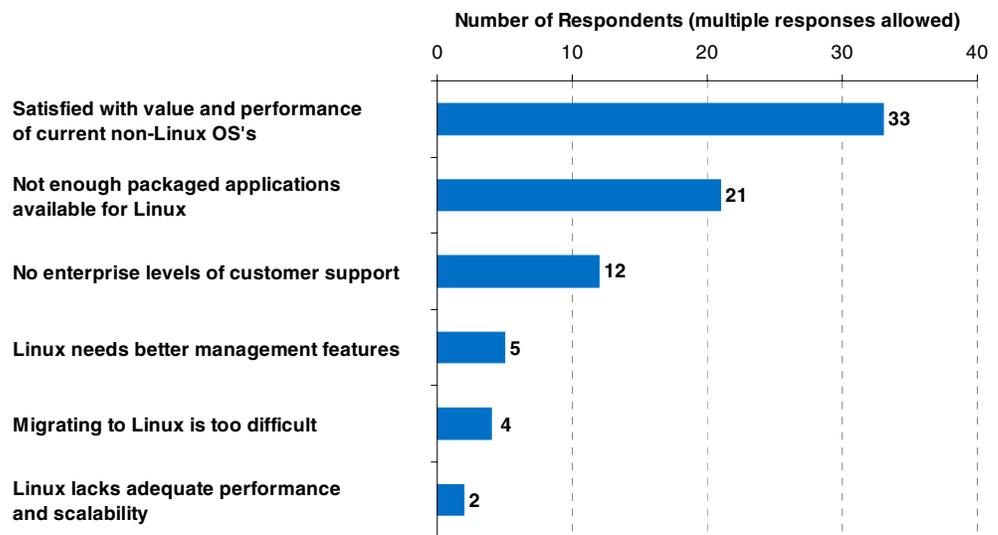
Also in Linux's favor is that leading enterprise hardware vendors like Dell, IBM, and Hewlett-Packard and top infrastructure software vendors like Oracle, BEA Systems, and Veritas have all thrown their support behind the operating system. This support is key, as these vendors' products are all required to deploy enterprise applications and enterprise customers would not consider Linux for their data center if these products were not available for use with the O/S. However, enterprise hardware and infrastructure software vendors have all recognized that the new economics that Linux puts into place in the data center are a driver for its adoption and have chosen to support the operating system for their products. As a result of this support, all pieces required for an enterprise platform—O/S, hardware, and infrastructure software—are now in place with Linux, and we believe it is now a truly viable choice for customers as an enterprise operating system.

Perceptions about barriers to Linux adoption mostly outdated

With more support and the release of enterprise-focused versions of the O/S, Linux has become a viable enterprise operating system, in our view.

Although we believe Linux in the data center presents an extremely favorable value proposition to enterprise CIOs, a combination of factors has held back its adoption in the enterprise. More than anything else, we continue to believe that the main barriers to Linux’s adoption in the enterprise market today are a lack of awareness about its benefits and an understandable “wait-and-see” attitude on the part of CIOs who wish to see extensive evidence of working deployments before taking the plunge themselves. However, other views on Linux have kept CIOs from considering it for their companies, many centering on the perception that Linux was not created for enterprise needs, both technologically and in terms of industry support for the product (Exhibit 10). Although we understand the reasoning behind many of the concerns and agree that the issues are legitimate concerns for corporations, **we also believe the recent groundswell of support of Linux and the release of enterprise-focused versions of the O/S have sufficiently addressed these concerns and that Linux has matured into a viable enterprise O/S.**

Exhibit 10: Largest barrier to Linux adoption is satisfaction with current O/S



Source: Goldman Sachs November 2002 IT Spending Survey.

Availability of packaged enterprise applications for Linux

IT managers point to the lack of Linux versions of popular packaged applications as one of the top reason not to move to Linux. Although we believe that this is something of a “chicken-or-egg” argument, it does have the potential to hold back adoption of Linux in the data center. **However, we believe that as more companies seek to realize the economic benefit of moving to Linux and as more of the infrastructure software companies whose products provide the platform for the packaged applications support Linux, packaged application vendors will realize that demand for their**

products on Linux is growing and will quickly port their products to the operating system. Further, as companies and application vendors continue to move to application server-based thin-client architectures like J2EE, application support of the operating system becomes moot, as the application server introduces an additional layer of abstraction between the application and the O/S. A packaged application written to a particular application server architecture will always work on that platform, no matter what operating system the application server is run on top of.

Enterprise-levels of support for Linux

For many corporate IT departments, the level of support provided by a software company for a product is a concern on par with the quality of the software. Because of Linux's open-source nature and the fact that there is no single company responsible for its development, many companies have shied away from Linux, as they feel that they would be left holding the bag when problems occur. However, a number of vendors that are closely in tune with Linux technology and the Linux development process, ranging from pure-play Linux vendors like Red Hat and integrated technology companies like IBM and Hewlett-Packard to pure hardware vendors like Dell and ISVs like Oracle, offer enterprise services and support along with their Linux software offerings. Although all these parties offering support for the Linux O/S may lead to confusion, the show of support from all areas of the industry is a positive and leaves customers only to choose which party to use as their source for support. **Thus, as companies begin to realize that enterprise levels of support for Linux exist and are being stressed by some of the leading enterprise computing companies, we believe this will become less of an impediment to adoption of Linux.**

Ability to deliver enterprise levels of performance

Another concern with the Linux was that it would be unable to provide the necessary levels of performance required for data center computing. In particular, until recently, Linux did not support the 64-bit processors required to address and use the large amounts of memory required by modern databases, while proprietary Unix/RISC vendors like Sun have been producing and supporting 64-bit processors for years. However, **versions of Linux supporting Intel's 64-bit Itanium architecture have already been released (although the processor itself has not received widespread support), and Red Hat has announced that it will provide a version of its Advanced Server product for AMD's upcoming 64-bit Opteron technology and Intel's more widely supported Itanium 2, making this issue of less concern in future.**

Detractors also point to the fact that Linux has not, and still does not, adequately support the large multiprocessor configurations that are currently the only way to run some of the large databases used in the data center. Current versions of Linux can only support up to 8-way (i.e., 8-processor) configurations, while proprietary Unix systems from traditional enterprise system vendors can support configurations of more than 100 processors in a single server. While it is true that Linux cannot support larger multiprocessor systems, development aimed at extend the multiprocessor capabilities of the O/S have been in the works. Given that this is the most often cited shortcoming of enterprise Linux and the resulting focused efforts on this front from enterprise computing companies and the Linux community, **we believe Linux should continue to scale up in**

this way and to add support for higher numbers of processors over the next two years.

In addition, the strides that have been taken to support newer clustering technologies, such as Oracle's Real Application Clusters (RAC) for database, on Linux could something of an offset to its current multiprocessing limitations. In this type of clustering, data and processing are spread among a number of separate one-, two-, or four-way servers to provide necessary levels of computing performance. With Oracle's RAC, applications treat the cluster as a single database, and applications written for traditional, unclustered versions of the database can be used with RAC without being rewritten. Although different forms of this type of technology has existed in the past, we believe it shows the greatest potential when it is used together with Linux and Intel-based hardware. In fact, we believe that, if these types of clustering technologies live up to their promise, they will contribute to Linux's advance in the data center.

Although there will always be a need for the functionality that large multiprocessor machines provide for certain high-end applications, in our view, continued development of database clusters such as RAC, in particular, will eventually do away with the need for these monolithic (single-system) symmetric multiprocessor (SMP) servers for the majority of applications, for two reasons. First, while the technology does not scale as seamlessly as monolithic SMP systems and will generally not work as well for applications that have high rates of data change, prices for monolithic SMP multiprocessor systems do not scale linearly as processors are added, while clusters do. A 32-processor server costs far more than 32 times the price of a single processor server or 16 times the price of a dual-processor server, while a 32-node cluster would cost approximately 32 times the price of the 32 single-processor servers used to create it. This economic advantage of clusters is compounded because the use of Linux allows clusters to be run on commodity Intel-based hardware, while most monolithic SMP multiprocessors available today are based on traditional Unix/RISC designs and pricing premiums. Thus, the use of clustering with Linux would allow companies to reap many of the performance benefits of multiprocessing without paying the premium cost.

Second, the more modular nature of clusters gives them a number of benefits over monolithic systems. They are more flexible and easily scalable, as servers can be added to a cluster as needed to provide more processing power. In addition, clusters have superior fail-over capabilities to monolithic SMP machines, as the individual nodes can fail independently from one another and the workload can be spread over the remaining nodes. Thus, due to its ability to combine the advantages of clustering with lower-cost Intel-based hardware to achieve enterprise-level scalability, Linux looks to have as much success in breaking scalability/price tradeoff in the data center as it has had in breaking the dependability/economy paradigm that previously existed.

Single standardized version of the operating system

The perception that a single company does not and cannot control development of Linux seems to have been the source of some concern for both enterprise IT departments and ISVs, although it was not mentioned in our survey. Multiple versions of Linux would result in the same situation as in the Unix world, with companies and ISVs forced to modify and certify their programs on each separate version of the O/S, and platform vendors would regain their ability to lock customers into their platform.

However, we believe that Red Hat, with the introduction of the Advanced Server version of Linux and its impressive array of partnerships with software vendors that have agreed to “certify” on the AS version, has decisively gained a considerable early lead in traction in the enterprise and has taken the lead in creating, in effect, an enterprise Linux standard.

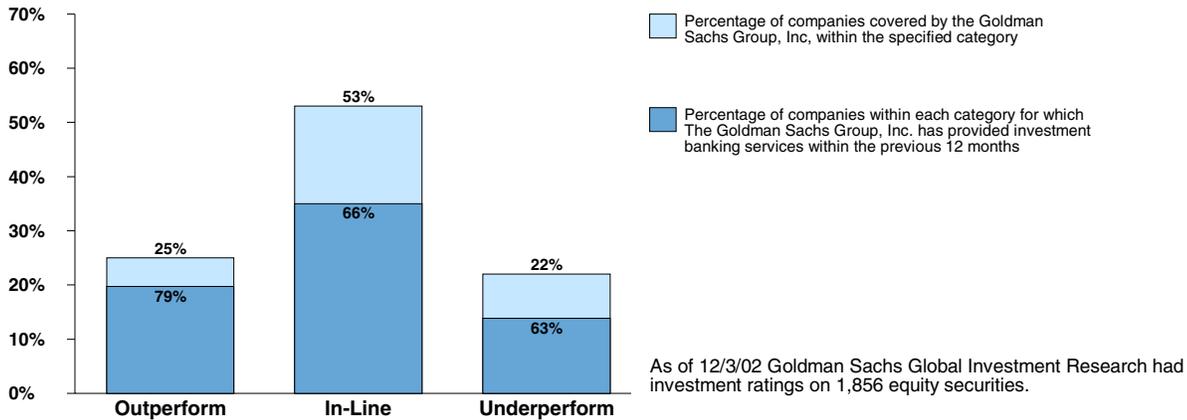
Although we believe that Advanced Server will continue to serve as the de facto standard for enterprise Linux, other efforts could challenge the standard Red Hat is attempting to create. A consortium of leading Linux vendors that have traditionally had larger presences overseas than in the US has released a common enterprise Linux standard called UnitedLinux that vendors can certify on. We believe UnitedLinux, made up of SuSE (Germany), Turbolinux (Japan), The SCO Group (US), and Conectiva (Brazil), will have a difficult time catching up with the lead Red Hat has already built, as Red Hat is the undisputed Linux market-share and brand-recognition leader, and its Advanced Server has gained significant enterprise traction since its introduction in May 2002, while UnitedLinux’s first common enterprise version was not released until November 2002. In addition, Red Hat has aggressively partnered and marketed with hardware and software vendors while UnitedLinux, to date, has been quieter on that front.

A more significant threat to a Red Hat-defined “standard” and Red Hat’s success in the enterprise may come from the platform vendors themselves. As Linux is open-source technology, there is nothing to stop hardware vendors from packaging and marketing their own modified distributions of Linux together with their hardware, providing a separate platform for ISVs to certify on. This has already begun to occur, in the form of Sun’s version of Linux based on Red Hat Advanced Server. However, we believe that demand from ISVs and customers for a single, standardized version of Linux will keep the operating system from fragmenting in this manner and that a single standard will eventually prevail.

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