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Explaining Adoption Patterns Of Process Standards

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EXPLAINING ADOPTION PATTERNS OF PROCESS STANDARDS

by

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ABSTRACT

This thesis investigates the adoption of process standards and consists of an introduction, a literature review, two theoretical chapters, a case study, and a conclusion.

The first theoretical chapter presents a model which examines equilibrium adoption patterns. The model incorporates heterogeneous agents who repeatedly choose which process standard to adopt. The agents' decisions are affected by economic processes within, as well as outside, the market. In contrast to the usual results of the literature on competing standards, inefficient equilibria are far less prevalent in this model. Interestingly, small changes in parameter values can have a large impact on the characteristics of the resulting equilibria in this type of model.

Chapter four extends the model developed in the previous chapter by adding a second country (or equivalently, industry). This chapter investigates the impact that adoption decisions in one country have on other countries under different levels of economic integration. It also investigates the effects that multinationals have on adoption patterns. The model predicts that adoption patterns will, in general, differ between countries when there are only local positive externalities. It also predicts that higher levels of integration between economies will increase adoption of generic standards (standards that can apply to firms in any industry or country), if the positive externalities associated with adopting it are global. The presence of multinationals increases the adoption of generic standards, as the multinationals act to economise on their adoption costs. Surprisingly, increases in the proportion of the population that are multinationals can reduce adoption of the generic standard for some ranges of parameter values.

Chapter 5 presents a case study of the adoption of process standards in the United States software industry. The theoretical results derived in Chapters 3 and 4 are used to explain the adoption patterns of software process standards. One finding of the case study is that the "chaos' and apparent redundancy of the many process standards co-existing in this industry serves a useful purpose. Furthermore, generic standards, such as ISO 9000, are unlikely to lead to substantial benefits from increased standardisation.

Key words: Process standards; Adoption patterns; Heterogeneity; Spatial Interactions; Software industry

For my mother, and in memory of Nan

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Chapter 1

Introduction

In 1987, the International Organization for Standardization released the ISO 9000 series of international quality assurance standards. This set of process standards is generally interpreted as providing a common international framework with which to assess the state of a firm's production technology.[1] By June 1994 over 70,000 organisations worldwide had successfully adopted one of the standards of this series (see Table 1.1). Over a half of these organisations were in the United Kingdom and another quarter were in Europe. The remaining quarter of the organisations were spread over the rest of the globe.

The ISO 9000 series of standards were developed to lower transaction costs.[2] The ISO believed that they would rationalise the seemingly "chaotic" situation

[1] Process standards are used for three, not necessarily independent, purposes: to produce information about the state of a firm's production technology; to decrease variability in the conformance of a good to the specifications of its purchaser; and to raise the quality, or lower the cost (by increasing efficiency of inputs employed), of goods that a firm produces. Process standards are used internally by firms, and externally in relationships among different firms. Many of the formal process standards that have been developed are used between firms and their suppliers.

[2] Ironically, the function of the standards is generally misperceived by most people. It is commonly thought that the function of the standards is to increase the quality of a firm's products per se. This is not the purpose of the standards. Instead, they were designed to lower transaction costs, in particular those associated with asymmetric information. Jacques (1990) discusses her experience when she was on ISO/TC 176, the ISO committee

where firms were commonly expected to conform to many different process standards.[3] The benefits of having a generic international standard were thought to be twofold. First, many different organisations, such as firms and national standards bodies, would stop needlessly developing and using their own standards. For instance, it cost an estimated $6.5 million for the Institute of Electrical and Electronics Engineers (IEEE) to develop their twenty-three software engineering standards.[4] There are 227 other process standards that also apply to the software industry. If we assume that the cost of developing the IEEE standards is representative of development costs in general, then these 227 standards may have cost as much as $640 million to develop. And this is for only one industry. Second, there would be substantial cost savings if firms had to adhere to only a single generic process standard, rather than many firm-specific or industry-specific standards. Thus, it was argued that a common standard would save resources and lower production and transaction costs by exploiting the benefits of standardisation.[5] But this argument ignores the benefits associated with variety. The existence of many process standards may reflect a desire for variety arising from the specialist needs of firms and industries that develop and use these standards, rather than that there are substantial standardisation benefits that have not been exploited. The chaos and apparent redundancy of the standards may exist for a good reason.

The previous discussion highlights an important issue that needs to be addressed: when can we expect a variety of standards to coexist, and when can we expect standardisation on only one standard? The adoption pattern of ISO 9000

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that developed the ISO 9000 standards. Randall (1994) and Price Waterhouse (1988) discuss the motivation behind the development of the ISO 9000 series.

[3] Johnson (1993, p. 27) reports that it is common for firms in the United States to adhere to a dozen different process standards.

[4] Tice (1988).

[5] See Peach (1992, Chapter 1) and *Quality Progress*, (1987), 3 (6), pp. 103-105.

Table 1.1
ISO 9000 Registrations by Region

Region	Jan 93	Number Sep 93	June 94
North America	1,185	2,589	4,830
Europe (excl. United Kingdom)	4,515	9,683	18,577
United Kingdom	18,577	28,096	36,823
Central & South America	39	156	533
Far East	683	1,583	3,091
Africa/West Asia	963	1,255	2,035
Australia/NZ	1,862	3,184	4,628
Total	27,824	46,546	70,517

Source: *ISO 9000 News*, (1995), 4 (1), p. 1.

in Table 1.1 highlights another issue concerning the adoption of process standards: what causes different adoption patterns to occur between countries and between industries? It is obvious that there are substantial differences in the adoption of ISO 9000 among the different regions. Different adoption patterns of process standards also exist among industries as well as among regions. We can, for example, contrast software with other industries. As was mentioned above, there are over 250 process standards that apply to the software industry. These include generic standards such as ISO 9000, industry-specific standards such as the Capability Maturity Model, and firm-specific standards such as the Trillium model (developed by Bell Canada). No one standard has become dominant. The United States auto industry has historically had only three process standards (developed by General Motors, Ford and Chrysler respectively) adopted by a significant number of suppliers. Recently, though, a common industry process standard, QS 9000, has been developed for the auto industry.[6] The development of QS 9000 has seen a widespread move by auto suppliers and the auto producers to abandon the firm-specific standards in favour of the industry standard. Suppliers of inputs in other similar industries, such as truck and construction vehicles, also appear to be heavily adopting QS 9000. In contrast to both the software and auto industries, the chemical industry appears to be increasingly adopting the general process standard ISO 9000, rather than industry or firm specific standards.[7]

Before proceeding further it will be useful to briefly discuss what a standard is, the different types of standards, and examples of process standards. What is meant by a standard? A standard defines the performance characteristics, either partially or fully, of a good or process. A standard that affects a good is the specification of the signal frequencies of television transmissions, as in the PAL, SECAM and NSTC standards. An example of a process standard is the code of conduct that a lawyer is expected to adhere to. An example of a standard that affects both the production process and the good itself is that concerning the production of concrete in the US.[8] This specifies what materials are used, how they are mixed, and how the concrete is dried.

David (1987) classifies standards into three types - compatibility standards, reference definition standards, and standards that specify minimal admissible attributes. He further subclassifies each of these into those that affect technical designs and those that affect behavioral performance. Process standards can be found in

[6] The QS 9000 process standard is based on the ISO 9000 series of standards, but has been heavily amended. It is specifically aimed at the auto industry and is far more comprehensive in its coverage than is ISO 9000.

[7] Merli (1991, pp. 149-152) briefly discusses the firm specific process standards, while Avery (1994) and Avery (1995) looks at ISO 9000 and QS 9000.

[8] Hemenway (1988, p. 193).

all of these categories. Professional licensing is a reference definition and behavioral performance standard. Safety standards specify minimal admissible attributes of a good, and therefore it's technical design. Those specifying commercial conduct, such as honesty, are interface compatibility standards that affect the behavioral performance of a producer.

There are many different examples of process standards and they affect many activities in many economic sectors. The automobile and software industries have previously been mentioned. Consider the health industry. The American College of Obstetricians has developed a 123 page booklet describing voluntary standard practices for obstetric and gynecologic services.[9] The Canadian Council on Hospital Accreditation in Canada and the Joint Commission on Accreditation of Health Care Facilities in the United States have each developed voluntary standards to which health care facilities in the respective countries can be accredited.[10] In 1985 approximately fifty percent of all Canadian hospitals had been accredited. The accredited hospitals accounted for over eighty percent of all hospital care in Canada. Approximately seventy-seven percent of all hospitals and 2800 other health care facilities in the United States in 1987 were accredited to the standards developed by the Joint Commission. The importance of these process standards is evident in the fact that third-party medical payers, such as Blue Cross in the United States, are increasingly using the accreditation status of hospitals in deciding payment schedules. Generic standards, such as ISO 9000, have also been adopted by health care facilities to assure the quality of their services in the United Kingdom.[11]

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[9] American College of Obstetricians and Gynecologists (1989).

[10] See Canadian Council on Hospital Accreditation (1985), Graham (1990), and Roberts, Coale, and Redman (1987).

[11] Lamprecht (1992).

Any person installing, maintaining, or altering electrical equipment in the United States typically follows standard practices contained in the National Electrical Code developed by the National Electrical Code Committee of the American National Standards Institute. When first developed in 1897 this code was voluntary, but since then, following it has become mandatory in most parts of the United States. There are even voluntary standards (not part of the National Electrical Code) specifying how electrical safety equipment in the United States should be made, used, and serviced.[12] For instance, standard F 496 developed by the American Society for Testing Materials specifies standard practices for in-service care of rubber sleeves, and standard F 123 provides descriptions of how to visually inspect rubber insulating equipment such as blankets, gloves, and sleeves.

These examples illustrate how important voluntary process standards are in most economic activities, as well as how widely they are used. Three questions concerning voluntary process standards come to mind. First, how are process standards written and how does the manner in which a process standard is written affect its properties? Second, what effects do process standards have on economic activity? Finally, once a standard is written will it be adopted and what factors will affect its adoption? Each of these questions is important since by far the majority of the process standards that have been legislated by governments were written by private sector organisations and had already been widely adopted prior to their being mandated.[13] While these are all worthwhile and interesting subject areas, this thesis addresses only the last question. In particular, this thesis addresses two issues concerning the adoption of process standards. First, when will process standards co-exist, and when will standardisation on only one standard occur? Second, when

[12] Cadick (1994, p. 2.21).

[13] See Hemenway (1975) and Utton (1986).

can we expect to see different adoption patterns between countries and industries, and when will the adoption patterns be the same?

The literature most naturally suited to answering questions about the adoption of process standards is that which focuses on the adoption of competing compatibility standards.[14] There are several assumptions that are "standard" in this literature. Models usually consider a small number of technological standards among which agents have to choose to fulfil a prespecified task. The choice is typically once and forever. It is also commonly, though not universally, assumed that agents choose sequentially. In addition, the net benefit of adopting a technology is assumed to increase with the number of agents who have already adopted the technology. This results from increasing returns to scale in production, learning by using, reduction in uncertainty about the payoffs of the standards, or the increased supply of complementary products. Consider what happens when agents have to choose between two technologies and there are increasing returns to their adoption. If the agents have perfect foresight and are capable of making side payments, then the socially optimal technology will be chosen. If the agents are unable to make side payments or lack perfect foresight then either technology can be chosen, but the equilibria typically have the property that the market share of one technology approaches one as the number of agents increases.[15] Empirical examples of these processes can be found in David (1985), David and Bunn (1988), Cowan (1990) and Cowan and Gunby (forthcoming).

[14] Compatibility standards are also known as uniformity or technological standards. A summary of this literature is given in David and Greenstein (1990). Representative examples of this literature are Arthur (1989), Cowan (1991), Farrell and Saloner (1985), and Katz and Shapiro (1986). Liebowitz and Margolis (1995) provide a critique of the standards adoption literature as it currently stands.

[15] Although Cowan and Cowan (1994), and David and Foray (1993) develop models in which different standards can coexist.

Process standards, however, have several features that distinguish them from compatibility standards. Usually many process standards coexist in an industry. In contrast, the typical result from the literature on the adoption of technological standards is that all but one standard is abandoned. In contrast to assumptions made in the technology choice models, agents repeatedly choose which process standard(s) to adopt. Potts (1993) reports that most firms are audited on average every six months to ensure that they are adhering to ISO 9000. On the occasion of each audit firms obviously have the choice of whether to continue with the standard, or whether to choose another course of action. Suppliers who adopt many other process standards such as the Target for Excellence standard are also audited periodically.[16]

In addition there are significant proportions of firms that adhere to multiple process standards or do not adopt any of the standards. Models of competing technological standards allow firms to adopt only one standard at any point in time. Modelling agents to choose only one technology seems reasonable in this instance since it is usually prohibitively expensive to use multiple technologies to produce a good or service. Process standards, however, serve a different purpose than technological standards and it is feasible that some firms may adopt more than one of them.

Finally, traditional models of competing compatibility standards ignore spatial aspects which can be important in determining the adoption of process standards. For example, some process standards can be applied across more than one industry, while others are industry specific. Traditional models assume that adopters exist in

[16] *The Globe and Mail*, (1994), 28 March, sec. B, p. 3.

only one homogeneous space. These differences between the two types of standards suggest that we cannot just reinterpret the existing results concerning compatibility standards to explain the adoption patterns of process standards.

As well as a lack of applicable theoretical results concerning the adoption of process standards, there have not been any empirical studies concerning their adoption either. This is in contrast to the adoption of compatibility standards, for which several empirical studies are available. This is a highly unsatisfactory state of affairs, since we know that process standards have several features that differ from compatibility standards. These differences imply that the factors affecting the adoption of process standards are probably quite different from those affecting the adoption of compatibility standards. It would be useful to know at what level of generality these differences turn out to be true.

It is obvious that existing models do not analyse the conditions under which a variety of process standards (as opposed to compatibility standards) will coexist, or conditions under which standardisation on a single process standard will occur. Nor does it address when we can expect similar adoption patterns of standards between countries or between industries, or when we can expect different adoption patterns to occur. In Chapters 3 and 4 I develop tools to address these two issues. It is worth pointing out that, in the spirit of Alfred Marshall, the models developed in these two chapters are designed to be an "engine of analysis" rather than "a photographic reproduction of the world".[17] In Chapter 5 I present a case study of the adoption of process standards in the United States software industry and I show

[17] See Friedman (1985, p. 232).

how the theoretical models developed in Chapters 3 and 4 are useful in analysing the "chaos" in this industry.

Chapter 2

Literature Review

The manner in which process standards are adopted touches upon four distinct literatures. Most process standards are designed to lower transaction costs that arise when an agent (typically the seller) has superior information about the quality of a good being traded.[1] The first section discusses why process standards are developed and used, drawing upon the literature analysing the implications and effects of asymmetric information. This provides a useful background for gauging which factors influence the adoption of the standards, and how they do so. At a first glance, we would expect that models analysing the adoption of technological standards may explain the adoption patterns of process standards. The similarities and differences between the two types of standards is the topic of Section 2.

[1] Process standards may also be appropriate when there exist barriers causing a suboptimal diffusion of technological innovations. Both Farrell and Saloner (1986b) and Cowan (1991) demonstrate that there may be instances where there is a bias to older technologies, either because of excess inertia or because the net benefit of the older technology is better known than the newer one. The latter affect will be heightened for industries in which it is difficult to measure productivity and quality. We could also expect suboptimal rates of diffusion when the technologies are embodied in the form of human capital. When firms have insecure property rights to their investments, such as training, they will expend fewer resources on them. Educational institutions may partly alleviate this problem if they teach up-to-date and specific rather than general material. A standard designed to transfer technologies among firms may consist of a list of state of the art production activities that a firm would be required to follow. It may even describe the technologies in some detail, in effect subsidising the adoption of newer technologies.

It is argued that this literature, while addressing an apparently similar problem, is deficient when trying to explain the adoption patterns of process standards. In particular, it is mainly concerned with conditions which cause inefficient equilibria, rather than trying to explain the many different adoption patterns of standards that we observe. The third section discusses a more general framework which encompasses the adoption of both types of standards. This is the literature which involves interacting agents. It is argued that this is indeed the natural structure with which to address the adoption of process standards, but some factors affecting their adoption pose considerable difficulties for standard techniques. Spatial considerations, which are prominent in the adoption of process standards, are one such factor. Finally, an agent choosing which standard to adopt is making a discrete choice. A discussion of the literature on discrete choices is the subject of section 4. While the problems addressed by existing discrete models have considerable overlap with the adoption of standards, the inability of this literature to generate aggregate results with interacting agents means that is not suitable for the problem at hand.

2.1 The Roles of Process Standards

2.1.1 Asymmetric Information

The major function of process standards is to lower transaction costs which result from asymmetric information. Standard economic analysis assumes that firms in an industry produce homogeneous goods and that all purchasers have full information about their characteristics. In reality, most goods and services have many attributes and firms within the same industry produce goods with different bundles of them.[2] Typically, sellers also have more information about the characteristics

[2] There are two types of characteristics. The first are vertical space characteristics in which the utility of a consumer increases with the amount of the attribute. Examples would be the fuel efficiency or comfort of an automobile. The second is durability. Quality in this case is measured by the time between the purchase of a good and its failure. Obviously the

of a good than the purchasers. For instance, Agriculture Canada recently discovered that an importer was selling a lower grade of olive oil than that displayed on the container's label.[3] Recently, there has been a major problem with poorly made fasteners in the United States. Counterfeit bolts have been found in M-60 tanks, aircraft carriers, and nuclear powered submarines in military products, and in freight vehicles, bridges, nuclear power stations, buildings, and small aircraft in civilian products. Several deaths, as well as many accidents and much damage, have been attributed to the substandard bolts. Suppliers of the bolts used fraudulent quality certificates and other misrepresentations to sell them.[4]

The presence of asymmetric information is related to the characteristics of a good or service as discussed by Nelson (1970) and Tirole (1990). There are three different types of goods based on the observability of their quality: credence; experience; and search. The quality of a credence good, such as health care, is never fully learned, even after consumption. The quality of an experience good is learned only after it's consumption. Examples are tins of tuna, or restaurant meals. The quality of a search good is perfectly observable even before purchase, but typically there is a cost to doing so. This implies that consumers are still subject to limited information since it is optimal for consumers to look at only a subset of the possible types in order to economise on search costs. Items of clothing or art are relevant examples. In practice most goods and services combine more than one of these characteristics. A baby stroller (from personal observation) is both a search and an experience good. Typically, one characteristic may be dominant and this dictates the classification of the good in question. The problems surrounding asymmetric

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utility of a consumer increases as durability of the good increases. Examples are lightbulbs and videotapes, both of which have finite lifespans. See Tirole (1990).

[3] *London Free Press*, (1994), 27 April, sec. C, p. 3.

[4] *Quality Progress*, (1990), 23 (3), p. 13; and *Quality Progress*, (1990), 23 (7), p. 12.

information are most severe in the case of credence goods and least severe for search goods. The nature of credence goods ensures that firms have a low probability of being caught cheating, creating a high incentive to do so. In contrast, low search costs ensure that firms have little incentive to cheat for fear of losing potential customers.

Two further factors affect the presence of asymmetric information. The more complex a good, such as a motorbike compared to say a bicycle, the greater potential for quality variation. In this instance there are more parts that can vary in quality in a motorbike than a bicycle. There are also more interactions among the parts of a motorbike compared to a bicycle. This increases the number of ways that the quality of an individual part can affect the quality of the motorbike. Furthermore, a motorbike has a greater possible range of performance characteristics compared to a bicycle. The cost of assessing the quality of a good also increases with it's complexity. For instance, assessing medical services can be exceedingly costly for an individual as it requires a large accumulation of human capital to understand the technology being used. The presence of asymmetric information is also related to the stability of both an industry and the good produced. A good which is undergoing rapid technological change, such as a computer, or is subject to a high turnover of firms, as in restaurant meals, increases the potential for information asymmetries and quality variation. If the definition of a good is changing rapidly it is more costly for consumers to ascertain it's quality since knowledge about it is less readily available. This implies that knowledge accumulated in the past about what a computer is and does, and hence what is meant by a low and high quality computer, quickly depreciates. There is also less certainty about what constitutes a high and low quality good because there is uncertainty surrounding the performance characteristics of the good, especially if it is at an early stage of development. A rapid turnover of firms lowers the incentive for consumers to invest in ascertaining reputations of firms, since benefits of such an investment flow over a shorter period.

In an illuminating article, Akerlof (1970) drew attention to the consequences of removing the two assumptions of homogeneous goods and perfect information. His model includes four types of cars: new or old, and good or bad. Consumers know which cars are old and new, but they do not know which are good or bad. They do know that a new car is good or bad with probability q or $1 - q$. The parameter q is taken as exogenous. Sellers of old cars are assumed to know their own quality. Since consumers cannot ex-ante distinguish between good and bad old cars, they sell for the same price in equilibrium. This means that only bad old cars are offered for sale. Owners of good old cars are better off consuming them than offering them for sale, since they cannot get their full value due to the averaging process determining equilibrium prices. In this case, only low quality goods are offered for sale, which is socially inefficient. This is an extreme example of adverse selection on the part of the sellers. Even when equilibrium is defined to include the constraint of asymmetric information there is still the potential for inefficiencies as noted by Hemenway (1975, pp. 47-49). Markets usually undersupply information because it is a public good and it is difficult to ensure that all those who benefit pay for it.

Even with the existence of asymmetric information, it is still possible that prices may optimally co-ordinate quantities supplied and demanded of a good. Wolinsky (1983) demonstrates how under certain conditions differences in prices can signal differences in qualities. Consider an industry with many consumers and conditions such that at least two firms can produce each quality. Firms incur higher costs to produce higher quality goods, and consumer's utility increases with quality. Consumers can visit as many firms as they like but they pay a small cost for each visit. Next assume that consumers receive a noisy but informative signal about the quality of a firm's good while visiting it. With this setup, consumers can form expected price schedules that assign a single quality to each price. It can then be shown that there exists a separating equilibrium in which this schedule is consistent with the actual outcome. When consumers repeatedly purchase the good, then there is a unique separating equilibrium. The assumption about receiving informative signals is important because it allows consumers to identify "cheaters" in out of equilibrium situations. This then supports the equilibrium outcome of prices signalling qualities. This result depends crucially on the informativeness of the signals. If they are too noisy then we are back to the Akerlof situation. Situations where it is likely that prices would signal qualities involve common consumer goods which are not undergoing much innovation and the industry producing them is stable.

The model of Wolinsky highlights two things. First, it shows that asymmetric information issues are really questions about signal extraction. Can an agent draw enough information out of a given situation, even if they do not know everything? If yes, then the resulting prices will be able to co-ordinate the actions of agents. If no, then we need other mechanisms to overcome the effects of the information asymmetry. Second, non-price interactions are important in markets. The only reason that prices can work in the Wolinsky model is because consumers can interact directly with firms and obtain useful information about them. This feature is typically not captured in conventional models and its importance in explaining many types of economic phenomena is taken up in Section 3.

Table 2.1
Mechanisms Commonly Used to Alleviate the Effects of Asymmetric Information

Developers of Mechanisms		
Individuals	**Industries**	**Governments**
Reputation formation	Grading	Subsidising information production
Warranties	Licensing	Labelling requirements
Guarantees	Standards	Right to sue
Conspicuous initial expenditures		Standards
Second-party audits		Licensing
Product testing		
Specifications		

2.1.2 Mechanisms Used to Reduce Asymmetric Information Problems

The presence of asymmetric information between buyers and sellers appears to be a common feature of everyday life. This implies that trade should be severely restricted. Yet we see an enormous range of goods and services being traded in seemingly well functioning markets. Why aren't markets more adversely affected? The answer is that several mechanisms have been developed to mitigate its effects. See Table 2.1 for some examples. A process standard is one such mechanism and can be developed by any of the three groups listed in Table 2.1.

Mechanisms Available to Individuals

These tend to fall into two types, either signalling the quality of the seller or screening low quality sellers from the market. Examples of signalling mechanisms are warranties and guarantees, conspicuous initial expenditures, and investment in reputation capital. Examples of screening mechanisms include conducting second-party audits of sellers, and using specifications in contracts.[5] Process standards may be of either type, but the majority are used to screen low quality firms.

One example of a process standard used by a firm is the 1979 quality assurance certification program instituted by Caterpillar.[6] It uses the standard it has developed to audit the processes employed by its 5,000 suppliers to ensure that each supplier can manufacture products that will conform to specifications, that they can deliver products on time, and that they can meet cost agreements. The standard is also being used to audit the processes of internal divisions of Caterpillar. Having each supplier, and internal division, conform to the same standard reduces variability in the quality of parts and assembled products. It also saves on transaction costs since they are all "talking the same language".

Three examples of mechanisms in this category have been studied by Heinkel (1991), Grossman (1981), and Shapiro (1983). Heinkel investigates the situation where consumers have an imperfect testing technology. In his model there are two sellers who are Cournot competitors, and they can each take an action to increase the quality of their good. One seller is assumed to have an inherent cost advantage in producing a good of a given level of quality than the other. Consumers cannot discriminate ex-ante the quality of the goods offered for sale. But, they can test the goods after purchase, although it is assumed that the results are not fully accurate. A seller that is found to have sold a good that is significantly below the average market quality incurs a penalty. Heinkel solves the model computationally, after assuming parameter values, since it cannot be solved analytically. As expected,

[5] There are three types of audits. A firm auditing itself is defined as first-party. Second-party are when a buyer audits a seller. Third-party are when a party independent of the transaction between buyer and seller audits the seller.

[6] Black (1993).

welfare with the testing technology is higher than without it, although it is not as high as the perfect information case. Welfare is concave with the size of the penalty, the accuracy of the testing technology, and the size of the region of the test statistic for which a penalty is imposed on a seller. This concavity reflects the fact that at extreme values of these factors any increase in consumer surplus from an increase in quality of the goods can be dominated by the expenses incurred by the producers, or vice versa. This reflects the assumption of diminishing returns to efforts by sellers to increase the quality of their good. These results are also dependent on the quadratic functional forms assumed for production costs and consumer benefits. Heinkel finds that altering the form of these functions can lead to very different results, such as welfare being a convex function of factors such as the size of the region for the test statistic for which a penalty is imposed on the seller.

Grossman studies the effects of private disclosures and warranties (which are a form of indirect disclosure). He assumes that there are many identical sellers who can make ex-post verifiable disclosures, such as doctors who can say which medical school they went to and their class standing. Assume that communication and verification costs are negligible, and that the disclosures have to be truthful. How much truth do sellers tell? Sellers with a bad product say nothing, whereas those with a good product say a great deal. In this framework, consumers rationally expect the quality of sellers to be the poorest consistent with their disclosure. Sellers know this and therefore disclose the highest possible quality consistent with the truth. This allows consumers to discriminate the quality of sellers in equilibrium. Now assume that communication and verification costs are prohibitively large, but that there are many sellers and they can each issue a warranty in case of product failure. In this case full warranties are issued by the sellers, which is Pareto optimal. This occurs because sellers that do not offer full warranties are treated by consumers as being of low quality. This assumes that consumers know the distribution of failure rates across firms. For obvious reasons, less than full warranties are issued when moral hazard is present on the part of the consumers.

A widely used source of information about the quality of firms is their reputation. This mechanism is studied by Shapiro. Assume that consumers can judge the quality of a good only after purchasing it, that they obtain more utility from higher quality goods, and that the costs of producing a good increase with its quality. In this situation it can be shown that there exists a steady state equilibrium where firms maintain their quality over time, consumers expectations are fulfilled, and price as a function of reputation is unchanging over time. How does this happen? Initially firms sustain losses by producing at high quality and being paid a low quality price while building up their reputations. Once established, they earn a return on their reputation investment by receiving a price above the cost of producing their good. The premium a high quality producer commands is high enough so that it does not want to damage its reputation by producing lower quality goods, but low enough so that no new firms wish to enter. Although the price received by a firm is above its marginal production costs, the difference reflects transaction costs due to the asymmetric information so there are no above normal profits being earned by the firm. The longer it takes for a firm to establish its reputation, the higher the premium needs to be for a firm to earn the same return on its reputation investment. Three assumptions are important in determining the results of this model. First, a firm must be able to establish its reputation within an economically useful period. Second, each firm must experience many purchases. Third, it is assumed that information about each firm's reputation is common knowledge. How it comes to be so is left unanswered. Trade and consumer journals may be one source of pubic information. An important source is likely to be word-of-mouth communication between consumers through their non-market mediated interactions.

Industry Mechanisms

In some cases it is optimal for producers in an industry to impose a mechanism on themselves, or on other industries.[7] Two such mechanisms are grading, and developing product or process standards. Industry mechanisms may be used when externalities are present. Hemenway (1975, p. 75) details how the American Gas Association developed a series of standards for gas appliance manufacturers in the 1920s. The quality of the appliances directly affected the demand for a complementary good, in this case gas. Hemenway (pp. 70-71) also reports that both zinc and brick manufacturers imposed minimum industry quality standards in the 1920s. Individual sellers in both industries were adulterating their products, adversely affecting the reputation of all sellers. As a result of the adulteration, demand had decreased for these products and increased for close substitutes, such as tin and copper, and cement. In this case buyers were forming and using beliefs about weighted industry quality in their purchasing decisions. Thus, individual sellers could increase their profits by free-riding on the efforts of other sellers. The seller obtained the price commensurate with the average quality in the industry, but reduced its expenses by lowering its own quality.

An example of an industry process (and product) standard is the American Softwood Lumber Standard PS 20-70 developed by the American Lumber Stan-

[7] These mechanisms may also be used for anti-competitive reasons. Safety standards, for instance, may reduce international trade by increasing entry costs or reducing potential benefits from economies of scale.

dards Committee (ASLE).[8] It is a product standard because it specifies the grades assigned to different types and qualities of wood. It is a process standard because it specifies how inspection agencies (such as Western Woods Products Association in the North-Western United States) are to grade wood, and how the ASLE is to inspect the inspection agencies. There is no law requiring a mill to adopt the standard, but for many purposes it is mandatory because the wood from a mill requires the ASLE stamp to be used under United States building codes. The standard was developed to promote uniformity among producers, so that users of wood could buy standardised grades. It was also developed to assure buyers that they were getting a quality consistent with the claims of the sellers. Without grades and an effective enforcement mechanism, sellers have an incentive to adulterate their product as the following example of Hemenway (1975, p. 72) amply highlights. United States lumber producers during the 1920s reduced the size of a two-inch board by three-eighths of an inch, and raised the moisture content of lumber in general. An individual producer had an incentive to adulterate their product because they could save on transportation costs and/or free-ride on the superior quality efforts of other producers.

Minimum industry quality standards are studied by Leland (1979). He develops a model of an industry that consists of a continuum of heterogeneous sellers, their quality denoted by their position on the unit interval. Consumers are represented by an inverse demand function. It is assumed that consumers do not ex-ante know the quality of an individual seller, only the average industry quality. If a minimum quality standard is set exogenously (say by a government), then welfare may be increased. This can occur if consumers are very sensitive to quality variations, there is a low elasticity of demand, there is a low marginal cost to producing extra

[8] Epley (1982).

quality, and a low value of low quality sellers. The standard increases the market price for the good by keeping out low quality sellers. This induces higher quality sellers to enter the market. Both effects increase average industry quality. Welfare increases when the benefits to increased quality outweigh the effects of the price increase. In contrast, the quality level of the standard may be set too high when the industry can choose it. In this case the industry uses the standard to collectively act as a monopoly.

Government Policies

Governments, at best, have no more information about the quality of firms than consumers, however they have a range of policies unavailable to individuals. These usually take the form of legislated controls on the actions of producers. These policies are normally implemented when there is a co-ordination failure in the market provision of other mechanisms. This commonly occurs when any information produced has a high public good content, externalities are present in the effects of individuals actions, and excessive transaction costs hinder the formation of contracts. In these cases the equilibria are inefficient even taking into account the presence of asymmetric information. Policies include subsidising the production of information about goods and services, developing labelling requirements, developing standards and licensing requirements, and establishing means of legal recourse from sellers who misrepresent their products. Examples of government mandated process standards are those developed and enforced by Transport Canada since 1969 for air carriers that use large airplanes. These standards provide requirements and guidelines that air carriers have to follow, including: what to do in an emergency; how air carriers should train air and cabin crews, and minimum training requirements;

the maximum amount of air time allowed for air crew; and what actions air carriers should take for different weather conditions.

The effectiveness of producer liability schemes is analysed by Spence (1977). He considers an industry that consists of perfectly competitive sellers who can alter the failure rate of their goods. Consumers are identical and they are characterised by a von Neumann-Morgenstern utility function. They may misperceive the failure rates of the goods, that is they do not have sufficient information to form reliable estimates of the failure rates. A seller can offer warranties to the buyers in case their good fails. When consumers are risk averse, seller warranties are insufficient compared to the first best outcome. They do not fully compensate buyers for failed goods, and they do not provide enough of an incentive for sellers to take optimal actions to reduce their failure rates. Spence shows that introducing a scheme whereby sellers are also liable to the state for failed goods, as well as warranties, restores the first best outcome. The liability in the scheme corrects for the misperceptions of the failure rates thereby providing the right incentives for sellers. Unfortunately, the government, in implementing the scheme, is required to know the utility functions of consumers, the degree to which they misperceive the failure rates, and the producers cost functions.

Carol and Gaston (1983) provide details of licensing schemes for television repair persons that were implemented by three United States municipal governments. They clearly demonstrate how government intervention can be effective in alleviating the effects of asymmetric information, and also how sensitive the effects of the schemes are on their design. New Orleans implemented a strict licensing scheme where the repair persons had to pass a strict examination. The municipal government of San Francisco randomly tested repaired televisions to check on the quality of the repairs. Washington D.C. had no government intervention in the television repair industry. Both New Orleans and Washington D.C. experienced very low quality repairs, whereas San Francisco experienced substantially higher quality repairs. Prices in San Francisco were not significantly higher than in Washington D.C. The licensing scheme in New Orleans decreased competitive pressures by acting as a barrier to entry. This allowed existing repair persons to lower their quality, but maintain the same price for their services.

General Comments

The main problem when asymmetric information is present is that prices cannot co-ordinate the actions of the relevant agents. Traditional supply and demand analysis assumes that prices equilibrate markets by conveying sufficient information to "co-ordinate" the actions of buyers and sellers. But this assumes that the quality of the goods is fixed. Introducing variable quality and asymmetric information between buyers and sellers places too many demands on the ability of prices to convey all of the necessary information. The result is that trade in these types of markets is typically inefficient. The mechanisms mentioned above are designed to provide extra information to market participants, allowing prices to equilibrate quantities.

There is a general weakness in the previously mentioned mechanisms in that they typically assume that buyers somehow know a great deal about the structure of the relevant market, including the average quality of sellers. This seems inconsistent with the assumption of asymmetric information and the fact that prices cannot convey all of the relevant market information. Even if buyers could in principle deduce average quality from the market price, it seems unlikely to happen in practice. There are a myriad of other events going on in an economy, such as movements in the prices of factors of production, and therefore also of household income, and movements in the prices of substitutes and complements. These would imply that the demand and supply curves would be shifting around creating a signal extraction problem in determining quantity and quality effects from market prices. This problem seems to be particularly acute for trade in inputs between firms. Traditionally, firms have resorted to second-party audits, which while being effective in increasing their information about the quality of sellers, are very costly. Process standards have been developed to lower these costs. It is also worth noting that their use does not rely on buyers knowing an average industry quality.

2.1.3 Process Standards

There are two ways process standards can be used to lower transaction costs that arise from asymmetric information. First, they can be used to produce information about the state of a firm's production technology. Typically a standard contains a list of common activities that firms use to produce a good or service. It is then used to check the extent to which a firm conforms to the listed activities. For instance, an activity may be testing a product for defects after it has been manufactured. A standard may list likely techniques for product testing and the firm would be checked to see how its product testing activities conform to those listed on the standard. A standard used for this purpose is designed to lower transaction costs. For instance, each of the forty European aerospace manufacturers has between 500 and 10,000 suppliers.[9] Assume for the moment for simplicity that each manufacturer has the same 500 suppliers and that manufacturers audit each of the

[9] Hutchins (1993, p. 61).

suppliers annually. Process standards could lower transaction costs in this industry in one of two ways. First, suppliers will have to conform to only one standard instead of forty different informal or formal ones used by each manufacturer. Second, a possible 20,000 second-party audits may be reduced to 500 third-party audits if a certification or registration system is organised in conjunction with the standard. Lowering transaction costs is the main purposes of quality assurance standards such as ISO 9000.

The standards may also be used to place restrictions on the production possibility sets of firms. A firm that purchases inputs from many suppliers may want them to use standardised processes, or prohibit or require the use of certain technologies or processes. This has the potential of increasing the quality of the firm's good by reducing variation in the inputs. For instance, an auto manufacturer may purchase steel from several producers to alleviate potential hold-up problems, or to increase price competition among suppliers.[10] The manufacturer would obviously like the steel to be of a uniform quality. One way to ensure this is to have the steel producers adhere to the same production process. The standard MoD-Std-0055 developed by the United Kingdom Ministry of Defence prohibits the use of assembly languages, as well as requiring static analysis (formal proof that the specifications of a program are consistent with its requirements), by producers of safety critical software.[11] The aim of this standard is to narrow the production possibility sets of producers so that there is less variability in the quality of software purchased.

One further point to note about any standard, including process standards, is that they obviously involve a tradeoff between the benefits of standardisation and

[10] Milgrom and Roberts (1992, pp. 136-138).

[11] *IEEE Software*, (1989), 6 (5), p. 95.

the benefits of variety. A firm-specific standard may provide more information about the capabilities of suppliers to the relevant firm, compared to a general standard, since the former is tailored to its specific circumstances. On the other hand, a general standard that is widely used may result in substantially lower auditing costs than a firm-specific standard.

This section argues that there are situations where process standards can reduce transactions costs associated with the the presence of asymmetric information. Industry observers also expect that the standards will lower transactions costs. A general manager of supplier development and quality assurance for General Motors of Canada had this to say about the QS 9000 series of auto industry process standards, "But most of the standards will be common, Mr Pearson says, which means that they will save time and money for suppliers — and for their Big Three Customers."[12] Furthermore, there is increasing evidence that these standards do indeed lower transactions costs (see Chapter 5). But their effectiveness in doing this depends on how heavily they are adopted. The more widely they are adopted, the more transactions costs will be reduced. We want to know when process standards will be heavily adopted, as this will dictate when they can be an effective mechanism. There is a literature that addresses an apparently similar question. I now turn to it to examine its ability to explain adoption patterns of process standards. In doing so it is shown that it is deficient in several respects when to comes to analysing these standards.

[12] *The Globe and Mail*, (1994), 28 March, sec. B, p. 3.

2.2 The Standards Adoption Literature

This literature can be broken into two parts, one dealing with theoretical issues, and the other investigating actual cases of competing technologies and their adoption paths.

2.2.1 Theoretical Models

The main focus of researchers has been the possibility of inefficient outcomes due to the dominance of inferior technologies, rather than explaining generally observed adoption patterns. Inefficiency is usually meant in an ex-post sense. Virtually all of the theoretical papers assume unbounded increasing returns to adoption. This guarantees that only one standard will be adopted, with the possibility that it may be the inferior one. Heterogeneity is sometimes assumed (typically two types of agents), but it either completely determines the adoption shares of the standards, or has no effect.

Co-ordination Issues

One of the first theoretical models is that of Farrell and Saloner (1985). They develop a single period model in which agents simultaneously choose one of two competing technologies. The benefits of the technologies increase with the number of adopters through externalities in use, as occurs in a telephone network. This simple model highlights the co-ordination problem inherent in the adoption of standards under increasing returns. There are two equilibria in this model. Either technology may be become dominant. Even if one of the technologies is obviously inferior, it may still be completely adopted. The inability of the agents to co-ordinate their actions means that this equilibrium is always possible. Arthur (1989) and Cowan

(1991) show that these results hold when the increasing returns are due to either learning-by-doing, or reductions in uncertainty about the merits of the technologies. It is also evident in these types of models that expectational effects serve to destabilise the adoption process, rather than solve any intertemporal co-ordination problems. As David (1990) points out, expectations amplify the tendency to lock-in to a technology, regardless of how good it is. Small events become very important in determining the eventual outcome in such an environment.

Compatibility Issues

Katz and Shapiro (1985) explore compatibility decisions by firms when adopting standards are subject to increasing returns. They posit a static model of an industry populated by n oligopolists who are Cournot competitors. It is assumed that there are increasing returns to adopting a technology from demand based network externalities. There are a continuum of heterogeneous consumers who choose a unit of the goods produced. The heterogeneity takes an unusual form. An individual consumer finds any technology inherently equally acceptable, but each consumer has a different basic willingness to pay for a good (regardless of the technology embodied in it). This assumes that technologies are identical, and it is only the size of the networks that matter in their decisions. This assumption is needed to obtain a linear downward sloping demand curve for the technologies. It also assumes away any co-ordination issues in the adoption of the standards on the consumer side. The equilibrium number of technologies in this model is driven purely by consumer expectations (which are self-fulfilling). The assumption of constant returns to producing the technologies is crucial in this instance. This allows multiple firms to exist since consumers expect firms with larger networks to charge higher prices than those with smaller ones. This assumption means that consumers effectively face constant returns to adopting a technology, but firms make different profits. This result would be invalidated if firms priced according to marginal cost. They find that the decisions by firms to make themselves compatible are highly dependent on the parameters of the model, even allowing for side payments. Thus, few generalisations can be made regarding this feature. Finally, they find that smaller firms have, in general, socially excessive incentives to build an adaptor. They do not take their effects on larger firms into account when making their decisions in this regard.

Sponsored Versus Unsponsored Standards

The effect that sponsorship, or lack thereof, has on adoption patterns of standards when they are subject to network externalities is the subject of Katz and Shapiro (1986). There are two periods and a "representative consumer" in each period. The two consumers have different tastes over the two possible technologies available for adoption. The first period consumers act like an installed base in this model. If both standards are unsponsored then the first period consumers have a strategic advantage over those in the second period. They can lock-in a technology even if it is optimal to standardise on the other one. When one of the technologies is sponsored, there is a bias towards it. The sponsoring firm can use penetration pricing in period one to create an installed base and lock-in standardisation on its technology. There is a second mover advantage when both technologies are sponsored which favours the cheaper technology in the second period, even if it is not the optimal one over both periods.

As nas been mentioned these "original" models have focused on finding inefficient equilibria, and not with explaining generally observed adoption patterns. This deficiency of most of the works in this literature is discussed in the next subsection.

Co-existence of Standards

David and Foray (1993) and Cowan and Cowan (1995) are two recent papers interested in explaining patterns of technology adoption in more general settings. In particular, they are interested in finding out when variety can arise, even when the standards are subject to unbounded increasing returns to adoption. Both of these papers employ techniques which encompass heterogeneous agents and spatial considerations. Space can be either geographic or product. David and Foray assume that the benefits to adopting a technology are an increasing function of the proportion of an agent's neighbours who are using it, due to the presence of deeper labour markets. This is a type of Marshallian externality. Cowan and Cowan assume that there are positive externalities from adopting the same technology as a neighbour, also due to the presence of Marshallian externalities. In addition, they assume that there is a negative global externality due to upward sloping supply curves in the provision of the goods embodying the technologies. The model of Cowan and Cowan exhibit multiple equilibria for many combinations of parameter values. The proportions of agents adopting each technology in David and Foray are unique, however the equilibrium can be supported by many different spatial patterns of their adoption. Both models find that variety is possible even when there are strong increasing returns to adoption.

The existing models are in general incapable of addressing the trade-off between standardisation and variety. Farrell and Saloner (1986, p. 71) point out this weakness in models such as Katz and Shapiro (1985). This is because incompatibility in their model is a form of spurious product differentiation, and so there are no social benefits from failing to standardise. In fact, this criticism in a different form can be targeted at all of the traditional models (including Farrell and Saloner), since they incorporate heterogeneity in a trivial sense. The incorporation of heterogeneity in these models creates a knife-edge situation, which seems unrealistic and potentially misleading. It is also a very restricted form of variety, which is defined by *The Oxford Dictionary* (1989, 2nd ed., p. 446) as "diversity of nature of character" or "absence of monotony, sameness, or uniformity". It is conceivable that introducing a less restrictive form of variety may lead to different conclusions. As Anderson, de Palma, and Thisse (1992, p. 10) point out, theoretical models that include product-taste heterogeneity soften price competition. This means that small changes in the price of a good do not result in huge changes in the demand for it. This intuition would seem to be applicable to the adoption of standards. With non-trivial heterogeneous agents we would expect that the adoption of standards would be dispersed. Agents whose inherent tastes are located "far away" from the standard may prefer not to adopt it, even with strong increasing returns to adoption. After all, not every household owns a computer, even though they might have tasks which a computer (Macintosh or an IBM PC) could accomplish. Increasing or decreasing the heterogeneity of agents will decrease or increase the numbers who adopt any standard, but we would not expect the drastic changes implied by existing models.

As was previously mentioned, David and Foray (1993) and Cowan and Cowan (1995) have recently begun to examine the trade-off between standardisation and variety for unsponsored standards. There are two assumptions driving their results:

introducing non-trivial heterogeneous agents; and incorporating spatially based increasing returns to adoption. Spatially based adoption effects is one non-trivial form of heterogeneity, with agents being spread out in their locales. This can lead to agents in one area of space doing different things from other agents in another portion of space, if they are far enough away from each other. The need to introduce spatially based adoption effects, when returns to adoption are increasing, is shown by Arthur (1990b). He shows that even when agents are heterogeneous (still in the trivial two-types sense) and increasing returns to adoption are bounded, coexistence of different standards only occurs for a very specific adoption path. This is when the number of agents adopting each competing standard goes hand-in-hand, so that no one standard obtains a lead over the others.

2.2.2 Empirical Findings

All of the empirical work undertaken has involved the adoption of competing technologies. None have looked at the adoption of process standards. This reflects the fact that the main concern has been to find examples of inefficient technologies that have become dominant. This concern is mainly a counter-factual one, and is difficult to examine empirically. It is in general necessary to examine relatively minor details of the histories of the technologies when following this route, since they are important in determining the outcome in a self-reinforcing system. The studies undertaken so far suggest that there are cases where inferior technologies have been adopted. Liebowitz and Margolis (1994 and 1995), however, argue that examples such as these are only found infrequently. They also argue that most situations will result in the efficient standard being adopted, even with increasing returns to adoption, since the increasing returns are pecuniary in nature, or are normally captured by a firm (sponsor) who internalises their effects. More evidence is needed before a definite conclusion can be drawn either way.

Probably the most well known study of technology adoption concerns the Qwerty keyboard layout. There are over 40 factorial different possible variations of keyboard layouts, but virtually all now follow the Qwerty standard. David (1985) argues that Qwerty became dominant due to increasing returns to adoption and a small favourable historical occurrence. He even claims that there is evidence that it is inferior to the Dvorak layout, although this is disputed by Liebowitz and Margolis (1990). They claim that typists using Dvorak are at best an average of two to five percent faster than if they used Qwerty, and that this difference seems to be just noise from the way the studies are organised. Regardless of whether Qwerty is inferior or not, this example shows how the features of competing standards combine to select one of the many possible technologies.

Other studies are David and Bunn (1988), Cowan (1990), and Cowan and Gunby (forthcoming). David and Bunn find that the adoption of alternating current and direct current technologies supports models which assume network externalities. In particular, returns from their adoption were increasing, minor events seemed to have large effects, and one standard became dominant even though neither was superior to the other. Cowan investigates the adoption of nuclear energy technologies. He finds that the dominant light water reactor type achieved its position due to increasing returns to adoption and small historical events. Strong evidence is also presented that an alternative, gas graphite reactors, may be a superior technology. The adoption of pest control technologies is also shown by Cowan and Gunby to be subject to influences of increasing returns to adoption and small historical events. In this case chemical control is the dominant technology compared to its chief alternative, Integrated Pest Management. Evidence is presented that chemical control may be an inferior technology. Interestingly, they show how the benefits of the two technologies are subject to direct (non-market mediated) interactions between adopters, particularly interactions involving information about the technologies.

A recent study by Saloner and Shepard (1995) test for the presence of network effects in the adoption of automated teller machines (ATMs) by banks in the United States from 1972-1979. This was before inter-bank networks became common so it gives a clear picture of the presence or absence of network effects for proprietary systems. They develop a simple model that shows that if there are network effects, then banks with larger networks will adopt ATMs sooner than those with smaller networks, all other things being equal. Having more branches means that the cost per ATM is lower because of lower location-specific costs such as those from purchasing and installing an ATM. It also means that the benefits per ATM increase for banks, since more ATMs increase the benefits of the network to consumers which a bank can capture. The network size they use is the number of physical locations at which any depositor can carry out a transaction. The estimations they carry out produce results that are consistent with the presence of self-reinforcing network effects. Adding an extra branch (but keeping the total number of customers the same) is estimated to increase the probability of a bank adopting an ATM by 6 to 11 percent.

The results of the case studies and the econometric study of Saloner and Shepard show that there are examples of competing technologies that conform to the results of the theoretical literature. The adoption of the technologies are subject to increasing returns, the adoption histories are path dependent, and there is evidence that some technologies that have been adopted may be inferior. However, as Margolis and Liebowitz (1994 and 1995) point out, there is a great deal of uncertainty about the prevalence of these circumstances in the real world. Since the standards adoption literature is relatively young, this is a particularly pertinent point that has not been settled at present.

2.2.3 General Comments

In addition to not being able to address the trade-off between variety and standardisation, the more traditional models are also incapable of explaining the adoption patterns of process standards. Most process standards are unsponsored. They are developed by some organisation, such as the International Organisation for Standardisation or the American Society for Quality Control, and left in the public domain. Where the standards are sponsored, they are sponsored by buyers, not by the suppliers as in Katz and Shapiro. If the buyers wield enough market power, as Ford, Chrysler and General Motors do, then they can force the sellers to adopt the standards as these three firms are doing with the QS 9000 standard. If not, then we are effectively back to the unsponsored case as process standards are not embodied in goods like technologies, and therefore there can be no penetration or other pricing effects. These features rule out using models such as Katz and Shapiro which only analyse sponsored standards.

In addition, agents repeatedly choose which process standard to adopt, not the once and for all decision of traditional models. There are typically other actions available, such as issuing warranties, and these actions may co-exist with standards. The presence of these actions implies that agents tastes are not clustered around a small number of points. There is also evidence suggesting that decreasing returns to adopting a standard set in eventually. Agents that adopt a standard appear to receive less of the gains associated with them when they have been adopted by a large number of agents. For process standards, the decreasing returns appears to be the result of a reduction in the bargaining power of suppliers vis-a-vis their customers. The customers are then able to capture a greater portion of the rents associated with a standard, than if only a few suppliers had adopted it. Only the number of adopters of a standard matter in this case because the standards are independent of each other, even though they are performing the same basic function of alleviating the effects of asymmetric information. Each standard usually covers different aspects of firm's production processes.

Importantly, adoption effects associated with process standards are generally spatially based. Some standards are country specific, while others are international. Some standards apply to one industry, while others apply to all industries. Thus, the adoption decisions in one country or industry will typically have effects on decisions of agents in other countries or industries. Two further factors complicate this environment. First, countries and industries are not usually isolated from each other, but they are not fully integrated either. Second, some agents straddle more than one country or industry. By their very definition, multinationals operate in several countries and multiproduct firms operate in several industries. It would be useful to know how each of these factors affect the adoption patterns of process standards, since they are obviously significant features in the real world. These features have not been explored by either David and Foray or Cowan and Cowan.

Finally, empirically, there are many different adoption patterns of process standards, not just the "one standard dominates" result of the traditional literature. In some cases many standards co-exist, in others one standard may dominate, while yet in others we see that most agents do not adopt any of the available standards. There is no traditional model of unsponsored standards that is possible of yielding all of these patterns. Furthermore, the existence of heterogeneous agents who interact with each other, either within or outside of the market, in a spatial environment suggests that more conventional techniques will be incapable of addressing these features. The natural literature to see which direction to take is that on interacting agents, which is the topic of the next section.

2.3 Interacting Agent Models

The third and fourth chapters use models which incorporate interacting agents. The particular type of technique employed in the models has the advantage that it encompasses the normal market mechanism, but it also allows the incorporation of a large but finite number of heterogeneous agents whose actions directly affect others. It is argued in Chapter 3 that these features are not only needed to generate realistic adoption patterns of process standards, but they also characterise the standards adoption environment.

2.3.1 Motivation for Incorporating Interacting Agents

Why use models of interacting agents? Kirman (1992 and 1994) argues persuasively that it is only through studying interactive agent models that we will understand how aggregate parts of an economy operate. He argues that Adam Smith's "invisible hand", which acts to co-ordinate the actions of the millions of agents in an economy, is missing in most models that deal with aggregate variables. Instead, the techniques of choice posit a representative agent, or many identical agents. The main reason for using these are their technical convenience. But as Kirman demonstrates, they can give very misleading results when used to study economic problems. For example, the representative agent may prefer situation a to b, but all the individuals that it represents may prefer b to a! These techniques also typically imply that no trading occurs in equilibrium.

One work which illuminates the effect of allowing agents to interact directly, as well as through the market, is that of Föllmer (1974). He employs a conventional Arrow-Debreu economy with the added feature that agents also directly interact with only a subset of agents, in addition to trading in markets. He proves that equilibrium prices may not exist when these interactions are strong. Furthermore, even when the interactions are weak and equilibrium prices exist, the laws governing the behaviour of the aggregate economy cannot be ascertained from the structure assumed for the individual agents. These results hold even when agents are homogeneous. The latter result of Föllmer clearly shows the tenuous nature of the results of conventional models using techniques such as the representative agent model when studying aggregate variables.

One of many papers providing empirical evidence supporting the presence of non-market mediated interactions between agents is that of Irwin and Klenow (1994).[13] They examine whether learning-by-doing existed in the semiconductor industry between 1974 and 1992, and if it existed, what form it took. They find that there was substantial learning-by-doing in this industry, and that the learning by one firm spilled over to other firms. In other words, there were non-market mediated interactions between firms, and interestingly enough, these occurred among firms in different countries in the semiconductor industry. Another example presenting evidence supporting direct interactions is Cowan and Gunby (forthcoming). They find evidence of both global and local transmission of information about pest control technologies. Information available in California about natural predators

[13] The results of Manski (1993) must be borne in mind when discussing empirical studies that try to determine whether interaction effects are present, where the interaction takes the form of average behaviour of a group. He shows that these forms of interaction effects are in general very difficult to substantiate or disprove. Accurate prior information is needed about the reference groups and the means of the relevant variables defining the reference groups. Non-linear interaction effects increase the identification problem.

of a citrus pest quickly became known to citrus growers in Israel, in their effort to combat a similar type of pest. In other circumstances, local sources of information, such as neighbouring farmers, proved to be important. Both of these examples highlight the importance of information production and exchange in direct interactions among agents.

2.3.2 Explaining Economic Phenomena

Herds and Fads

Papers by Scharfstein and Stern (1990), and Bikhchandani, Hirshleifer, and Welch (1992) highlight how conventional models ignore the important "market for information". Explicitly incorporating the way in which agents obtain information about economic conditions produces interesting and realistic aggregate phenomena that traditional techniques have problems explaining. The key to their results is allowing agents to interact directly. Both models assume that there are many agents who learn information from directly observing the behaviour of others, as well as from their own private signals. When this is allowed, herd or fad behaviour can result. In Scharfstein and Stern, agents try and follow the actions of others, since they are effectively penalised for being different. There is a "sharing-the-blame" effect which encourages agents to do the same thing, thereby avoiding penalties in bad states. Agents in Bikhchandani, Hirshleifer, and Welch eventually ignore the information contained in their private signal in choosing an action, and "follow-the-crowd". In such a setting, releases of public information can have very large consequences, and cause mass rejection of one behaviour in favour of another that had been previously ignored. This offers a plausible explanation of why rational agents follow fads.

Economic Dynamics

Durlauf (1992) and Ellison (1993) show how allowing agents to interact directly can affect the dynamics of an economy. Ellison considers a large population of myopic agents who are matched and play a simple co-ordination game. There are two equilibria, one better than the other. Traditional models with anonymous agents result in very slow convergence to the better outcome. Allowing local interactions, representing those between friends, colleagues, or neighbouring firms, considerably increases the rate of convergence. This happens because it allows a faster rate of learning by the agents. Durlauf is interested in demonstrating that spatial models which allow interaction between agents can generate path dependence in aggregate output. This phenomenon has been found in macroeconomic data. His model consists of many industries which are located in product space. The productivity of the available technologies is a function of what a firm does within an industry, as well as what firms do in related, or neighbouring, industries. This captures the notion of technological learning-by-doing and inter-industry information spillovers. Aggregate shocks in this environment lead to path dependence, and multiple steady state equilibria exist if the technological complementarities are strong enough. Some of these are inefficient.

Spatially Based Phenomena

David and Foray (1993), Cowan and Cowan (1994), and Brock and Durlauf (1995) are interested in explaining the patterns of economic activity over geographic and product spaces. David and Foray are interested in why firms in different areas can use very different technologies. It is assumed that labour markets are deeper if neighbouring firms choose the same technology. This is a form of Marshallian externality. In this situation, different technologies can co-exist and they do so by clustering geographically. Cowan and Cowan are interested in the co-existence of standardisation and variety of technologies in either geographic or product spaces. They allow heterogeneous agents to affect each other, both locally (Marshallian externalities) and globally (upward sloping industry supply curves). There are typically multiple equilibria in such a model and standardisation on a technology can occur for different regions of a space, but the regions standardise on different technologies. They argue that their model produces results which can explain observed patterns such as why we see hard disks come in a few sizes, but many speeds. The local externality pushes firms to do the same thing, but the global externality penalises all firms from doing the same thing. Brock and Durlauf are interested in explaining socio-economic patterns, such as the congregation of crime in some areas, but not in others. This is motivated by the results of empirical studies, such as Glaeser, Sacerdote and Sheinkman (1995), that find that models estimated without social interactions are strongly rejected by the data. They develop a model where the benefits of actions available to agents depend not only on their own circumstances, but also on the average action by all other agents. This creates pressure for agents to conform to social norms. Intuitively this seems sensible, since we would expect that the probabilities of dropping out of high school, taking drugs, or having births out of wedlock, are functions of a society's tolerance for these behaviours. They find that multiple equilibria are possible. As would be expected, they also find in such an environment that a population of relatively heterogeneous agents can choose similar actions.

The last three papers are just a few in a long line that have been developed to explain spatial distributions of economic activity, where some of the economic forces are not market mediated. These authors include Marshall (1890), Hotelling (1929), Weber (1929), Lösch (1939), Isard (1956), Christaller (1966), Eaton and Lipsey (1975) and Arthur (1990). Typically the models have agglomerative factors such as the presence of transportation costs and deeper markets, as well as congestion factors such as higher prices for inputs like land and competition for market share. Some models have a unique equilibrium, whereas others have many possible equilibria. In many cases equilibria do not exist. The only general result is that the outcomes of the models are very sensitive to the following factors: the topology defining the spaces; the functional forms associated with the choices of agents, such as those governing transportation costs (quadratic or linear); the number of agents; the heterogeneity of the agents; and whether agents choose actions simultaneously or sequentially.

Consider Eaton and Lipsey who study the location of firms in one and two dimensional space. Their analysis highlights the effects of the assumptions involved in modelling spatial patterns of economic activity in which agents interact. The interaction in this setting is the impact that a firm's location decision has on the market shares of other firms, and hence on their location decisions. They explore spatial features such as the impact of boundaries (line versus a circle in one dimension), conjectures of firms ("other firms will not change their location decisions" versus "other firms will relocate to cause maximum loss of market share"), the number of firms, and the distribution of consumers in taste space. They find that the presence or absence of boundaries has little effect on equilibrium configurations in one dimension. In contrast, the density of consumers is very important. In most cases equilibria do not exist with a non-uniform density. There is typically no way that the taste space can be broken up to ensure that a firm does not have an incentive to relocate. Moving to two dimensions makes the presence of boundaries matter a great deal. They conjecture, but cannot prove, that an equilibrium does not exist for more than two firms who are choosing where to locate on a disk. There is an incentive for firms to move to the boundaries if they are clustered in the centre. But once firms are on the boundary, there is an incentive for them to move back to the centre. Interestingly, they find that existence of an equilibrium is less prevalent in their different configurations if firms take into account their impact on the location decisions of other firms.

2.3.3 General Comments

What general conclusions can we say about interacting agent models? First, there are typically multiple equilibria in such models. This is true of Durlauf, Cowan and Cowan, and also the herd models. The interactions usually promote conformist behaviour, and which action agents conform to is very much a matter of chance. The existence of multiple equilibria is not surprising given the results of Föllmer. Second, getting existence, let alone any general results in models with agents who interact spatially is very difficult. Eaton and Lipsey show that conclusions drawn from these types of models are very sensitive to the underlying assumptions, and conjecture that an equilibrium typically exists for only a small number of dimensions. Third, including expectations usually serves to destabilise the choice processes of agents. In effect it is harder to co-ordinate behaviour because it expands the set of possibilities that agents have to take into account when making a decision. An agent not only has to know what is optimal for itself, but also what is optimal for others (that is, where other agents are located in the space under consideration), how they interact, and the effect that the interactions have.

These results highlight the difficulty of modelling the adoption of process standards. We know that agents choosing which standard to adopt are located in some taste space, that they are also located in geographic or product space, and that they interact directly with each other as well as through the market. The literature on interacting agents suggests that we need to be careful about which technique we would use to model such an environment. In particular, a Hotelling type of model will be insufficient to cope with this problem, as demonstrated by the results of Eaton and Lipsey.

2.4 Discrete Choices

The choice an agent faces about which standard to adopt is by its very nature discrete. There is a large literature which has studied this subject. This section discusses this literature and evaluates its suitability for studying the adoption of process standards.

2.4.1 Background

The basis for discrete choice theory originates in biometrics and psychology, which began studying this area in the mid-1800s.[14] Biometricians use discrete choice models to study the effects of things like drugs and pesticides on subjects. If testing for the effects of pesticides, the "choices" of the subject may be to live, or to die. Psychologists use discrete choice models to study the responses of subjects to physical stimuli, the learning behaviour of subjects, and preference decisions of subjects who have to choose one of many alternatives. A psychophysicist would expose subjects to various sound waves, and the subjects "choose" how loud each one is. Economists began studying discrete choice problems in the early 1960s, and since then have developed an extensive theory about them and how to estimate the parameters governing the choices. Of course studying discrete choices in economics

[14] See Copenhaver and Mielke (1977) for an example from biometrics, and Luce, Bush, and Galanter (1963) for foundations of discrete theory in psychology.

is different from that in other disciplines. Economic data are not usually from tightly controlled experiments, and economic agents form expectations about the choices they make. Even so, Anderson, de Palma, and Thisse (1992) show how economic theory about discrete choices is based on the work from other disciplines.

2.4.2 Theory

A comprehensive treatment of discrete choice theory can be found in Anderson, de Palma, and Thisse (1992). The main features of this subject can be seen by considering the following framework (see Chapter 1 of Anderson, de Palma, and Thisse). There exists a population of N agents who each choose one of I possible actions. The payoff to action $i \in 1, ..., I$ is given by the utility function $U_i = u_i + \epsilon_i$. The first part, u_i, represents deterministic elements in an agents choice. Agents may inherently prefer driving a car to using public transportation. The other part, ϵ_i, is a random variable. The random component has two observationally equivalent interpretations. It may represent idiosyncratic differences among agents that cannot be measured or observed by the modeller. This is a common approach taken by econometricians in estimating discrete choice models.[15] It could also represent stochastic parts of the choice process. An agent may be transferred to an office where public transportation or car parking is not readily available.

Given this structure there are two things we wish to know: the probabilities that an agent will choose each action; and the proportion of all agents who choose each action. We can derive the individual choice probabilities once we assume a specific distribution governing the random parts of an agent's choice process. A common assumption is that the random components are i.i.d. and drawn from the

[15] See Amemiya (1990) for a comprehensive theoretical treatment of estimating discrete choice models, and Rothwell and Rust (1995) as one recent example.

double exponential distribution which is described by,

$$F(x) = \Pr(\epsilon_i \leq x) = e - [e - \{\frac{x}{\mu} + \gamma\}],$$

where γ is Eulers constant and μ is a positive constant. Then we know that the probability of an agent taking action $i \in 1, \ldots, I$, denoted by $\Pr(i)$, is given by,

$$\Pr(i) = \frac{e^{u_i/\mu}}{\sum_{j=1}^{I} e^{u_j/\mu}}.$$

The double exponential distribution is used because it is a close approximation to the normal distribution, and it gives closed form solutions (unlike the normal). Note that if $\mu \rightarrow 0$ then the variance of the ϵs tends to zero. We then get back the neoclassical deterministic model. If $\mu \rightarrow \infty$ then the variance of the ϵs tends to infinity. Then all actions become equally probable. Furthermore, assume that the choice of each agent is independent of the choices of the other $N-1$ agents, and the ϵ_is for all agents are drawn from the same distribution. Then the distribution of choices is multi-nomial with the mean of each action given by the number of agents multiplied by the probability an agent takes that action. This is the expected aggregate demand for each action.

There are a couple of points worth noting about the above results. First, there are several independent methods for deriving the individual choice probabilities. See Anderson, de Palma, and Thisse (Chapter 1) for more details. The remarkable thing is that each of the independent methods arrives at the same result. Second, the techniques used to derive the choice probabilities assume the independence of irrelevant alternatives (IIA). Say there are two main methods of transportation, car and bus. The IIA assumes that breaking up buses into blue and red types so that we now have three methods of transportation, car, blue buses and red buses, is not going to affect the overall probabilities of choosing a bus or a car. Effectively what the IIA is saying is that to use the above results we should treat actions that similar as a single action.

2.4.3 General Comments

The assumption of IIA is innocuous for the carrying out of theoretical work, but it implies that empirical research involving discrete choices needs to be undertaken with care. In particular, the IIA means that researchers need sufficient background knowledge about the actions available to agents to ensure that only dissimilar actions, or dissimilar groups of similar actions, are considered.

The assumption that the choices of agents be independent rules out the application of the theory to study the adoption of standards, including process standards. The decision of an agent to adopt a standard is decidedly dependent on the decisions of other agents. This means that we cannot use the existing theory on discrete choices to study aggregate patterns of standard adoption.

2.5 Conclusion

The brief surveys of the literatures above illuminate where process standards fit into existing theoretical work and also the type of approach needed to study their adoption. The problem of explaining the adoption patterns of process standards is similar to the problem of explaining adoption patterns of technological standards. But since process standards are mainly used to alleviate the effects of asymmetric information, they have several features that differ from technological standards.

These different features imply that we cannot simply use variants of models such as Katz and Shapiro (1985 and 1986) or Arthur (1989) to analyse the adoption of process standards. The techniques of Cowan and Cowan (1995) or David and Foray (1993), however, seem able to cope with many of the difficulties involved.

The literatures on interacting agents and discrete choices also suggest that these techniques are the obvious ones to use. Spatially based interactions, particularly for those above one dimension, are not coped with at all well by traditional models. There are problems in obtaining existence of equilibrium. Furthermore, even when equilibria exist, their characteristics are not robust to minor changes in the assumptions of their models. The theory on discrete choices has several powerful and attractive results. However, aggregate results of the theory as it stands only apply to choices of agents which are independent from the choices of other agents. In contrast, the decisions of agents about which standard to adopt depend on the decisions of other agents.

Given the previously mentioned problems with conventional techniques, it seems as though the features present in the adoption of process standards make it too difficult to analyse theoretically. But as with the discrete choice model literature, there are techniques from other disciplines that can overcome the aforementioned problems. The models in Chapters 3 and 4 study the adoption of process standards using one such technique. The technique also produces results that are similar in structure to discrete choice models, but it is able to cope with heterogeneous agents who interact spatially. One such similarity is the invocation of the IIA assumption. This does not pose any theoretical problems. It is an important reason, however, for the detailed background of the software industry and the relevant process standards presented in the case study in Chapter 5.

Chapter 3

Adoption Patterns In A Single Industry Model

3.1 Introduction

This chapter develops a one industry model that captures the important features influencing the adoption of process standards. Doing this serves two purposes. First, it will allow us to gain an understanding of how the basic model works in a simplified setting. Only after we have built up intuition about how the model works will we proceed to analyse the effects of incorporating geographic or product spaces. This is done in Chapter 4. The only spatial considerations considered in this chapter are to do with the tastes of the agents. Second, it also allows us to compare the the results of the model to existing ones in a similar environment. In doing this it highlights two serious deficiencies in the literature on competing standards as it currently stands. First, models in the literature typically result in the abandonment of all but one standard. There are many instances where this does not hold. Process standards are one example; computer operating systems are another. While MS-DOS and Windows operating systems dominate the personal computer world, Apple, with its different operating system, has continued to supply roughly fifteen percent of this market.[1] Surveys by *Datamation* in each of 1992, 1993, and 1994 found that managers of information systems planned to purchase a variety of server operating systems. The most popular server operating system in 1994 was to be purchased by only twenty-seven percent of the managers, with several other operating systems also featuring prominently.[2] Second, either heterogeneity among agents in the models has no effect in determining the equilibria, or it alone dictates which equilibria occur. Intuitively, this aspect of the literature is worrying since we would expect that heterogeneity should play a part in determining the adoption shares of standards, but that it is unlikely to be the only factor. Of more concern is that the models fail to address the trade-off between variety and standardisation. Under what circumstances can we expect a variety of actions to be taken by agents, and when can we expect agents to concentrate their actions around one or two standards? These models implicitly dispense with variety, or downplay its role, by assuming either that agents are homogeneous, or that there are a small finite number of agents (usually two matching the number of standards).

The inability of models in the literature to generate results in which more than one standard is adopted, except under very special circumstances, is hardly surprising. Four key assumptions are responsible for this result. Returns to adoption are typically assumed to be increasing and unbounded. This implicitly pushes standardisation as the end result and the question is then which standard becomes dominant. Second, the number of agents is assumed to be either very large (infinite) or very small (typically two). When there are a very large number of agents, traditional models usually "lose" heterogeneity as a parameter in determining the adoption shares. This occurs in the course of aggregating over the heterogeneous

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[1] *The Wall Street Journal*, (1995), 1 May, sec. B, p. 4.

[2] Sharp (1994).

agents, which typically involves taking expected values, when calculating the adoption shares. When there are a very small number of agents, heterogeneity becomes all important, or it does not matter, in determining the adoption shares. Third, if heterogeneity is assumed to exist among agents there are typically only two types, each type has an inherent preference for one of the two standards. This usually means that there exists a threshold level of the strength of the inherent preference for a technology below which having different agents does not matter, and above which it completely determines the adoption pattern of the standards (each type chooses its inherently preferred technology). This also biases the result so that standardisation will occur, particularly with respect to process standards. We can expect producers to be heterogeneous, and therefore, see many different production methods employed by them. Finally, a conventional assumption is that agents exist on a point of zero dimension and/or that goods only come in one characteristic. David and Foray (1993), and Cowan and Cowan (1995) show that relaxing this assumption can result in dispersed adoption shares, even with unbounded increasing returns to adoption. The effects of relaxing this assumption in this model are examined in Chapter 4.

One way to preserve variety in these models would be to assume a different form of returns to adoption. But there are problems using this approach. Consider unbounded decreasing returns. A very large number of agents results in an even split of the adoption shares, whereas a small number of agents means that the adoption shares are determined solely by whether the strength of their inherent preferences are above, or below, a threshold value. Adoption shares under constant returns depend only on the strength of the inherent preferences. Even more troublesome is the fact that we have strong evidence of increasing returns to adopting standards, at least for early adopters.[3] In addition, there is some evidence that decreasing returns exists for later adopters of process standards. This clearly rules out using only decreasing or increasing returns to adoption, even without the other problems they have. This leaves either bounded increasing returns, or this in combination with decreasing returns for later adopters. Arthur (1989) shows that even if increasing returns to adoption are bounded, then we can only expect dispersed adoption shares if the dynamics are just right. This entails that the adoption of each standard goes hand-in-hand with the other. The presence of increasing and then decreasing returns will in general result in many equilibria, as shown by Arthur (1990a). In any event, we do not want to have only a very small number of adopters, for the reason given earlier. But, there do not seem to be any conventional economic techniques which incorporate a large number of heterogeneous agents, and which do not average out the heterogeneity to the point where it does not influence the adoption shares. The model developed in this chapter uses a statistical technique that allows us to have a model with both a large finite number of heterogeneous agents, and heterogeneity that matters. Before presenting the formal model I describe in some detail the features present in the standards adoption environment.

3.2 The Standards Adoption Environment

There are several features of the standards adoption environment that drive the adoption of process standards.

3.2.1 Heterogeneity of Orders

Suppliers experience heterogeneous environments. This heterogeneity arises from three sources: idiosyncratic differences among suppliers; orders which have

[3] See Chapter 2 for a discussion of empirical studies that demonstrate this for technological standards. Evidence for process standards is given in Chapter 5.

different properties; and differences that arise among the "matches" between firm's orders and suppliers. These can be generated by the following: the change in 1992 in the method by which General Motors ordered parts from it's suppliers; the finite life cycle of product models; differences in locations of suppliers in product spaces; differences in production techniques; technological changes in both products and processes; taste shocks; and changes in government policies. Invariably orders change even if a supplier repeatedly supplies to the same firm since products undergo technological change. Other factors include the relationship between a supplier and the firm it sells to, and the type of part that the supplier produces.

3.2.2 Uncertainty Of Tasks

Suppliers typically do not fully know the exact tasks that need to be done to fulfil the orders they have been awarded. In part this reflects the fact that it is common for firms to change the specifications of an order which a supplier has received.[4] It also appears to be common for suppliers in some industries to receive orders which are in effect "experience orders", similar in nature to experience goods, as discussed in the classic work of Nelson (1970), as the suppliers only learn the exact nature of the next task that needs to be performed after they have fulfilled the previous task.[5] The increasing tendency to involve suppliers in the design of parts increases the likelihood that future tasks will not be fully known.[6]

3.2.3 Life Cycle of a Competitive Auditing Industry

Typically, sellers are periodically audited to ensure that they are conforming to the requirements of the relevant standard(s). Thus, auditing fees are one cost of

[4] See Gibbs (1994).

[5] As examples of this see Stix (1994); and *The Wall Street Journal*, (1995), 18 May, sec. A, pp. 1 and 9.

[6] Taylor (1994) discusses the increasing shift of the design of parts from firms to their suppliers in the US auto industry. This is already common practice in Japan. Other examples are given in Tully (1994).

adopting a process standard. For standards such as ISO 9000 and the CMM, the adopting firm is audited by an independent third party which charges it fees. The available evidence on the number of third party auditors, the price for their services, and the number of audits they have undertaken, is consistent with the typical life cycle path of a competitive industry as described in Spence (1981), Jovanovic (1982) and Jovanovic and MacDonald (1994).[7] This framework implies that over time the price of auditing services for a particular standard is assumed to be downward sloping with increases in its adoption (though not at a given point in time where the usual upward sloping supply curve holds). Spence models this type of time trend in industry prices and output as learning by doing, Jovanovic models it as the weeding out of inefficient firms, and Jovanovic and MacDonald model it as the result of technological innovation.

3.2.4 Marshallian Externalities

In addition to auditing costs, implementing a standard also involves costs. The available evidence suggests that these costs are subject to positive Marshallian externalities (Marshall (1920)).[8] Thus, the cost of implementing a process standard falls with increases in its adoption. Marshallian externalities arise in the following ways: the development of a secondary market of consultants services; the development of products such as computer programs; the generation of information about standards in the form of books, trade journal articles and videos; and the dissemination of information about them through conferences and other interactions between agents. These combine to lower the expected cost of adopting a standard; either the cost decreases, or the probability of a successful adoption increases.

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[7] See Chapter 5.

[8] See Chapter 5.

3.2.5 Bargaining Between Firms and their Suppliers

Most process standards apply to the contractual situation where firms buy inputs from suppliers. Bargaining between firms and their suppliers occurs over both price and quality (where quality is usually measured by many different facets of the product) conditional on future states of the world.[9] There typically exist a pool of potential suppliers in the background. The existence of bargaining between firms and their suppliers, and the fact that the main impetus to adopt a process standard is to increase the gains from trade, raises the question of how much of the resulting surplus is obtained by the supplier and by the firm. The appropriate framework would appear to be a bargaining game between two agents that have outside options. As Osborne and Rubinstein (1990, pp. 54-63) point out, the question then becomes how credible is the threat of opting out. The model of Shaked and Sutton (1984) provide conditions for when we can expect the threat of a firm opting out, and choosing to bargain with another supplier, to be credible. There are two conditions: firms must not be able to bargain with more than one supplier at a time, and firms must not be able to switch instantaneously between suppliers. In the context of firms bargaining with suppliers, it seems reasonable to assume that the more suppliers that can provide the service (which includes information about the capabilities of the suppliers) the easier (faster) to negotiate with other suppliers. In this case an increase in the number of suppliers who adopt a process standard raises the threat point of the firm, and allows the firm to extract a bigger portion of the available surplus.

[9] Dobler, Burt and Lee (1990).

A related point is that most process standards differ widely in their coverage of the production activities of firms.[10] As Bamford and Diebler (p. 2) note in comparing ISO 9000 and the CMM, "The two models are independent: complying with either model does not predict compliance with the other. Each model address unique aspects of the software development organisation ...". This means the threat point of a firm involved in bargaining with a supplier who has adopted a standard is primarily affected by the number of adopters of the same standard. There may be affects from adopters of other standards, but these would only be of second order.

3.2.6 Overall Environment

The features mentioned have several economic implications. They imply pecuniary externalities (the auditing industry life cycle and Marshallian externalities) and non-pecuniary externalities (the influence of the actions of each supplier on the bargaining power of other suppliers). Since suppliers experience considerable uncertainty about their future tasks, they are likely to strongly discount the future. Changing products and technologies lead to bankruptcies and start ups of suppliers in the normal evolution of an economy. Most models which analyse endogenous technological change, such as Aghion and Howitt (1992), feature externalities in the generation and diffusion of knowledge. Furthermore, there is normally substantial learning associated with the introduction of new products and technologies, as shown by Irwin and Klenow (1994). A changing population of suppliers implies incomplete markets because suppliers cannot enter into contracts before they start up.

[10] See Tingey (1994), Bamford and Diebler (1994), Price Waterhouse (1988) and Computing Software and Services Association (1995).

Each of the features mentioned in the preceding section has been studied individually in mainstream economics. When they appear in combination it is likely that the economy to be studied is quite different from that normally investigated in economics. Arrow (1988) and Brock (1988) show that any one of externalities, increasing returns, experience based learning, incomplete markets, or high discounting of the future, will most likely to lead to complex dynamics. Equally, as Arrow (1988, p. 278) points out, many forms of economic phenomena are not well covered by linear stochastic systems, particularly those phenomena involving cycles or patterns. The presence of complex dynamics combined with Kirman's (1992) well-founded criticisms of the use of representative agent and identical agents models presents a problem in selecting a modelling technique.[11] We want techniques that encompass the fact that some economic problems invariably involve many heterogeneous agents, and possibly complex economic processes. Unfortunately, the majority of the standard economic techniques are not suited to address either of these difficult aspects, let alone both of them in combination. There exist techniques from other disciplines, however, which can address these aspects. The model developed in the next section uses one such technique. Of course, it is adapted for the purpose of analysing economic problems.

The model also incorporates several features that some economists, such as Kirman (1992 and 1994), argue are missing from traditional models and as a result considerably weaken their relevance for economic analysis. The model contains a finite number of agents, complex economic processes, and interactions between agents that lie outside the market. Of course the model also includes the normal market mechanism as a part of its structure. At the same time the procedure used

[11] Stoker (1986) is one empirical example which provides evidence against the use of the representative agent.

to incorporate these features does so in a way that addresses two issues raised by Föllmer (1974). Föllmer models a conventional economy with the added feature that agents are allowed to directly interact only with a subset of agents. He proves that an equilibrium may not exist when these interactions are strong. Furthermore, even when an equilibrium exists the laws governing the behaviour of the aggregate economy cannot be ascertained from the structure assumed for the individual agents.

Non-existence of equilibrium in the model of Föllmer is due to his strict interpretation of the law of one price. His definition of equilibrium requires that agents face the same price for each commodity. Obviously this definition is problematic once spatial aspects are introduced. Although prices are not explicitly analysed in the model of this chapter, the equilibrium concept can be thought of as corresponding to that which allows prices faced by agents to be different, due to factors such as transportation costs. The inability in Föllmer's model to characterise the aggregate economy is due to the inadequacy of "averages" to convey all of the necessary information about the behaviour of individual agents. Not only is the average behaviour of agents needed to characterise such an economy, but a measure of the variation in the agent's behaviour is also needed. The technique in this chapter aggregates the behaviour of agents in such a way as to preserve measures of variation. This allows the laws governing the aggregate behaviour of the economy to be attained.

3.3 The Model

The formal model is now developed and applied to explain adoption patterns of process standards.[12] There is a single industry which has a fixed population of

[12] This model uses technical results from Cowan and Cowan (1995). Brock and Durlauf (1995) also use a similar technique, but with much stronger assumptions.

Table 3.1
Actions Available to Suppliers

	No Standard Adopted	r
Action	Adopt Standard a	a
	Adopt Standard b	b

N suppliers. Each supplier receives an order to produce a good of variable quality which it sells to producers of final goods (called firms). The time taken to fulfil the order is finite and random. An order is assumed to be made up of many tasks. A supplier periodically decides which one of three possible actions it wishes to take (these are summarised in Table 3.1). A supplier may adopt one of two process standards.[13] Alternatively, a supplier may choose not to adopt a process standard. It is important to note that an action, including the adoption of a process standard, is not assumed to be a once and forever action. Suppliers repeatedly face the choice of which action to take.

The actions available provide a benefit to the supplier. They are assumed to alleviate the effects of asymmetric information between a firm and a supplier.[14] A supplier knows the current task in making a decision about which action it will take. The remaining tasks that constitute the rest of the order are not perfectly known by the supplier implying that they are myopic.[15] Suppliers are also assumed to be non-strategic.

[13] The process by which the standards are written is taken as given. See Farrell and Saloner (1988) who begin to examine conditions under which standards are likely to be developed.

[14] Alternatively, they may subsidise the acquisition of technological knowledge if the standards are being used to increase the rate that new technologies are adopted.

[15] This is not as restrictive an assumption as it first seems. Suppliers could learn about their environment without changing the nature of the equilibria, however, it would slow down the speed with which any equilibria are reached.

For each order, suppliers solve the usual economic problem of choosing an action to maximise their current net benefits. That is, supplier n solves the problem,[16]

$$\underset{q \in \{r, a, b,\}}{\text{Max}} \ \frac{1}{2}(1 - \lambda Z_q)(G_q + \psi_q Z_q + h_{n,q}).$$

It is assumed that there exist gains from trade between a firm and a supplier which result in a surplus. The expression $G_q + \psi_q Z_q + h_{n,q}$ represents the increase in this surplus, or net benefit, from taking action q.[17] The term G_q measures the "gross" benefit from taking action q. In terms of a standard this incorporates the cost of implementing it, the cost of being audited to ensure conformance to it, and the benefits of lower transaction and production costs between suppliers and firms. Benefits from adopting a standard may also arise in the form of lower defect rates and lower production costs in the goods that the suppliers produce. The term $\psi_q Z_q$ (with $\psi_q \geq 0$) captures factors such as the existence of Marshallian externalities and the life cycle of an auditing industry. The variable Z_q denotes the proportion of suppliers taking action q. It is assumed that ψ_r is zero. The term $h_{n,q}$ will be discussed later in this section.

The net benefit, $G_q + \psi_q Z_q + h_{n,q}$, is split between the firm and the supplier using a reduced form function which is based on some underlying bargaining process. A formal modelling of this process is beyond the scope of the issues under

[16] The supplier's payoff functions for each action have the following properties, ignoring the idiosyncratic term. When $Z_q = 0$, then a supplier's payoff equals $\frac{1}{2}G_q$. When $Z_q = 1$, then the payoff equals $\frac{1}{2}(1 - \lambda)(G_q + \psi_q)$. The maximum payoff value occurs when $Z_q = (\psi_q - \lambda G_q)/(2\lambda\psi_q)$. Say $\psi = 3$, $G_q = 1$, and $\lambda = 1$. Then the payoff values when $Z_q = 0$ and $Z_q = 1$ are 1/2 and 0 respectively. The maximum payoff value in this case is 2/3 and occurs when $Z_q = 1/3$. If $\lambda = 0.5$ then these values are 1/2 and 1 respectively, and the maximum payoff value is 1.021 and occurs when $Z_q = 0.8333$.

[17] This model is framed in a dynamic setting, but time subscripts are suppressed in the endogenous variables since an equilibrium consists of finding their steady state, or time invariant, values.

consideration, would distract from the problem at hand, and is unlikely to change the qualitative results. It is thus assumed that the share of the net benefit accruing to a supplier from adopting a particular process standard falls as the number of adopters increases.[18] The expression $\frac{1}{2}(1 - \lambda Z_q)$ dictates how the net benefit is split between suppliers and firms, with $\lambda \in [0, 1]$. The parameter λ is intended to measure the affect that the other suppliers who take the same action have on the bargaining strength of an individual supplier. The bargaining strength of a supplier is most affected by other suppliers who take the same action when $\lambda = 1$, and least affected when $\lambda = 0$.

It is clear that the problem faced by each supplier is deterministic given the myopia assumption. However, it is assumed that there is a part of each supplier's payoff that is unobservable to the modeller, and as a result, suppliers are characterised stochastically in analysing this environment. This assumption is used by econometricians when specifying a model for estimation purposes. An observationally equivalent assumption is to assume that the modeller has complete information about the payoffs, but the payoffs change over time due to stochastic features underlying the environment of suppliers. See Anderson, de Palma, and Thisse (1992, Chapter 1) for more details. Thus, I assume that there is an idiosyncratic component, $h_{n,q}$, from supplier n taking action q with its current task. It is assumed that

[18] Two conditions are required to obtain the results of Shaked and Sutton (1984): a firms cannot make simultaneous offers to suppliers, and there is some finite time before a firm can decide to switch to another supplier. In the context of the standards adoption model we would need that the time that a firm can switch from a supplier who has adopted a standard is negatively affected by the number of firms who have adopted the standard. No doubt this switching time would also be affected by the number of suppliers who take other actions. This could be incorporated in the model but is of second order effect, would complicate the model, and would not change the qualitative results. The key assumption for the present model is simply that the bargaining power of suppliers who adopt a standard is negatively and more strongly affected by the number of adopters of the same standard than adopters of other standards. This assumption seems likely to be robust to many changes in the underlying bargaining framework.

the $h_{n,q}$ are i.i.d., non-negative, and have mean μ. The idiosyncratic factor shifts the relative merits of the actions for each supplier.

Define $X = (\mathbf{q}, \phi)$ as a micro-state of the system, where $\mathbf{q}$ is a vector listing the actions taken by the N agents, and ϕ is a matrix listing the realisations of the idiosyncratic components (the $h_{n,q}$s). This is an $(N \times 3)$ matrix with $X_{n,q}$ taking the value 1 if supplier n takes action q and 0 otherwise. We wish to analyse the effects of changing values of the parameters describing a supplier, but our interest is in macro-variables, not micro-states. Since many different micro-states can be associated with a particular value of a macro-variable, more structure is needed to generate the relationship between the supplier's problem and the macro-variable. In models like the one just described it is innocuous to assume that the probability of observing a state q takes the form,

$$\Pr(\mathbf{q}) = \frac{e^{\beta \overline{P}(\mathbf{q})}}{\sum_{\mathbf{q}'} e^{\beta \overline{P}(\mathbf{q}')}}, \tag{3.1}$$

where $\mathbf{q}$ is a state of the economy, $\overline{P}(\mathbf{q})$ is the aggregate payoff averaged over the idiosyncratic components, and β is an aggregate measure of heterogeneity among suppliers, we can derive this relationship.[19] A justification for using this distribution is given in Appendix 3.1. Higher values of β mean that the idiosyncratic

[19] Over the last 150 years, several different methods have been developed to study systems that involve many individual components, where the components are assumed to experience random perturbations, and to interact with one another. The economic model developed in this chapter is, of course, such a system. Different examples of these methods can be found in Shrödinger (1967), Wannier (1966), Pathria (1972), Waldram (1985), Ruelle (1991), and Sonntag and Van Wylen (1991). Each of these methods, using different assumptions and different derivations, arrived at the same answer; the Gibbs-Boltzmann distribution (equation 3.1), so named after the two creators of a new branch of the physical sciences who discovered this property of complex systems. These methods have taken a very long time to become integrated into the practices of the pertinent subject areas as discussed by Sklar (1993) and Ruelle. Both authors describe the conceptual difficulty researchers have had in understanding these methods, this difficulty existing even today. Of course the methods are applicable to complex economic systems, as is shown by Wilson (1967). He uses a derivation similar to the argument found in Appendix 3.1, in an economic model that studies transportation patterns. He reports (Wilson (1991)) that acceptance

benefits of each action with the current tasks facing suppliers become less important relative to other factors influencing which action to take. An aggregate state is a description of the states of the N suppliers. But, we are interested in the prevalence of certain actions, or equivalently, the probability that a supplier takes a particular action such as adopting standard a. We can derive this probability, given by,

$$\Pr(q_n) = \frac{e^{2\beta\overline{p}(q_n)}}{\sum_{q'_n} e^{2\beta\overline{p}(q'_n)}}, \tag{3.2}$$

from equation (3.1) and where $q \in \{r, a, b\}$. The term $\overline{p}(q_n)$ represents the expected payoff of action q over the idi yncratic components to agent n. Appendix 3.2 shows how this probability is derived from (3.1).

3.4 Equilibrium Conditions

An equilibrium in this model is defined by three steady state probabilities. They describe the likelihood that a supplier will choose one of the three available actions when it has a decision making opportunity. These probabilities are also equivalent to the proportions of suppliers taking each action since they are identical

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of his work has been very slow, even though his model has been extremely successful in explaining transportation patterns. He attributes the slowness in the acceptance of his work to the inability of researchers to grasp fully the workings of the technique he uses to cope with a model that involves many agents, where the agents are assumed to experience random perturbations, and to interact with each other. The distribution derived by Anderson, de Palma, and Thisse (1992) from a random utility discrete choice model, where the idiosyncratic components are assumed to be distributed double exponential, and in which agents do not interact, turns out to be the Gibbs-Boltzmann distribution. In a similar vein, Brock and Durlauf (1995), again making strong distributional assumptions, show that the aggregate economic properties of a random utility discrete choice model, with strong restrictions placed on how the decision of an agent can affect the decisions of other agents, can be described by the Gibbs-Boltzmann distribution. The double exponential distribution is not assumed for the idiosyncratic components in the model of this chapter, nor are arbitrary restrictions placed on the interactions between agents, because of the specificity of the derivations of Anderson, de Palma, and Thisse, and Brock and Durlauf, and hence their results. The same results can be attained with far less restrictive assumptions, as is shown in Appendices 3.1 and 3.2, allowing the study of much richer economic systems.

ex-ante. Three factors affect the adoption decision of a supplier. First, there is the idiosyncratic component which represents the inherent benefit of taking an action with the current task facing the agent. This factor encourages suppliers to ignore what other suppliers are doing and choose an action that best fits their current idiosyncratic requirements. The Marshallian externalities and life cycle auditing path create an incentive for suppliers to co-ordinate their decisions and take the same action. The reduced form bargaining expression also creates an incentive for suppliers to co-ordinate their decisions, but instead of wanting to do the same thing, suppliers want to choose an action different from those around them. This has the effect of tempering the agglomeration of suppliers around any one action, and can cause suppliers to favour dispersion when they choose which action to take. An equilibrium occurs when all three factors are in balance. Note that an equilibrium may mean that an individual supplier chooses different actions over time. The aggregate adoption fractions, however, will remain unchanged. An equilibrium here is a balancing of "forces", not constancy of choices.

The following system of equations describe the equilibrium of the model,

$$Z_r = \frac{e^{\beta(1-\lambda Z_r)(G_r+\mu)}}{D}, \tag{3.3}$$

$$Z_a = \frac{e^{\beta(1-\lambda Z_a)(G_a+\psi_a Z_a+\mu)}}{D}, \tag{3.4}$$

$$Z_b = \frac{e^{\beta(1-\lambda Z_b)(G_b+\psi_b Z_b+\mu)}}{D}, \tag{3.5}$$

where,

$$D = e^{\beta(1-\lambda Z_r)(G_r+\mu)} + e^{\beta(1-\lambda Z_a)(G_a+\psi_a Z_a+\mu)} + e^{\beta(1-\lambda Z_b)(G_b+\psi_b Z_b+\mu)}.$$

To obtain the set of equilibria for the model requires simultaneously solving equations (3.3) to (3.5) for the proportions of suppliers who have taken each action.

In general this system cannot be solved analytically. It can, however, be solved computationally if parameter values are fixed. Carrying out this procedure for many values of the parameters will provide us with a comprehensive description of the model.

3.5 Comparative Statics

All of the results reported assume that the mean of the idiosyncratic components equals one. Changes in μ produce the same effects on the adoption shares as changes in the gross benefit parameters. Welfare for each equilibrium is calculated using the expected utility of a supplier before the supplier realises its idiosyncratic term. Anderson, de Palma, and Thisse (1992, pp. 60-61) show that this is the correct definition of welfare for this type of economic structure, since a Pareto ranking will not in general exist when different equilibria arise. There will be extreme realisations of the idiosyncratic terms that will cause some suppliers to adopt an action that is not widely adopted in one equilibrium, but is in another. Of course there will be suppliers in the reverse position as well. They will, therefore, disagree about which equilibrium is better.

There are two cases to consider: when the alternative action is always inferior to both of the standards; and when it is superior to at least one of the standards. Table 3.2 summarises the properties of the equilibria when gross benefit of the alternative action is zero. This is approximately the case analysed in the existing literature. It assumes that the standards are predominately competing with one another, rather than with any alternative action. As is to be expected, the parameter values for the functional forms critically affect the nature of the equilibria. More surprisingly, small changes in these parameters can have very large consequences. Appendix

3.3 presents a selection of figures which show adoption patterns for different values of the parameters. A detailed explanation of each figure is also contained in the beginning of this appendix.

3.5.1 Multiple Equilibria and Inefficiencies

There are several conditions that have to be fulfilled before multiple equilibria can occur. First, suppliers have to be relatively homogeneous, implying that they are strongly influenced by the actions of others. Second, the bargaining heterogeneity needs to be weak. This means that suppliers capture a large fraction of the gains associated with adopting a standard, regardless of the actions of other suppliers. Third, the positive pecuniary externality has to be large relative to the gross benefit from adopting a standard. This allows bandwagons to form. In this situation suppliers all adopt the same standard to benefit from the associated positive externality. When these three conditions are fulfilled, it is in the interests of suppliers to adopt a common standard. The suppliers are very similar which means that they derive little benefit from adopting an uncommon standard. The suppliers also capture a large fraction of the surplus associated with adopting a standard, even if many other suppliers have also adopted it. Finally, there are large benefits from having suppliers adopt a common standard.

Typically, some of the multiple equilibria are inefficient, for reasons similar to the results from the existing literature on standards adoption. As long as the degree of Marshallian externalities and auditing life cycle effects are sufficiently large, then there is an incentive for a supplier to do the same thing as everyone else. Multiple equilibria arise because both standards are beneficial and a supplier follows the crowd. From the perspective of a supplier, if all the other suppliers have adopted a standard it should adopt it too, regardless of which standard the other suppliers have adopted. Carry this logic over to each supplier and it is easy to see why either standard can become dominant, even if one of the standards is the inferior one.[20]

3.5.2 Coexistence of Different Standards

Different standards can coexist in two main ways. Suppliers may be relatively heterogeneous, in which case the main factor influencing their behaviour is their own idiosyncratic circumstances. This inhibits suppliers adopting the same standard. When the bargaining externality is strong, different standards will also generally coexist. If suppliers all adopt the same standard, they receive little of the benefit from the associated reduction in transaction costs. It is more worthwhile for a supplier to choose a standard that is less heavily adopted, even if it is an inferior one, so that they have a more favourable bargaining position. They can then capture a significant fraction of the associated benefits.

3.5.3 Phase Changes

There are many examples of a small change in the value of a parameter, holding the values of the other parameters constant, causing very large changes in the resulting equilibrium adoption shares. These are commonly referred to as phase changes, and they happen in the following circumstances. Consider investigating the effects on adoption shares from changing one parameter. Hold constant the values of the other parameters, but make their values such that suppliers have an incentive to adopt a common standard. In general, there will exist a small range of values of the parameter of interest in which a phase change occurs. It is comparable to the situation where decreasing returns to production imply the existence of a very large number of firms, and increasing returns imply the existence of just one

[20] Note that a standard is considered to be inferior if it has a smaller gross benefit than another standard, but the same degree of positive externalities. Similarly a standard is considered inferior if it has the same gross benefit as another standard, but a smaller degree of positive externalities associated with it.

Table 3.2
Summary of Equilibria when the Alternative Action is Inferior to Both Standards

		Producer Heterogeneity			
		Low		High	
		Bargaining Power Externality		Bargaining Power Externality	
		Low	High	Low	High
Strength of the Positive Externalities versus Strength of the Gross Benefits	Low	Single equilibrium, which is efficient. Dispersion of adoption shares. Adoption shares strongly affected by differences in the standards.	Single equilibrium, which is efficient. Dispersion of adoption shares. Adoption shares weakly affected by differences in the standards.	Single equilibrium, which is efficient. Dispersion of adoption shares. Adoption shares weakly affected by differences in the standards.	Single equilibrium, which is efficient. Dispersion of adoption shares. Adoption shares are unaffected by differences in the standards.
	High	Multiple equilibria, some of which are inefficient. All but one standard are abandoned. Adoption shares are unaffected by differences in the standards.	Single equilibrium, which is efficient. Dispersion of adoption shares. Adoption shares weakly affected by differences in the standards.	Single equilibrium, which is efficient. Dispersion of adoption shares. Adoption shares moderately affected by differences in the standards.	Single equilibrium, which is efficient. Dispersion of adoption shares. Adoption shares weakly affected by differences in the standards.

firm. The knife-edge occurring when returns are constant. The same sort of effect is causing the phase changes to occur.

3.5.4 A Superior Alternative Action

The presence of a superior alternative action does not change the qualitative nature of the results in most cases, it merely causes an increase in the proportion of suppliers who take this action compared to when it was inferior to the standards.

In some circumstances, however, it is possible that a sufficiently high gross benefit of the alternative action can lead to an inefficient equilibrium. This occurs when the standards are characterised by large positive externalities, but only have small gross benefits. Since the gross benefit of the alternative action is relatively high compared to the standards, it never pays suppliers to adopt one of them and risk being stranded. The heavy adoption of the alternative action in such a case corresponds to the situation where the dynamics never allow one of the standards to reach a critical adoption mass to overcome the difference between its gross benefit and that of the alternative action. Thus, adoption of a standard in these cases never gets off the ground.

3.5.5 Adoption of Multiple Standards by Suppliers

It would be straightforward in this setup to allow suppliers to adopt more than one standard at a time, say a and b. This would effectively create a new standard which could be easily analysed using the previous results.[21] There are two critical details. The degree of substitutability or complementarity in the coverage of the standards, and the overlap of resources required to adopt them. If the standards contained considerable overlap in the information they conveyed about the state of the suppliers production technology, then the increase in the benefit from adopting them both is small. If adopting both standards required substantially different forms of say record keeping, then the costs of adopting both standards would be large. In this case we could expect the net gain from adopting both standards to be less than from adopting only one of them. Thus, only a small number of suppliers would adopt both standards. On the other hand if they were complementary and costs could be shared, then we could feasibly expect the net gain from adopting

[21] It should be noted that this discussion is temporarily "ignoring" the assumption of independence of irrelevant alternatives mentioned in Chapter 2, since similar standards should be treated as a single one.

them both to be higher than adopting a single standard. This would mean that a large number of suppliers would adopt both standards.

3.6 Conclusions

This chapter explores the effects of extending the conventional literature by incorporating non-trivially heterogeneous agents, an action other than adopting a standard, and decreasing as well as increasing returns to adoption. Introducing a more realistic environment results in many cases in which the adoption shares are dispersed. This holds even when there are strong increasing returns to adoption, in contrast to the results of the existing literature. Introducing heterogeneity shows that while inefficient equilibria are possible, there are several conditions needed before they exist. Although, these can still occur if the increasing returns are strong enough, and they dominate other factors influencing the adoption decisions of agents. This outcome suggests that we should be very careful in scrutinising claims that the adoption of a particular standard is inefficient. It also suggests that inefficient equilibria may not be as prevalent in practice as is commonly thought.

As predicted by Arthur (1990), there are examples of parameter values which result in many equilibria when they imply increasing, and then decreasing, returns to adoption. Surprisingly, there are very few parameter combinations that produce them. The existence of so few such parameter combinations is due to the presence of the non-trivial heterogeneity among agents.

A surprising outcome of this model is that small changes in parameter values can have large consequences, commonly referred to as a phase change. A small change in a parameter value, such as the gain accruing from adopting a standard, can mean that one standard is almost completely adopted while others are abandoned. Given the structure of the model, particularly that governing the heterogeneity of the agents, we would have instead expected that the adoption shares would change more gradually with changes in the parameter values.

The robustness of these results to explicitly introducing the third key element affecting the adoption of standards, the location of suppliers in geographic and/or product space, is the subject of the next chapter.

Appendix 2.?

Characterising the Aggregate Economy

The following argument is taken and adapted from Cowan and Cowan (1995). The reader is advised to refer to their paper for a more comprehensive and general presentation and explanation of this material. The technique about to be described is used in response to the difficulty of analysing macro-economic relationships in a complex economy. In principle, analysing such an economy could be achieved by writing down the characteristics of each agent in the economy under consideration, incorporating how the agents affect each other, assuming particular forms of probability distributions for any random variables, and then aggregating. In practice this is not done due to intractability problems. There are two possible approaches to circumvent this problem, as discussed by Sonntag and Van Wyler (1991, pp. 17-18). The first approach is to reduce the number of variables in an economy to a manageable few, such as the stock of money, aggregate investment and consumption, and the aggregate unemployment rate. Relationships between these gross, or average, variables can then be analysed. This is the common approach taken in macroeconomics, where an economy is typically assumed to behave like a "representative agent", with the relationships analysed involving only aggregate variables.[22] A second approach is to look at the individual agents constituting an economy, but use "statistical considerations and probability theory" (Sonntag and Van Wyler (1991, p. 18)) to analyse the economy. This approach deals with the "averages" of

[22] I would imagine most macroeconomists may disagree with this description since they commonly claim, rather emphatically, that their models have "microeconomic foundations". In practice what this means is that they restrict attention to certain functional relationships between aggregate variables, those that conform to the representative agent. See Kirman (1992) and (1994) for a more thorough critique and repudiation of the representative agent paradigm.

the agents being analysed. The technique about to be described follows the second route.

Consider an economy consisting of N agents (or suppliers in the model in the text) where N is large, but finite. Each agent chooses one of Q possible actions (where there are three possible actions in the model in the text: adopt one of standards a or b, or do not adopt a standard), where $\mathbf{q} = (q_1, \ldots, q_n, \ldots, q_N)$ is the vector describing the choices of the agents. Associated with each action, for each agent, is an idiosyncratic component. The idiosyncratic components are distributed i.i.d. Define a micro-state of the economy as the matrix $X = (\mathbf{q}, \phi)$, where ϕ describes the idiosyncratic components. The economy is moving around from micro-state to micro-state within this space. Assume that in the absence of any further economic considerations, the economy is equally likely to be in each micro-state (this will be referred to as the equipartition assumption). Furthermore, make the innocuous assumption that the values of any macro-variables in which we are interested, can be determined by the micro-state. That is, assume that for any macro-variable, V, $V = V(\mathbf{q}, \phi)$. The payoff to an agent from taking an action is given by $p_n(\mathbf{q}, h_{n,q})$, where $h_{n,q}$ is the idiosyncratic component. Note that the payoff to an action for an agent can depend, in an arbitrarily complex fashion, on the actions of other agents, including forms of spatial interactions between the agents. Associated with a micro-state of the economy is a value of the macro-variable, which in the model in the text is defined as $P(\mathbf{q}) = \sum_{n=1}^{N} p_n(\mathbf{q}, h_{n,q})$, where P denotes aggregate payoffs. Since N and Q are finite, there are a finite number of values that P can take, denote them $\{P_1, \ldots, P_m, \ldots, P_M\}$. A macro-state of the economy is a collection of micro-states all having the same value of the macro-variable.

How do we analyse the above economy? As Cowan and Cowan demonstrate, instead of analysing a single economy, we instead imagine an ensemble of economies and make calculations on the average values of the variables in the ensembles, implicitly treating the ensemble as a collection of observations of a single economy.[23]

Consider an ensemble of T like, but distinct economies, where T is large. Each member of the ensemble is in a particular micro-state, which corresponds to a particular macro-state. The state of the ensemble can be written as a vector of T macro-variables, which in the model in the text would be aggregate payoffs, P. We can describe the ensemble by a frequency distribution $A = (a_1, \ldots, a_m, \ldots, a_M)$, where a_m of the members of the ensemble are in a micro-state that has the value of the macro-variable P_m. What is the probability that a particular distribution A will occur? First, recall that we have assumed that the probability that the ensemble will give rise to the distribution A is proportional to the number of states that give rise to the distribution A (this is the equipartition assumption discussed earlier). The number of combinations that generate a distribution A from an ensemble of size T is given by,

$$\Omega(A) = \frac{T!}{a_1! \ldots a_m! \ldots a_M!}.$$

If T is large then the distribution $\Omega(A)$ has mass concentrated at its modal value (Pathria (1972, pp. 53-61)). Thus there is effectively only one distribution of macro-states which (following Cowan and Cowan) we will call A^*. We can find A^* by maximising Ω with respect to A. Thus we maximise the following Lagrangian

[23] As they point out, this approach is an operationalisation of the "frequency of observation" view from the philosophy of probability.

with respect to a_m,

$$\mathcal{L}(A, \beta, \lambda) = \ln \Omega - \lambda \left(\sum_{m=1}^{M} a_m - T \right) + \beta \left(\sum_{m=1}^{M} a_m P_m - T\widehat{P} \right).$$

Note that the log is taken for technical convenience and does not affect the results since it is a monotonic operator. The first condition is simply an adding up constraint. But what is the role of the second condition? First, maximise Ω with only the first constraint. This is the expected frequency distribution with no economic constraints added to the economy. But now suppose we are interested in an economy in which the expected value of the macro-variable (which would be determined by the economic fundamentals) is $\widehat{P}$. This information will clearly affect the nature of the most probable frequency distribution. We can take account of it by including it as a constraint in the maximisation problem — that is, we will look for a maximum among the ensembles that have $E(P) = \widehat{P}$. As Cowan and Cowan note, any condition or restriction on the properties of the system at the macro level can be included here, the conditions being determined by the relationships in which the modeller is interested.

Because T is assumed to be large, we can approximate Ω using Stirling's formula for factorials: $\ln x! \approx x(\ln x - 1)$. Thus, the Lagrangian is now of the form,

$$\mathcal{L}(A, \beta, \lambda) = \ln (T(\ln T - 1)) - \sum_{m=1}^{M} \ln (a_m(\ln a_m - 1)) - \lambda \left(\sum_{m=1}^{M} a_m - T \right) + \beta \left(\sum_{m=1}^{M} a_m P_m - T\widehat{P} \right).$$

Maximising this with respect to a_m we get,

$$\frac{\partial \mathcal{L}}{\partial a_m} = -\ln a_m - \lambda + \beta P_m = 0,$$

which can be immediately rearranged to give,

$$a_m = Ke^{\beta P_m}.$$

where $K = e^{-\lambda}$.

We now have the distribution over the aggregate payoffs for the economy given by the a_ms. Normalising these (by solving for λ) gives us the probability of an economy having a particular aggregate payoff, which is given by,

$$\Pr(P_m) = \frac{e^{\beta P_m}}{\sum_{m=1}^{M} e^{\beta P_m}}.$$

All that is left to do now is to integrate out the idiosyncratic components. First note that an aggregate payoff is completely determined by the actions of the agents and the realisations of the idiosyncratic components. Thus we know that $\Pr(\mathbf{q}, \phi) \propto e^{\beta P(\mathbf{q},\phi)}$. Normalising, we can rewrite this as,

$$\Pr(\mathbf{q}, \phi) = \frac{e^{\beta P(\mathbf{q},\phi)}}{\sum_{\phi'} \sum_{\mathbf{q}'} e^{\beta P(\mathbf{q}',\phi')} f(\phi)},$$

where $f(\phi)$ is a probability density function for the idiosyncratic components. Next integrate over ϕ to get the aggregate distribution of $\mathbf{q}$, or,

$$\begin{aligned}\Pr(\mathbf{q}) &= \sum_{\phi} \Pr(\mathbf{q}, \phi) f(\phi) \\ &= \frac{\sum_{\phi} e^{\beta P(\mathbf{q},\phi)} f(\phi)}{\sum_{\phi'} \sum_{\mathbf{q}'} e^{\beta P(\mathbf{q}',\phi')} f(\phi)} \\ &= \frac{e^{\beta \overline{P}(\mathbf{q})}}{\sum_{\mathbf{q}'} e^{\beta \overline{P}(\mathbf{q}')}}, \qquad (A3.1.1)\end{aligned}$$

This relationship provides a complete description of the macro-economy.

Additional Comments

First, how appropriate is the use of Stirling's approximation? Cowan and Cowan (and Wilson (1967)) show that the use of Stirling's approximation is innocuous for even relatively small systems.

Finally, it may seem counter intuitive that the probability of observing a macro-variable is proportional to the (positive or negative) exponential of that value. But Cowan and Cowan explain the intuition behind this relationship. Ignore, temporarily, the second constraint. Then the maximum of Ω occurs when the a_ms are all the same. Denote the maximising value of A in this case as A'. Now include the second constraint. The optimising value of A will be A^*. There will exist some value of $\widehat{P}$, call it $\widehat{P}'$, such that $A^* = A'$, and the a_ms will take on the same values in both cases. Obviously if $\widehat{P} \neq \widehat{P}'$, then the a_ms will not all be the same. The probabilistic relationship derived above describes how the a_ms must differ from the uniform. As Cowan and Cowan note, the relationship "...simply describes some of the properties of the arithmetic of calculating mean values when there are a large number of possible states over which the mean must be calculated." This result is not immediately obvious since $\widehat{P}$ does not appear in ($A3.1.1$). But it is easily shown that $\widehat{P}$ is monotonically related to β, hence β can be replaced by $\widehat{P}$ in ($A3.1.1$). It is also worth noting that the exponential nature of the distribution that results from the derivation is driven by the form of the second constraint. If we were looking at say geometric means, instead of arithmetic means, we would not in general get an exponential distribution. The form of the resulting distribution is an artifact of the particular macro-variables in which the modeller is interested.

There are three key assumptions needed to obtain the above result. First, the number of suppliers in an economy has to be finite, but sufficiently large.[24] Second, the idiosyncratic components have to be truly exogenous. Third, in the absence of any economic considerations we need to assume that each micro-state is equally likely to occur. This is the equipartition assumption (note that it is assumed before any economic theory is introduced), and Cowan and Cowan (1995, Appendix) show that it is innocuous.[25]

What role do these assumptions play? Having a large enough number of suppliers ensures that technical approximations used in deriving (3.1) are sufficiently accurate. Having a finite number of agents and possible states is a technical assumption which allows the aggregation technique to work. The technique works by "counting" the number of possible aggregate states of the economy and then working out the likelihood that each of them occurs. Wannier (1966, Chapter 3) or Sonntag and Van Wylen (1991, Chapter 16) provide good summaries of how counting can be used to derive average behaviours of arbitrarily complex systems. With a sufficiently large number of agents this gives us the only distribution of aggregate payoff values with non-zero probability.[26] We can then derive the equi-

[24] It has been shown in simulations that $N > 100$ is more than sufficient. See Waldram (1985).

[25] They show that we can take a world where each micro-state is not equally likely to occur, and map it into an observationally equivalent world where all micro-states are equally likely. For example, assume a world with two micro-states s_1 and s_2, where the probabilities of s_1 and s_2 occurring are 0.6 and 0.4. Obviously the micro-states are not equally likely so it seems as though we cannot use equation (3.1) to characterise it. But relabel the micro-states as $\bar{s}_1$, $\bar{s}_2$, $\bar{s}_3$, $\bar{s}_4$, and $\bar{s}_5$, where the first three micro-states are identical with s_1 and the last two are identical with s_2. Each micro-state is equally likely in the second world so we can use (3.1) to characterise it. It is also observationally equivalent to the first world, therefore the results we obtain for the second world hold exactly for the first world. It is also the case that some deviations from uniformity can be included simply as constraints in the Lagrangian. If for example the macro-variable is believed to have bounds, this can be written as a constraint that is added to the Lagrangian.

[26] See Pathria (1972, p. 61).

librium numbers of agents that choose each action. There may be more than one such equilibrium configuration.

Interestingly enough, there are several other aggregation techniques available for analysing the structure implied by the model.[27] Furthermore, the form of equation (3.2) is very similar to that derived in discrete choice theory. But (3.2) is obtained after assuming the much less restrictive condition that the decisions of suppliers are interdependent. In fact it allows an arbitrarily large amount of complexity in the decision making processes of agents. This can include highly complex spatial interactions between the agents. The model of Chapter 4 exploits this very useful feature, which is not present in most conventional techniques. Or if it is, is of limited use due to the non-robustness of results that occur for small changes in the specifications of models, see for example Eaton and Lipsey (1975). Chapter 2 discusses these issues in more detail.

[27] See Pathria (1972, Chapter 3) and Wannier (1966, Chapter 18).

Appendix 3.2

Characterising An Individual

This appendix takes the forms describing the aggregate economy, developed in Appendix 3.1, and manipulates them to obtain the equilibrium characteristics of an individual. This will give us equation (3.1) in the main part of this chapter.

From Appendix 3.1 we know that the aggregate economy can be described by the equation ($A3.1.1$). We will use this to derive the proportions of agents who take each action. We accomplish this by deriving the probability that an arbitrary agent, denoted by n, takes action q.

First, fix the states of all other agents except n (where the state of an agent now refers to the action chosen by the agent) and denote their joint state by $\mathbf{q}_{-n}$. We can ask about the probability of this joint event, or $\Pr(q_n; \mathbf{q}_{-n})$. This is the joint probability that agent n takes action q while all other agents are in state $\mathbf{q}_{-n}$. Since $(q_n; \mathbf{q}_{-n})$ is now a complete description of the joint states of the agents, we know from ($A3.1.1$) that,

$$\Pr(q_n; \mathbf{q}_{-n}) = \frac{e^{\beta \overline{P}(q_n; \mathbf{q}_{-n})}}{\sum_{\mathbf{q}} e^{\beta \overline{P}(\mathbf{q})}}. \qquad (A3.2.1)$$

where the sum on the denominator over $\mathbf{q}$ is over all possible joint states of the agents in the economy.

To find the unconditional probability we integrate over all possible values of $\mathbf{q}_{-n}$, which gives us,

$$\Pr(q_n) = \frac{\sum_{\mathbf{q}'_{-n}} e^{\beta \overline{P}(q_n;\mathbf{q}'_{-n})}}{\sum_{\mathbf{q}} e^{\beta \overline{P}(\mathbf{q})}}. \qquad (A3.2.2)$$

Next decompose $\mathbf{q}$ into two terms representing all possible states for agent n and all possible states for the other agents. This gives us,

$$\Pr(q_n) = \frac{\sum_{\mathbf{q}'_{-n}} e^{\beta \overline{P}(q_n;\mathbf{q}'_{-n})}}{\sum_{q'_n} \sum_{\mathbf{q}'_{-n}} e^{\beta \overline{P}(q'_n;\mathbf{q}'_{-n})}}. \qquad (A3.2.3)$$

where $q'_n \in 1, \ldots, Q$. To perform these sums we need to rewrite the costs in the following manner. Divide the payoff incurred by an arbitrary agent into the payoff generated by interactions with agent n and denote this by $\overline{P}_n$, and the payoff generated by interactions without agent n, and denote this by $\overline{P}_{-n}$. We can now rewrite equation $(A3.2.3)$ as,

$$\Pr(q_n) = \frac{\sum_{\mathbf{q}'_{-n}} e^{\beta \overline{P}_n(q_n;\mathbf{q}'_{-n})} e^{\beta \overline{P}_{-n}(q_n;\mathbf{q}'_{-n})}}{\sum_{q'_n} \sum_{\mathbf{q}'_{-n}} e^{\beta \overline{P}_n(q'_n;\mathbf{q}'_{-n})} e^{\beta \overline{P}_{-n}(q'_n;\mathbf{q}'_{-n})}}. \qquad (A3.2.4)$$

The form of equation $(A3.2.4)$ allows us to draw an immediate observation about the nature of the solution. Agents are indistinguishable to the analyst, so each agent has the same probability of taking action q. This must be the same as the proportion taking action q. Since the payoffs to agents are determined by this proportion, any payoffs generated by interactions not involving agent n will be constant. Thus all of the $\overline{P}_{-n}$ terms cancel from equation $(A3.2.4)$ which leaves us with,

$$\Pr(q_n) = \frac{\sum_{\mathbf{q}'_{-n}} e^{\beta \overline{P}_n(q_n;\mathbf{q}'_{-n})}}{\sum_{\mathbf{q}'_{-n}} \sum_{q'_n} e^{\beta \overline{P}_n(q'_n;\mathbf{q}'_{-n})}}. \qquad (A3.2.5)$$

But when we consider the payoffs to supplier n we observe that they are determined by the proportions taking the Q actions. So we can perform a change of variables and integrate, not over $\mathbf{q}_{-n}$, but over each of the Z_q, where Z_q is the proportion of agents taking action q. But because the agents who take an action are indistinguishable, the proportion of agents taking action q_n is constant. As a result, the sum over $\mathbf{q}_{-n}$ cancels and we are left with,

$$\Pr(q_n) = \frac{e^{\beta \overline{P}_n(q_n, Z_q)}}{\sum_{q_n'} e^{\beta \overline{P}_n(q_n', Z_{q'})}}. \qquad (A3.2.6)$$

What is $\overline{P}_n(q_n)$? The payoff to agent n is determined entirely by interacting with agents who take the same action. Each of these agents has an analogous interaction with n, so the payoffs associated with interactions in which n is "the second party" will be identical to those in which n is the "first party". Thus $\overline{P}_n(q_n, Z_q) = 2\overline{p}(q_n, Z_q)$, where $\overline{p}(q_n, Z_q)$ is just the payoff function for an individual agent, so we can rewrite $(A3.2.6)$ as,

$$\Pr(q_n) = \frac{e^{2\beta \overline{p}(q_n, Z_q)}}{\sum_{q_n'} e^{2\beta \overline{p}(q_n', Z_{q'})}}. \qquad (A3.2.7)$$

This procedure can be carried out for each action, and the relationship derived completely characterises an individual agent.

It is worth noting that this procedure also holds for any number of countries and for any number of actions. Consider what happens if there are two countries, say A and B. Equation $(A3.2.4)$ allows us to draw another observation. Assume that agents in either country can again take one of Q actions, and that the interaction effects may occur across the countries. Then the solution to this equation will be in the form of $2Q$ simultaneous equations, Q for each country. Thus we would be able to treat the agents in country B as fixed (remembering that agents within a country are indistinguishable). This implies a constant value of the proportions of agents taking all Q actions in country B. This argument works for any number of countries.

Interpretation of Beta

The parameter β is important in determining the aggregate choice patterns, yet it is not immediately obvious what interpretation to give to it. Anderson, de Palma, and Thisse (1992, pp. 39-40) show that if the idiosyncratic random variables are drawn from a double exponential distribution, and there are no interactions among agents, they have variance $\frac{2}{3}(\frac{\pi}{\beta})^2$. Thus, the variance of the average aggregate payoffs is a function of β, and an increase in β decreases the variance of the idiosyncratic random variables, or equivalently decreases the degree of heterogeneity of the agents.

More generally, consider an economy without any interaction between agents and two process standards, q_1 and q_2, each with average payoff $\bar{p}_1$ and $\bar{p}_2$ over the distribution of orders. The probability that agent n adopts process standard q_1 is then equal to,

$$\Pr(\bar{p}_1) = \frac{e^{\beta\bar{p}_1}}{e^{-\beta\bar{p}_1} + e^{\beta\bar{p}_2}}.$$

Consider the limiting values of this probability. As $\beta \to 0$ then $\Pr(\bar{p}_1) \to \frac{1}{2}$ and as $\beta \to \infty$, $\Pr(\bar{p}_1) \to 1$ if $\bar{p}_1 > \bar{p}_2$ or $\Pr(\bar{p}_1) \to 0$ if $\bar{p}_1 < \bar{p}_2$. In other words, if β is large agents will tend to choose the same process standard and if β is small agents are equally likely to choose either process standard. If agents are choosing the same process standard then they must all be facing the same decision problem at each moment they choose a process standard. This implies that there is no heterogeneity in the orders assigned to agents. On the other hand, if agents are equally likely to choose either process standard there must be a large degree of heterogeneity in the orders assigned to agents. The parameter β is thus a measure of the heterogeneity of order assignment (for the current problem being studied). Large values of β imply little heterogeneity among agents and small values of β imply substantial heterogeneity among agents.

Appendix 3.3

Examples of Equilibrium Adoption Patterns

Interpreting the Figures

The following figures display examples of the equilibria attained in solving the model for various parameter values. The figures show how adoption shares vary as one parameter is varied while all others are held constant. Below each figure identifier are the values of the parameters held constant in obtaining the results. When parameters are displayed without subscripts, then their value is the same for each action. The equilibrium adoption shares of all three actions are presented on each figure. Note that there are cases of multiple equilibria for some sets of parameter values. Finally, and without loss of generality, the parameter μ is set to one for all of the reported results.

What are the effects of varying each of the parameters? Decreasing the degree of heterogeneity (larger values of β) increases the proportion of suppliers who take the same action. This increase may be very large (Figures 3.2, 3.4, 3.21, 3.22, and 3.23) or be very small (Figures 3.1, 3.3, 3.24), depending on the values of the other parameters. Multiple equilibria may also exist with larger values of β ($\beta > 3.6$ in Figure 3.4). Note that the equilibrium in Figure 3.2 where $Z_a = 0.5$ and $Z_b = 0.5$ is unstable. Decreases in the strength of the bargaining externality have the same qualitative effect as increases in β (compare Figures 3.2 and 3.6, and Figures 3.3 and 3.7). Similar qualitative effects also occur from decreases in the gross benefits, or increases in the positive pecuniary externalities, of both standards (compare Figures 3.12 and 3.16 with Figure 3.4).

Varying the gross benefit, or pecuniary externality, of one of the standards while keeping the parameters describing the other standard constant, produces changes in the adoption patterns that would be expected. An increase in the gross benefit of a standard results in an increase in the proportion of the suppliers who adopt it (Figures 3.17 and 3.18). The same result holds for increases in the parameter measuring the strength of the pecuniary externality (Figures 3.19 and 3.20).

Consider now the effect that the gross benefit of the alternative action, G_r, has on the adoption patterns. This is displayed in Figures 3.27 and 3.28. When the degree of heterogeneity is large and/or the bargaining power externality is strong, then increases in G_r weakly increases the proportion of suppliers taking the alternative action. A small amount of heterogeneity and weak bargaining power externalities produces different results. If G_r is small it is adopted by few suppliers ($G_r < 3$). If it is large it is adopted by most suppliers ($G_r > 4$). But, there also exists a range of values of this parameter ($2.5 < G_r < 4$), which give rise to multiple equilibria, even though there is no positive pecuniary externality from taking the alternative action.

Even when one standard is obviously superior to the other, it can still be the case that either one can become dominant. This result is shown most vividly in Figure 3.4 when $\psi_a = 6$ and $\psi_b = 4$. Clearly in this set of circumstances it is in the interest of suppliers to adopt the same standard. High values of β imply that suppliers are performing similar tasks so there is little inherent benefit to an individual supplier from using a standard different from everyone else. At the same time, suppliers get to keep a substantial fraction of the gains from using a standard ($\lambda = 0.5$), even when a large number of suppliers adopt it. It is worth noting that both equilibria are stable.

The effects of a superior alternative action on the adoption shares can be seen in Figures 3.24 and 3.27 and 3.28. This situation holds except when economic conditions create a strong incentive for suppliers to take the same action. Consider the case, shown in Figure 3.22, when the degree of heterogeneity and the bargaining externality are low, the Marshallian externalities and auditing life cycle effects are strong ($\psi_a = \psi_b = 4$ when $G_r = 4$, $G_a = G_b = 1$, $\lambda = 0.4$), and the gross benefit of the alternative action is superior to that of the standards. There is a unique equilibrium where for $\beta > 4$ all suppliers take only the alternative action. But this is inefficient compared to all suppliers adopting a process standard.

Figure 3.1
$\lambda=1$ G=1 $\varphi=4$

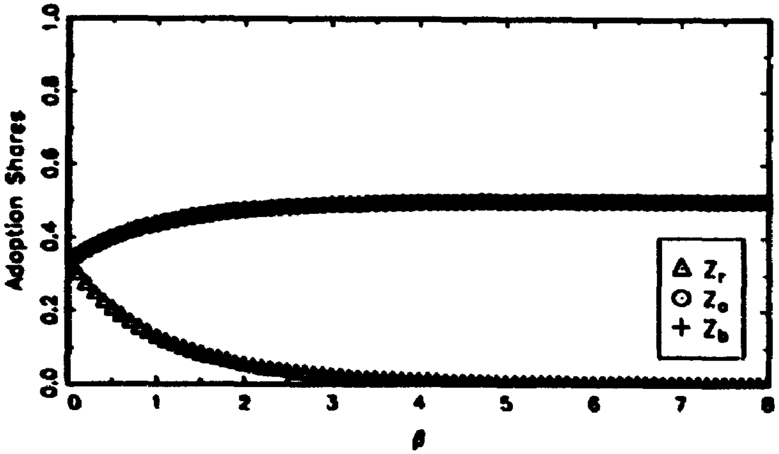


Figure 3.2
$\lambda=0.5$ G=1 $\varphi=4$

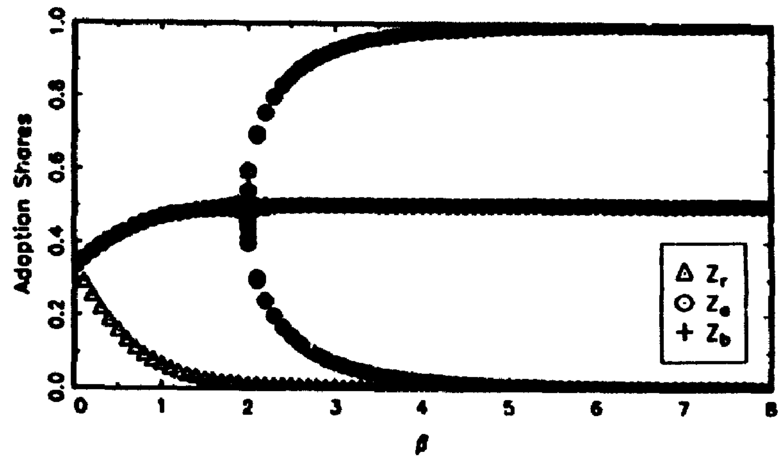


Figure 3.3
$\lambda=1$ $G_a=1$ $G_b=2$ $\varphi=4$

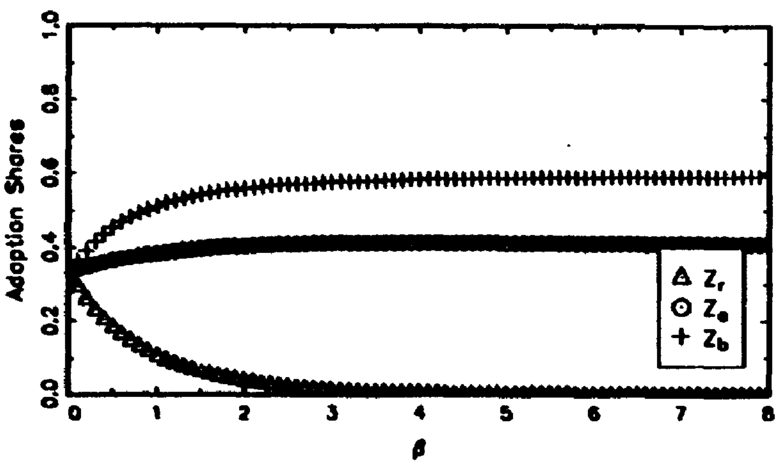


Figure 3.4
$\lambda=0.5$ G=1 $\varphi_a=6$ $\varphi_b=4$

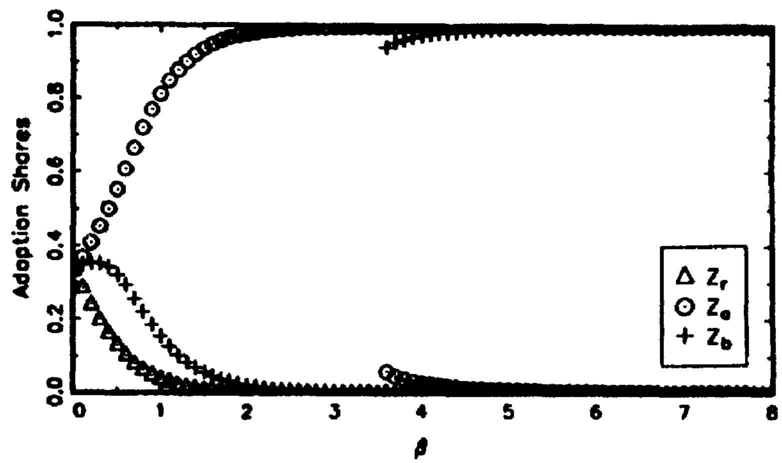


Figure 3.5

β=0.5 G=1 φ=4

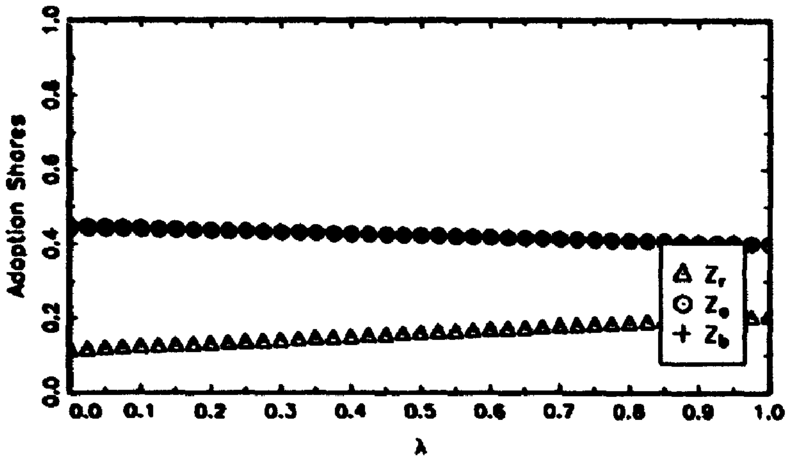


Figure 3.6

β=5 G=1 φ=4

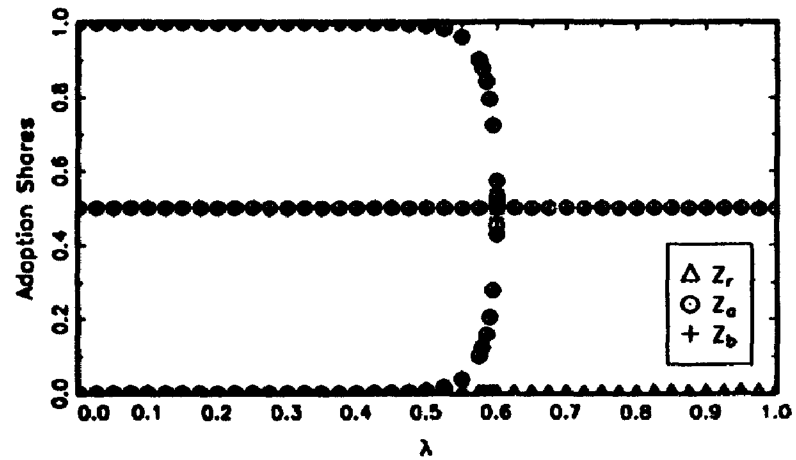


Figure 3.7

β=0.5 G=1 φ_a=2 φ_b=4

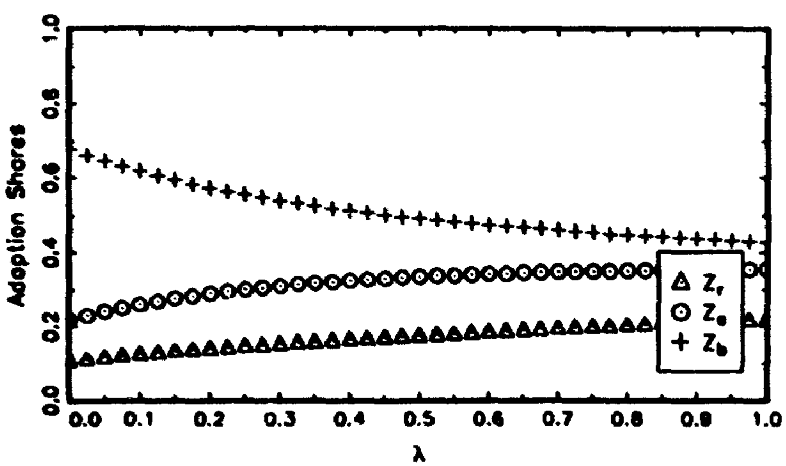


Figure 3.8

β=5 G=1 φ_a=2 φ_b=4

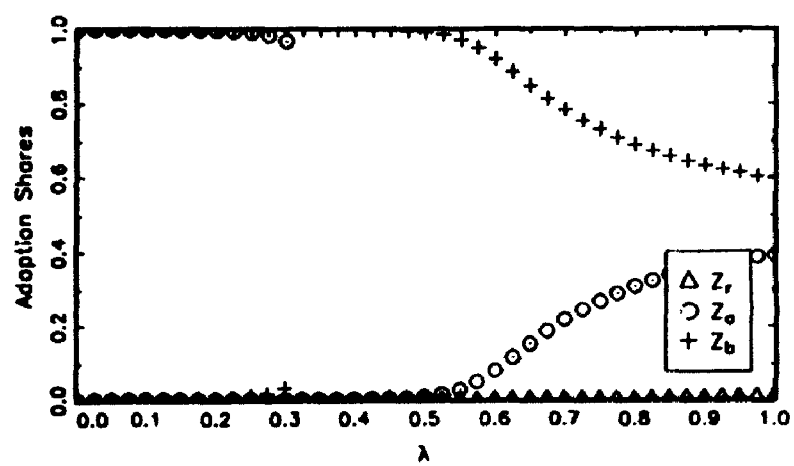


Figure 3.9
β=0.5 λ=1 φ=4

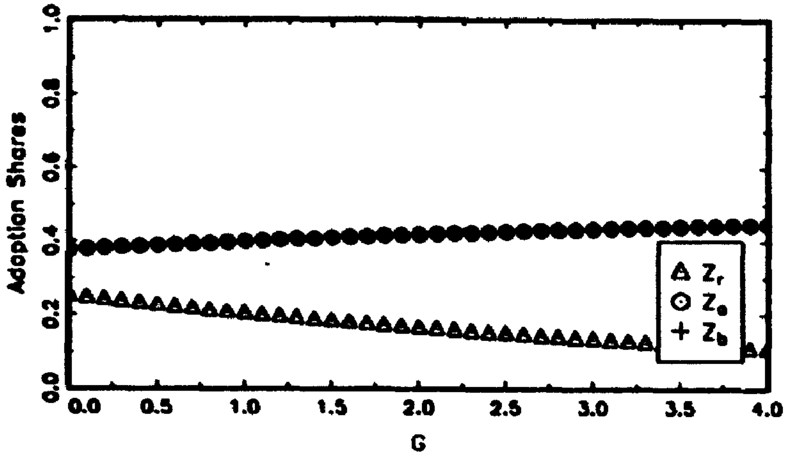


Figure 3.10
β=5 λ=0.5 φ=4

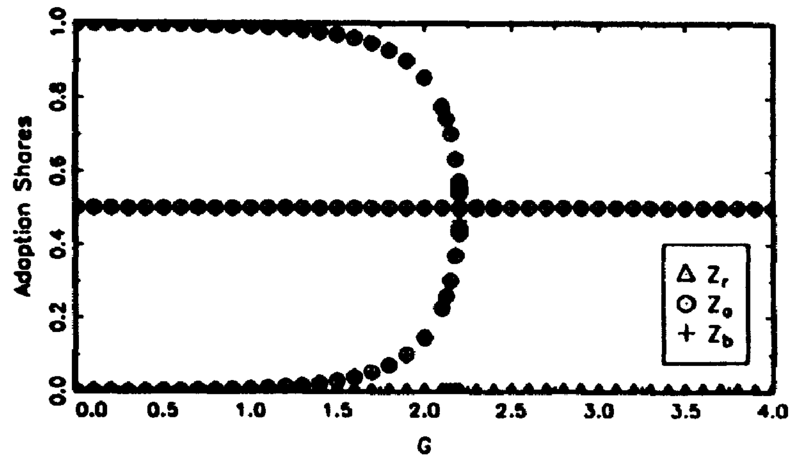


Figure 3.11
β=0.5 λ=1 φ_a=2 φ_b=4

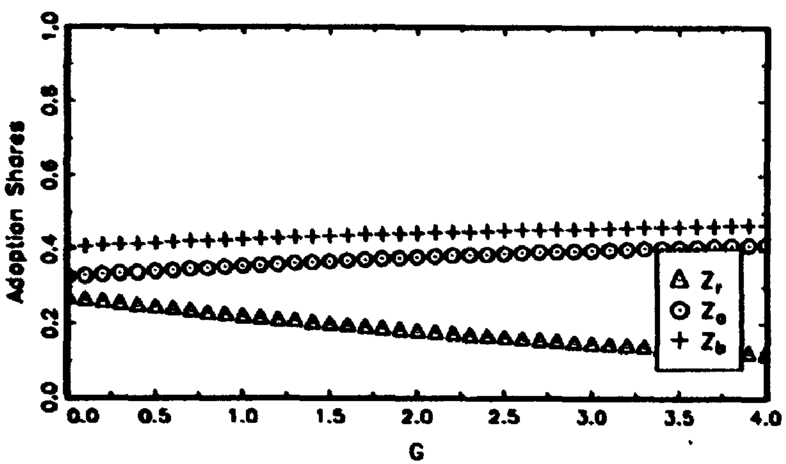


Figure 3.12
β=5 λ=0.5 φ_a=2 φ_b=4

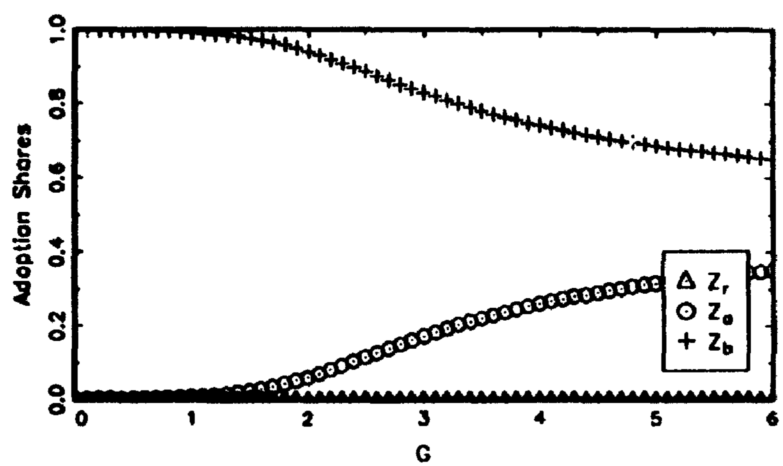


Figure 3.13
$\beta=0.5$ $\lambda=1$ $G=1$

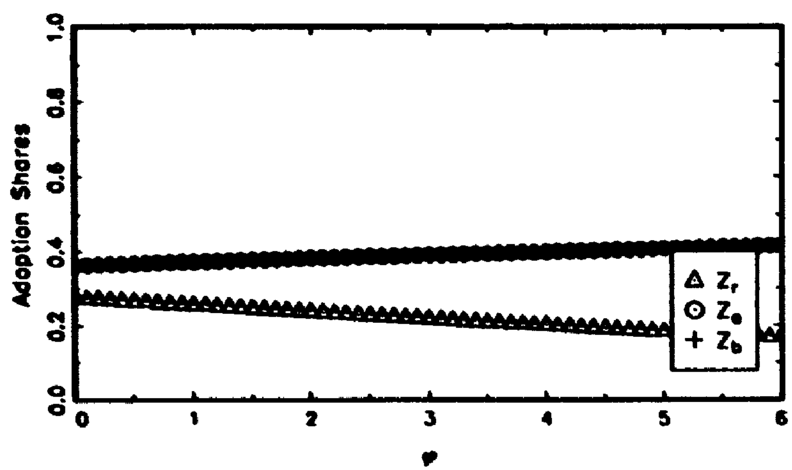


Figure 3.14
$\beta=5$ $\lambda=0.5$ $G=1$

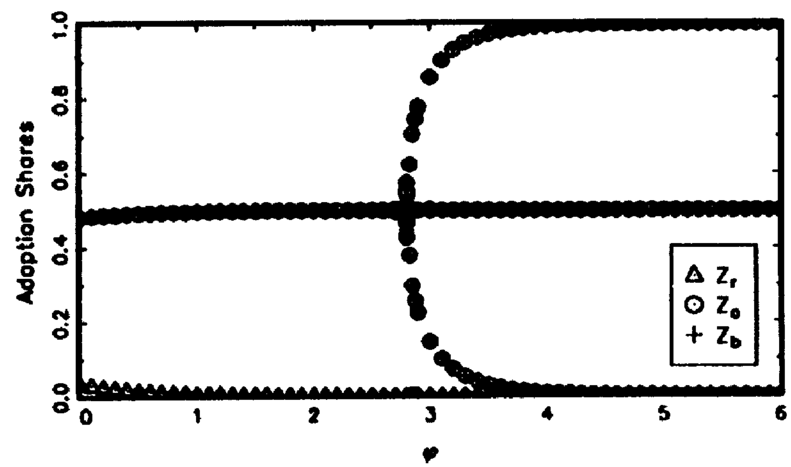


Figure 3.15
$\beta=0.5$ $\lambda=1$ $G_e=2$ $G_b=1$

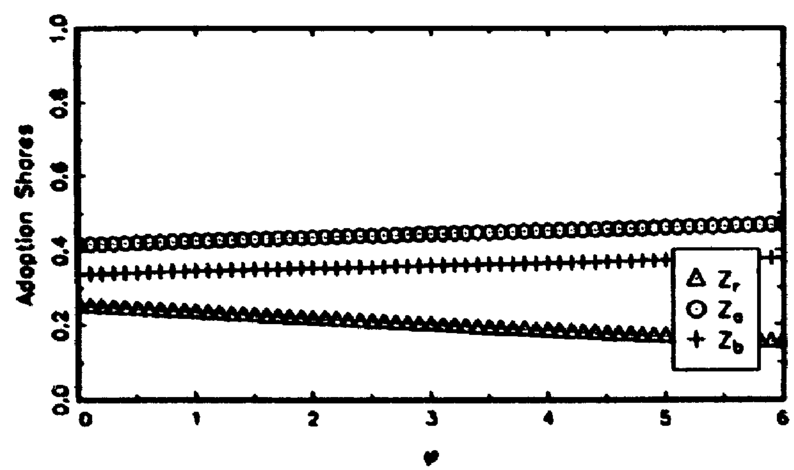


Figure 3.16
$\beta=5$ $\lambda=0.5$ $G_e=2$ $G_b=1$

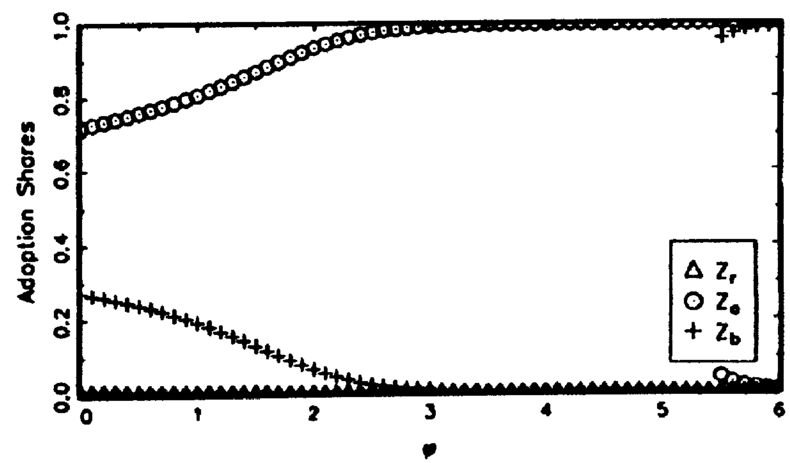


Figure 3.17
$\beta=5$ $\lambda=0.5$ $G_b=1$ $\varphi=4$

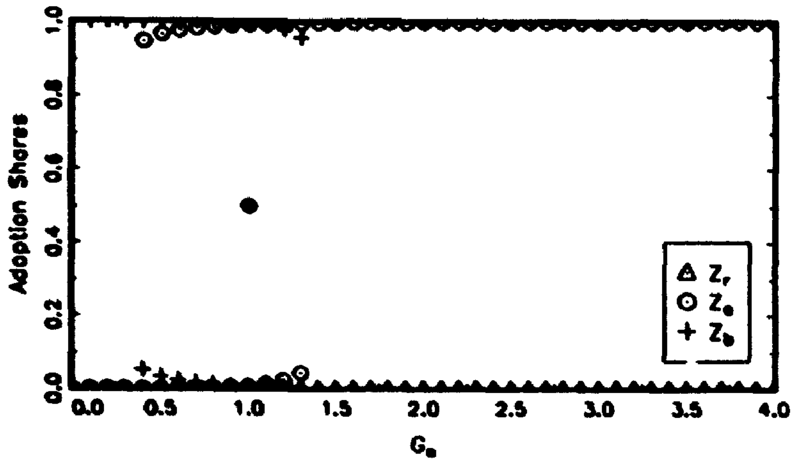


Figure 3.18
$\beta=5$ $\lambda=0.5$ $G_b=1$ $\varphi_a=2$ $\varphi_b=4$

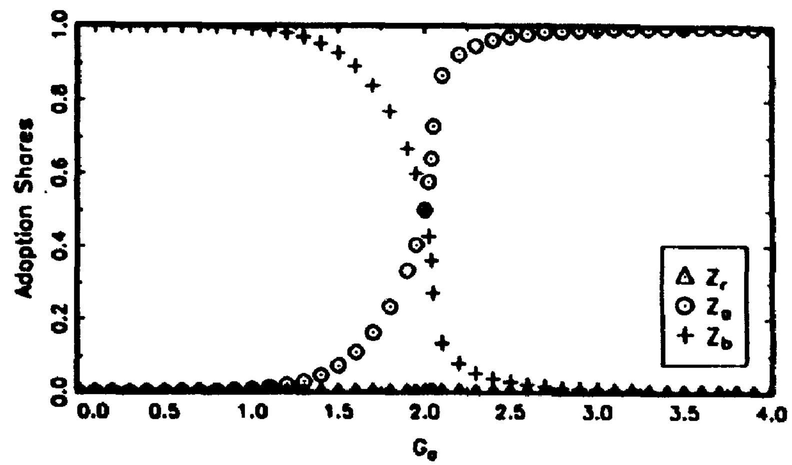


Figure 3.19
$\beta=5$ $\lambda=0.5$ $G=1$ $\varphi_b=4$

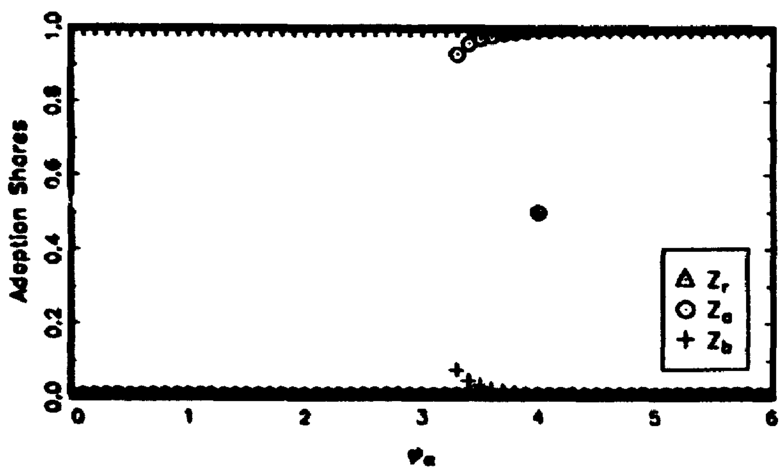


Figure 3.20
$\beta=5$ $\lambda=0.5$ $G_a=2$ $G_b=1$ $\varphi_b=4$

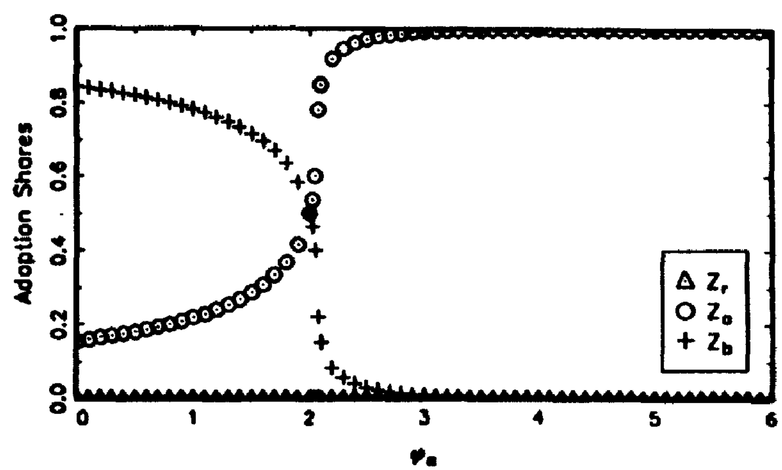


Figure 3.21
$\lambda=0.4\ G_o=G_b=1\ \varphi=4\ G_r=3$

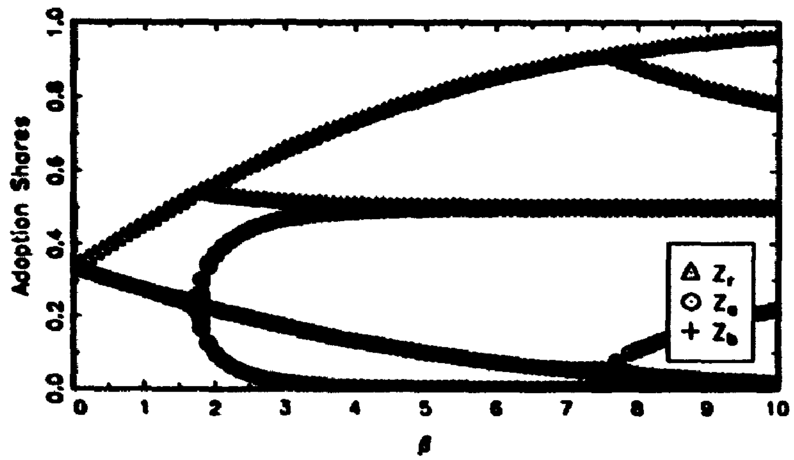


Figure 3.22
$\lambda=0.4\ G_o=G_b=1\ \varphi=4\ G_r=4$

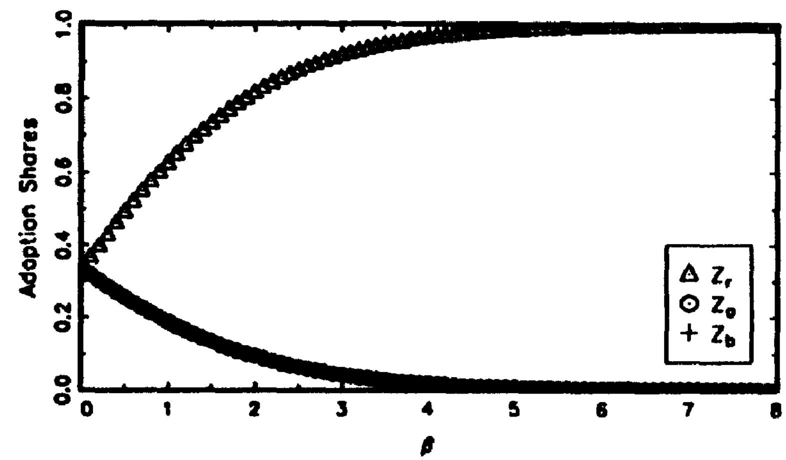


Figure 3.23
$\lambda=0.4\ G_o=1.5\ G_b=1\ \varphi=4\ G_r=2$

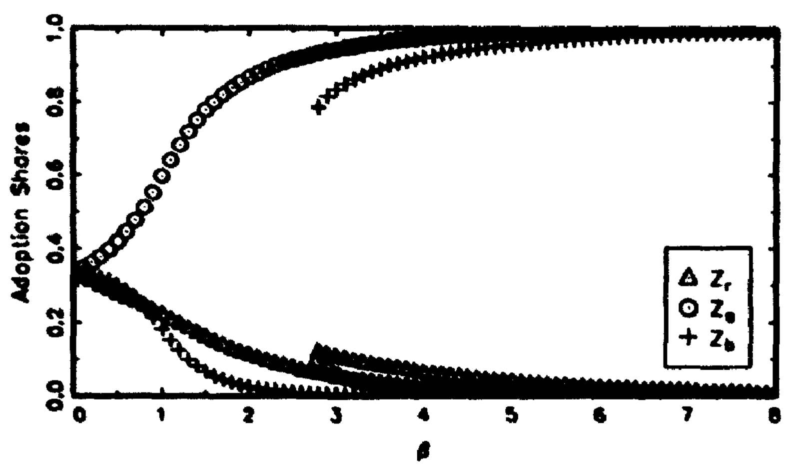


Figure 3.24
$\lambda=0.8\ G_o=1.5\ G_b=1\ \varphi=3\ G_r=2$

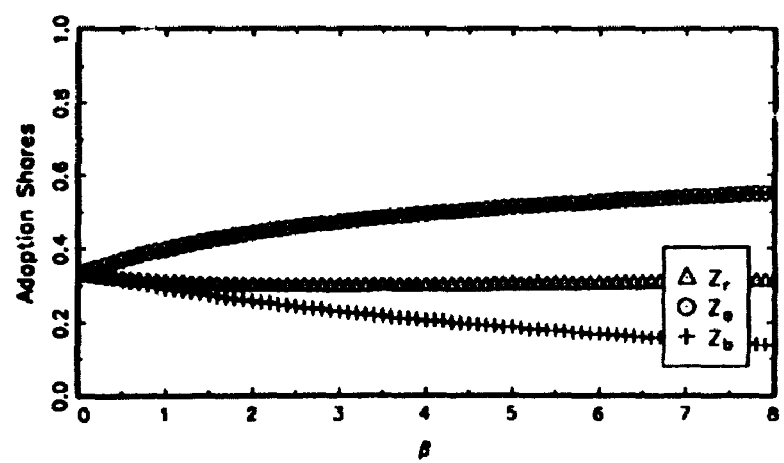


Figure 3.25
β=0.5 G_a=G_b=1 φ_a=6 φ_b=4 G_r=4

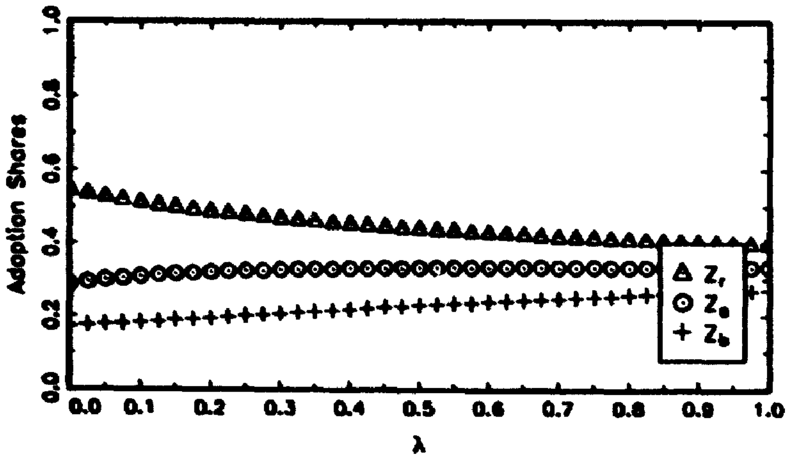


Figure 3.26
β=6 G_a=G_b=1 φ_a=2 φ_b=1 G_r=2

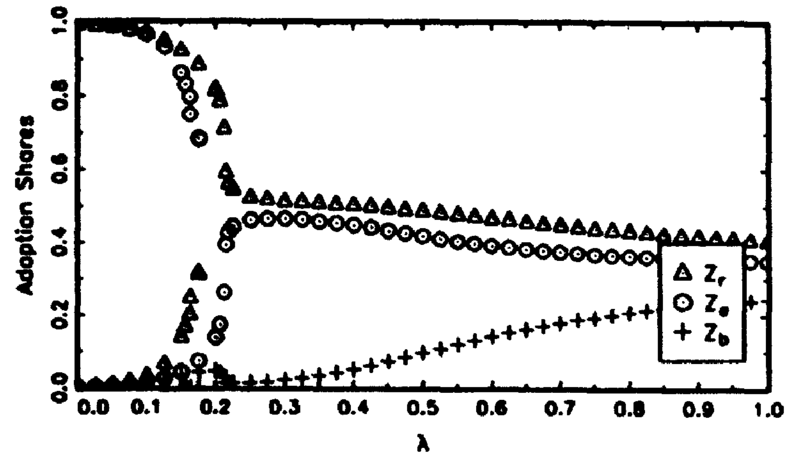


Figure 3.27
β=0.5 λ=0.5 G_a=1 G_b=2 φ_a=6 φ_b=4

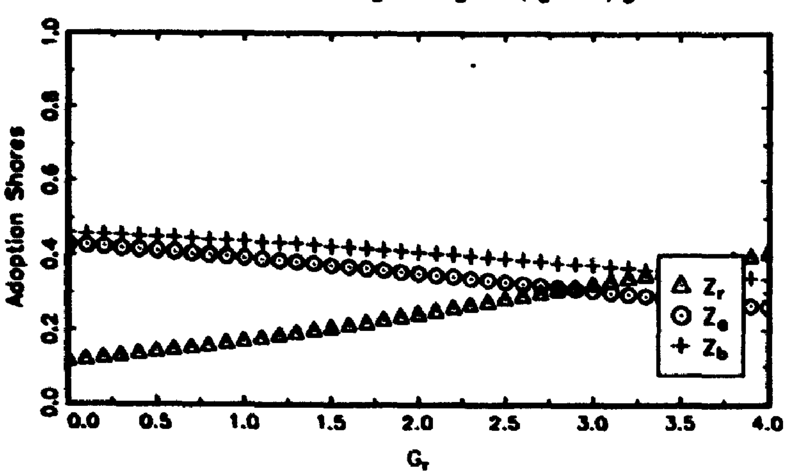


Figure 3.28
β=5 λ=0.4 G_a=1 G_b=2 φ_a=6 φ_b=4

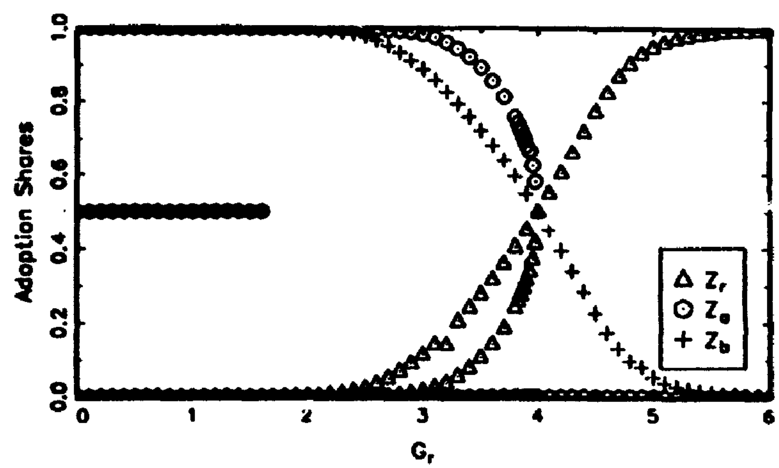


Figure 3.29
β=0.5 λ=1 G_b=0.5 φ_a=6 φ_b=4 G_r=4

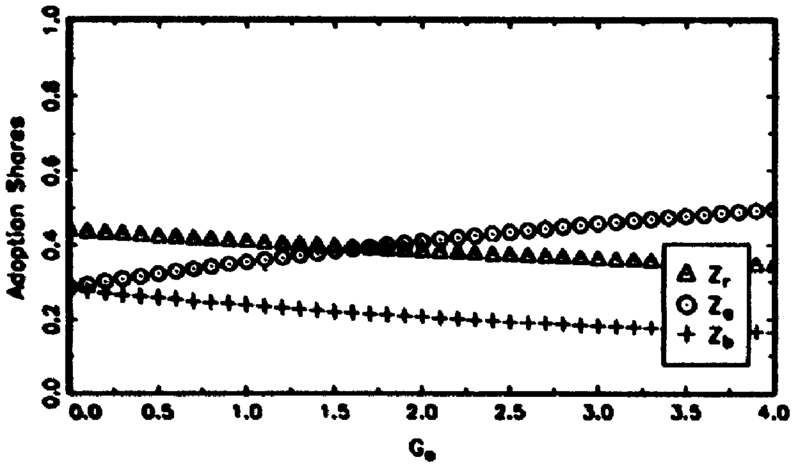


Figure 3.30
β=5 λ=0.4 G_b=0.5 φ_a=6 φ_b=4 G_r=4

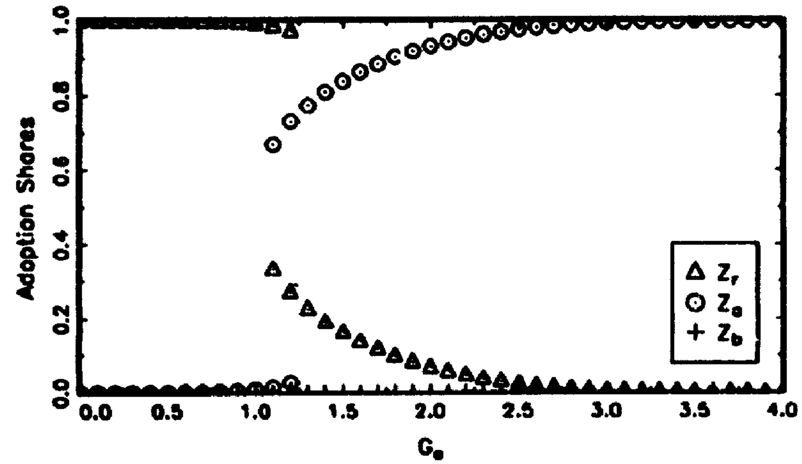


Figure 3.31
β=0.5 λ=1 G_a=G_b=1 φ_b=4 G_r=4

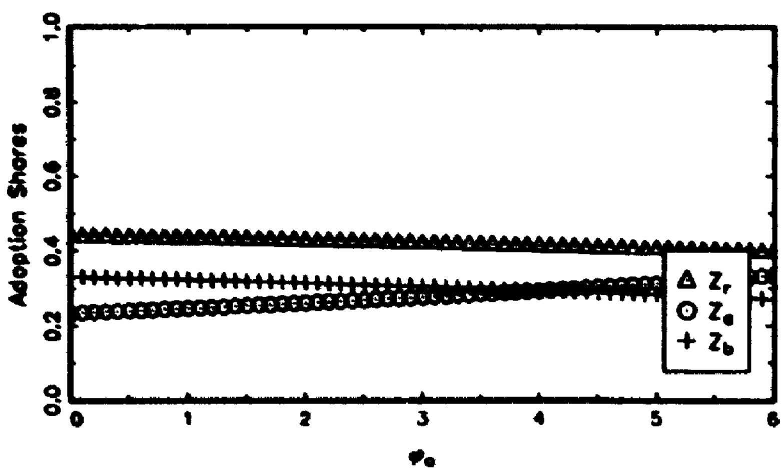
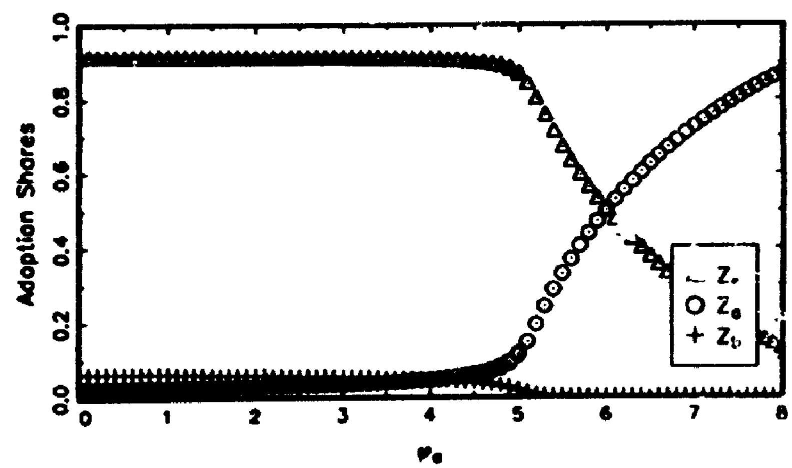


Figure 3.32
β=5 λ=0.5 G_a=G_b=1 φ_b=4 G_r=4



Chapter 4

The Impact Of Linkages Between Countries Or Between Industries On Adoption Patterns Of Process Standards

4.1 Introduction

The previous chapter explored adoption patterns of process standards in one country or industry. This allowed us to form intuition about how the model works, as well as illuminated possible deficiencies in the wider literature that studies the adoption of technologies. One key feature present in the adoption of process standards was missing from the model studied in Chapter 3. This was the presence of multiple geographic or product spaces. The real world decisions by firms about whether or not to adopt a standard are influenced by their location in one, possibly both, of these types of spaces, and the locations of other firms.

Consider geographic spaces. Canadian health care facilities can adopt the country specific standards developed by the Canadian Council on Hospital Accreditation, or the international standard ISO 9000. Facilities in the United States can adopt the country-specific quality assurance standard developed by the Joint Commission on Accreditation of Hospitals, or ISO 9000. The adoption decisions of producers concerning the relevant region-specific standards have no direct impact on producers' decisions in other regions. But their decisions concerning the generic standard do affect each other, if there exist variable returns to its adoption. The interconnectedness of producers' adoption decisions is also present when thinking about industrial space. Health care facilities in the United States can adopt the generic ISO 9000 or Malcolm Baldrige National Quality Award standards, or their industry specific standard. Obviously the adoption decisions of producers concerning the industry specific standards are not a direct function of the actions of producers in other industries. But the decisions of producers in different industries are interconnected through the generic standard. The linkages of producers' adoption decisions between countries and between industries is obviously a general phenomenon. There exist many country or region-specific generic standards such as the Malcolm Baldrige National Quality Award in the United States and the European Quality Award in the European Community. For many industries there exist generic standards such as ISO 9000, or industry-specific standards such as the Capability Maturity Model in the United States software industry.

The presence of multinational and multiproduct firms also link the adoption decisions of producers in different countries or industries. Firms whose production activities span more than one country or industry have a choice between the specific and generic standards, and their decisions have a direct impact on firms in all of the countries or industries in which they operate. A small selection of firms based in the United States that operate in multiple countries and industries is given in Tables 4.1 and 4.2. Each of the firms operates in many different countries as is shown in

Table 4.1
Examples of Multinational Firms and the Geographic Distributions of their Sales

	%		%		%
Minnesota Mining and		General Electric		Johnson & Johnson	
Manufacturing		– United States	82	– United States	51
– United States	51	– Other	18	– Europe	29
– Europe	29			– Asia	11
– Asia	15	Johnson Controls		– Canada & Latin	
– Other	8	– United States	77	America	9
		– Europe	18		
Amoco		– Other	5	International Business	
– United States	80			Machines	
– Canada	9	AMP		– United States	41
– Europe	4	– United States	43	– Europe, Africa &	
– Other	7	– Europe	31	Middle East	35
		– Asia	21	– Asia	16
General Motors		– Americas	5	– Americas	8
– United States	72				
– Europe	18	Motorola			
– Canada & Mexico	6	– United States	56		
– Latin America	4	– Other	44		
– Other	1				

Source: *Hoover's Handbook of American Business - 1995*

Table 4.1. Each of the same firms also produces a wide variety of products as can be seen from Table 4.2.

The importance of spatial considerations in determining adoption patterns of standards has also been highlighted by both Cowan and Cowan (1995) and David and Foray (1993). They show that incorporating geographic or product space can produce very different adoption patterns of technologies. It would be expected that moving to multiple spaces would also affect the possible adoption patterns of process standards.

Table 4.2
Examples of Multiproduct Firms
and Selected Products

Minnesota Mining and Manufacturing – roofing granules – imaging equipment – telecommunications testing equipment – dental supplies	General Electric – motors and engines – light bulbs – locomotives – satellites – nuclear engineering services	Johnson & Johnson – toiletries – pharmaceuticals – surgical appliances – dental equipment
Amoco – plastics – petroleum and natural gas – fiber optics – lasers – construction	Johnson Controls – batteries – industrial relays – automotive seating – plastic bottles	International Business Machines – computers – software – office machines – consulting services – semiconductors
General Motors – motor vehicles and parts – locomotives – tanks – aircraft engines	AMP – electrical connectors – circuit boards – screw machine products	Motorola – semiconductors – electronic ceramics – telecommunications equipment – software – vehicle parts

Source: ***Ward's Business Directory - 1992***

When considering more than one country or industry there is an important issue that needs to be addressed. This is how to model the external effects. In particular, which interaction effects are local, and which are global. It would seem that there is no general answer to this question; it depends on the economic context being studied.

It may be the case that the positive external effects are global in nature. Irwin and Klenow (1994) investigate whether learning-by-doing spillovers exist between firms that produce dynamic random access memory semiconductors between 1974-

92, and if so, what form they take. They find strong evidence supporting the presence of spillovers, implying substantial non-market-mediated learning (or interactions) among firms. What is more, firms learn just as much from those in other countries as from those located in domestic markets. This is not surprising given the large amount of trade of this product. Cowan and Gunby (forthcoming) also find that some forms of learning are globally based. In their case they find that information about natural predators of insect pests was shared globally over large geographic distances. On the other hand, Cowan and Gunby also find that other cases of learning are primarily local. Farmers learn about how to implement pest control technologies mostly from their neighbours.

Consider geographic space. It is likely that knowledge about, for instance, how to implement a generic standard, is transmitted easily between producers in Canada and the United States since the countries are contiguous. In contrast, there are likely to be more barriers and higher costs to the transmission of such learning between producers in India and the United States. There is a large distance between these two countries, and their states of economic development are very different, implying different stocks of infrastructure capital, such as telecommunications facilities. It is the strength of the barriers (or costs) to transmitting information and trading with agents that is important in determining the impact of an agent's action on the actions of agents located in other regions. These barriers and costs determine the extent to which learning about, for instance, how to implement a standard, flows between agents located in different regions. When considering product space, learning about how to implement a generic standard is likely to be easily transferable between producers of plastics or bulk chemicals. Producers in these industries have very similar production methods. In contrast, producers of software are unlikely to benefit greatly from the experience of producers in the transportation industry who implement such a standard. Producers in these industries have very different production methods.

Consider now the potential for negative effects experienced by agents in one region or industry caused by the adoption of the generic standard by agents in other regions or industries. If producers in one country adopt a generic standard, their action will decrease the bargaining power of producers who adopt it in another country. This impact occurs through the presence of trade. The strength of the transmission of the negative externality between countries depends on the amount of trade between them (and hence the factors that influence this variable). In contrast, if producers in one industry adopt a generic standard, there will be no impact on the bargaining power of producers who adopt it in another industry.

Obviously, the modelling of the interaction effects is complex and complicated, with lots of possibilities. I am going to present a stylised model, picking certain cases, and ignoring some complications, in order to highlight the effects of the linkages between countries and between industries on the adoption patterns of process standards.

4.2 Two Countries

Assume that there are two spaces, A and B, which can be interpreted as countries. There are a total of N suppliers in the two countries with a fraction n^j of them in country j, where $j \in \{A, B\}$. Suppliers in each country periodically decide which one of three possible actions they wish to take (these are summarised in Table 4.3). A supplier may either adopt a country-specific standard; adopt a generic standard; or not adopt any standard. In the present context the country-specific

Table 4.3

Actions Available to Suppliers

		Country	
		A	B
Action	No Standard Adopted	a_r	b_r
	Adopt Country Standard	a_a	b_b
	Adopt Generic Standard	a_g	b_g

standards are only useful in their respective countries. This is an extreme form of the innocuous assumption that the country-specific standard is likely to be more valuable at home than abroad. It could easily be relaxed to allow for the possibility that country standards may be adopted by either country. Suppliers are assumed to repeatedly face the choice of which action to take.

For each order, supplier n in, say, country A solves the problem,

$$\max_{q \in \{a_r, a_a, a_g,\}} b(n,q,A)R(n,q,A)\,.$$

where $R(n,q,A)$ is the surplus from action q, and $b(n,q,A)$ dictates the share of this surplus that accrues to supplier n. As in Chapter 3 it is assumed that there ar› no positive pecuniary externalities associated with the alternative action. The benefit t҆ a supplier adopting the country standard is given by the same functional forr as in Chapter 3.

The presence of trade implies that suppliers from different countries compete with each other, and can therefore affect the bargaining strength of a supplier who adopts the generic standard in other countries. Thus the negative externality associated with the generic standard is global. Consider supplier n in country A who takes action g. The bargaining externality, denoted $b(n, a_g, A)$ for this supplier takes the form,

$$b(n, a_g, A) = \frac{1}{2}\left(1 - \lambda\left(\frac{n^A Z_g^A + \epsilon n^B Z_g^B}{n^A + \epsilon n^B}\right)\right) .$$

The quantity multiplied by λ is a measure of competition faced by a domestic supplier. The parameter $\epsilon \in [0, 1]$ measures the strength of the impact that adopters of the generic standard in one country have on the adopters of it in the other country. When $\epsilon = 0$ there are no links between the countries, and the adoption of standards in each country is analysed using the same framework as in Chapter 3. If $\epsilon = 1$ then a supplier adopting standard g has the same impact on both countries. Intermediate values of ϵ obviously imply an impact in between these two extremes.

There is, however, no a priori reason to expect that the spatial nature of the positive pecuniary externality is always global, or local, in its effect. It may be that learning about how to implement the generic standard, or the provision of goods and services which reduce the cost of implementing it, are predominately local in nature. Or they may be global. Learning by adopters of ISO 9000 in Canada is likely to be easily transmitted to suppliers in the United States, but is far less likely to be transmitted to suppliers in Malaysia. For the moment assume that the positive pecuniary externality is stronger locally than globally. Thus, considering action g in country A, it is assumed that,

$$R(n, a_g, A) = \left(G_g^A + \psi_g^A Z_g^A + h_{n,g}^A\right) .$$

The distance metric governing interactions between suppliers is assumed to be such that any suppliers within a country are local whereas suppliers in different countries are not local. This metric was chosen for it's analytical simplicity and again there is no reason in principle why a more complicated metric can not be chosen. This metric implies that the equilibrium probabilities also represent the proportions of suppliers taking each action in each country. In this case Z_q^j denotes the proportion of suppliers taking action q in country j.

Define $X = (\mathbf{q}, \phi)$ as a micro-state of the system, where $\mathbf{q}$ is a vector listing the actions taken by the N agents, and ϕ is a matrix listing the realisations of the idiosyncratic components (the $h_{n,q}$s). This is an $N \times 6$ matrix with $X_{n,q}$ taking the value 1 if supplier n takes action q and 0 otherwise. A micro-state is a complete description of the states of the N suppliers.

4.2.1 Equilibrium Conditions

An equilibrium now consists of six probabilities (or proportions). The probabilities describe the likelihood that a supplier in either country will choose one of the three available actions when they have their decision-making opportunity.

The following system of equations describes the equilibria of the model,

$$Z_r^A = \exp\left[\beta(1 - \lambda Z_r^A)(G_r^A + \mu)\right] / C^A, \tag{4.1}$$

$$Z_r^B = \exp\left[\beta(1 - \lambda Z_r^B)(G_r^B + \mu)\right] / C^B, \tag{4.2}$$

$$Z_a^A = \exp\left[\beta(1 - \lambda Z_a^A)(G_a^A + \psi_a^A Z_a^A + \mu)\right] / C^A, \tag{4.3}$$

$$Z_b^B = \exp\left[\beta(1 - \lambda Z_b^B)(G_b^B + \psi_b^B Z_b^B + \mu)\right] / C^B, \tag{4.4}$$

$$Z_g^A = \exp\left[\beta\left(1 - \lambda\left(\frac{n^A Z_g^A + \epsilon n^B Z_g^B}{n^A + \epsilon n^B}\right)\right)(G_g^A + \psi_g^A Z_g^A + \mu)\right] / C^A, \tag{4.5}$$

$$Z_g^B = \exp\left[\beta\left(1 - \lambda\left(\frac{n^B Z_g^B + \epsilon n^A Z_g^A}{n^B + \epsilon n^A}\right)\right)(G_g^B + \psi_g^B Z_g^B + \mu)\right] / C^B, \tag{4.6}$$

where,

$$C^A = \exp\left[\beta(1 - \lambda Z_r^A)(G_r^A + \mu)\right] + \exp\left[\beta(1 - \lambda Z_a^A)(G_a^A + \psi_a^A Z_a^A + \mu)\right]$$
$$+ \exp\left[\beta\left(1 - \lambda\left(\frac{n^A + \epsilon n^B Z_g^B}{n^A + \epsilon n^B}\right) Z_g^A\right)(G_g^A + \psi_g^A Z_g^A + \mu)\right],$$

and,

$$C^B = \exp\left[\beta(1 - \lambda Z_r^B)(G_r^B + \mu)\right] + \exp\left[\beta(1 - \lambda Z_b^B)(G_b^B + \psi_b^B Z_b^B + \mu)\right]$$
$$+ \exp\left[\beta\left(1 - \lambda\left(\frac{n^B Z_i^B + \epsilon n^A Z_i^A}{n^B + \epsilon n^A}\right)\right)(G_i^B + \psi_i^B Z_g^B + \mu)\right].$$

To obtain the set of equilibria for the model requires simultaneously solving equations (4.1) to (4.6) for the proportions of suppliers who have taken each action in each country. As in Chapter 3 this system of equations is solved computationally after assuming specific parameter values.

4.2.2 Effects of Linkages Between Countries

This section presents the general results and an explanation of why they occur. The main parameter of interest is ϵ, which governs the linkages between the countries. Appendix 4.1 presents a selection of figures which show adoption patterns for different values of the parameters. A detailed explanation of each figure is also contained in the beginning of this appendix.

Cases in Which the Linkages have No Effect

There are two general instances in which ϵ has no effect on the adoption shares. The first case involves a strong bargaining externality and a high degree of heterogeneity. Both of these push suppliers to adopt uncommon standards. A strong bargaining externality means that if suppliers all adopt the same standard, they receive little of the benefit from lower transaction costs associated with it. Instead they are captured by the firms which buy the output of the suppliers. The firms have considerable power in bargaining with a supplier because they can switch between suppliers at little cost. A high degree of heterogeneity means that suppliers are mainly concerned with how each standard fits their idiosyncratic requirements. Other factors, such as the cost savings to be had from having many suppliers adopt the same standard, have only a secondary affect in their choice of which action to take.

The second case involves a weak bargaining externality and a low degree of heterogeneity. Both of these push suppliers to adopt a common standard. A weak bargaining externality means that suppliers capture much of the benefits associated with a standard, no matter how many suppliers have adopted it. A low degree of heterogeneity implies that suppliers are strongly influenced by the actions of other adopters. As a result, suppliers are predominately influenced by the positive pecuniary externality, which causes most suppliers to adopt the same standard to enjoy the benefits of doing the same thing.

The overriding concern of suppliers in both of these cases is with what happens locally. Their links with the other country are not an important influence in the decisions they make.

Cases in Which the Linkages have an Effect

Given the above discussion, it is clear that ϵ only has an effect when the bargaining externality is neither very strong nor very weak, and heterogeneity is neither very high nor very low. If these conditions are met, then sufficiently large linkages between the countries can influence the adoption patterns of the standards. Strong links between countries, arising from factors such as higher levels of trade, affect the degree of competition faced by a supplier who adopts the generic standard. A supplier receives a lower fraction of the benefits associated with the standard when it experiences greater competition from foreign suppliers. In this set of circumstances it is the firms who buy the output of the sellers that capture most of the benefits associated with the generic standard. In such an environment, it becomes worthwhile for suppliers in a country to adopt the country-specific standard (or to take the alternative action if the benefit associated with it is high enough), even if it is inferior to the generic standard. This enables suppliers to gain some market power, and therefore increase the fraction of the gains associated with the action they take. The larger the degree of integration between the countries, then the more suppliers find it worthwhile to take an action other than adopting the generic standard.

Surprisingly, increasing the strength of the linkages between countries eventually causes the suppliers in one country to standardise on one standard, and suppliers in the other country to standardise on the other standard. In addition, suppliers in a country can standardise on either the generic or country-specific standards, even if one is inferior to the other. This latter result raises the possibility that government intervention, in specific cases and in the environment studied, may increase the welfare of one country, and worsen the welfare of the other country. A government could implement a policy to increase the benefit of the superior standard to domestic suppliers. This would then increase the number of domestic suppliers who adopt the standard, and through the global linkages and the negative bargaining externality, lower the number of foreign suppliers who adopt it. As a result, this type of government policy may be able to tilt the adoption path of the standards so that domestic suppliers standardise on the superior standard, at the expense of the foreign country.

Effect of the Linkages on the other Parameters

Small to moderate links between the countries have little impact on the resulting adoption patterns. In contrast, large values of ϵ have two effects. First, multiple equilibria can arise for some values of the other parameters, for which only a single equilibrium exists if ϵ is small (when ϵ is small we are effectively back to the framework of Chapter 3). Second, the equilibria that arise are characterised by the countries standardising on different standards, as mentioned above.

4.2.3 The Effects of Government Policy

What happens if a government decides to increase the gross benefit of, say the generic standard, to domestic firms? This could be in the form of a direct payment to domestic firms that adopt the standard, or more likely, subsidisation of the adoption costs for them.[1] Either type of policy is captured by an increase in G_a^A (if we assume the government in country A is taking this action). If there are strong net decreasing returns to adopting a standard, this action causes more suppliers in A adopt the generic standard, and the negative global externality makes the generic standard less attractive to the average supplier in B. Thus fewer suppliers in B adopt this standard. The same effect occurs if there are strong net increasing returns to adopting standards, although quantitatively the effect is weaker. In some instances, the suggested policy action can also eliminate all but the equilibrium where suppliers in A adopt the generic standard, and the suppliers in B adopt their country-specific standard. This can occur even when the generic standard is better than both country-specific standards. This result confirms that it is possible (at least in the framework studied) for a government to attempt to influence the

[1] Regulations that require firms to have adopted the generic standard to sell their output to the government, as has happened with ISO 9000, will affect both domestic and foreign firms.

adoption of the standards to increase the welfare of the country, at the possible expense of the other country. The global negative externality can cause suppliers in different countries to standardise on different standards. A government thus has the option of implementing policies to ensure that domestic suppliers standardise on the superior standard. The suppliers in the other country will then standardise on the other standard, because even though it may be the inferior one, the global negative externality makes it even less attractive to adopt the superior standard.

4.2.4 Global Positive Externalities

The positive pecuniary externality was assumed to be local in its effect in the previous section. Assume now that it is global in its effect. Thus the benefit to taking, say action g in country A, is now assumed to be of the form,

$$R(n, a_g, A) = \left(G_g^A + \psi_g^A(n^A Z_g^A + \epsilon n^B Z_g^B) + h_{n,g}^A\right) .$$

What difference does this make compared to the environment with purely local positive externalities? With only local positive externalities, higher values of ϵ cause equilibria to arise where suppliers in different countries do different things. In comparison, when the positive externalities are global, higher values of ϵ cause equilibria in which suppliers in different countries do different things to be eliminated if the bargaining externality is weak enough, when both the negative and positive interaction effects are global. When the bargaining externality is sufficiently small, greater integration between the countries also increases the adoption shares of the generic standard, compared to the situation where the positive externalities are local. This occurs because it strengthens the positive interaction effects between suppliers in different countries, relative to the negative bargaining externality. When the bargaining externality is sufficiently large, then an increase in the linkages between the countries reduces the adoption shares of the generic standard. This occurs because suppliers seek to differentiate themselves from their foreign competitors by adopting a standard different from them. This means that they get to capture a large fraction of the associated transactions cost savings than would otherwise be the case.

4.2.5 Two Industries

Consider now a model with two spaces, but interpret them as industries instead of as countries. What are the differences between this situation and looking at countries? When modelling countries it was noted that a supplier who adopts the generic standard in one country affects the bargaining power of a supplier who adopts the same standard in another country. This is not so when considering industries. The bargaining power of a supplier who adopts the generic standard will only be affected by other adopters of it if they operate in the same industry. The share of the surplus associated with the generic standard, say in country A, $b(n, a_g, A)$, is therefore equal to $(1 - \lambda Z_g^A)/2$. Also consider the case where the positive pecuniary externalities are global in nature (otherwise we are back to the framework of Chapter 3).

What effect does the strength of interactions between adopters of the generic standards in the two industries have in this framework? When parameter values are such that suppliers want to take different actions (agents are very heterogeneous or there are strong decreasing returns to taking an action), then linkages (say because learning how to implement process standards is readily transfered between suppliers in the different industries) between the industries have no effect on the resulting adoption patterns. When agents are relatively homogeneous and there are weak decreasing returns to taking an action, then it turns out that linkages between the two industries have two noteworthy effects. First, even small linkages in the interactions between suppliers in different industries can cause the adoption patterns of the two industries to be the same (absent of differences between the benefits of the standards in the industries). Second, increases in the linkages between the industries increases adoption of the generic standard. This is because increased linkages strengthen the positive externality adopters of the generic standard in one country confer on adopters of it in other countries, without altering the associated negative externality (since it is local). This increases the benefit to adopting the generic standard, hence more suppliers in both industries adopt it.

4.3 Multinational and Multiproduct Firms

As was mentioned in the introduction to this chapter, there are many firms that have sales in multiple countries or industries. This section investigates the impact that the presence of these firms has on adoption patterns of process standards. Assume that there are two countries, call them A and B. But now assume that there are three types of suppliers. Type A and B suppliers sell their goods solely to firms located in countries A and B. Type C suppliers sell a fraction α of their output in country A and $1-\alpha$ in country B. No other links are assumed to exist between the countries other than the presence of the multinational firms. This will enable us to see clearly the impact they have. The actions available to type A and B suppliers are the same as in the previous section. Multinational suppliers have a greater range of choices available, since they have to choose an action for each country. It is assumed that multinationals have the choice of actions given in Table 4.4.

For each order, a type A or type B supplier n solves the problem,

$$\max_{q} b(n,q,j)R(n,q,j).$$

Table 4.4

Actions Available to Multinational Suppliers

Take action r in both countries	c_r
Adopt standard a and take action r in country B	c_a
Take action r in country A and adopt standard b	c_b
Adopt both country standards	c_c
Adopt the generic standard	c_g

where $R(n, q, j)$ is the surplus from action q and $b(n, q, j)$ dictates the share of this surplus that accrues to supplier n. For type A and B suppliers, their choice sets are $\{a_r, a_s, a_g\}$ and $\{b_r, b_b, b_g\}$ respectively. The basic functional forms governing the surplus from an action and the bargaining share are the same for type A and B suppliers as have been used previously. The presence of the multinationals, however, changes the interaction (or externality) terms. Consider country standard a. The positive pecuniary externality for this standard is affected by the proportion of type A suppliers who adopt it, and the proportion of type C suppliers who adopt it (actions c_a and c_c), weighted by the fraction of their sales that occur in country A (the relevant weight being α). The bargaining split is a function of these proportions as well, but the proportion of type C suppliers who adopt it is weighted by the fraction of their sales that occur in country A .

Multinational suppliers have a more complicated payoff structure associated with their actions than do type A and B suppliers, since they have more complicated spatial characteristics. Their payoffs are a weighted sum of the net payoffs associated with the part of an action relevant to country A and the part relevant to country B (given by the same functional forms as for type A and B suppliers). In addition, the positive pecuniary externality associated with the generic standard is a function of the proportions of suppliers who have adopted it in both countries. This reflects the international structure of multinationals and how they benefit from the experiences of adopters of standards in many countries.[2]

Finally, there is one further aspect of the payoff structure that needs to be incorporated into the model. Previously, when suppliers could only adopt one standard, both the noninteraction benefits and costs associated with adopting a standard were subsumed into its gross benefit. These need to be explicitly separated into two components when suppliers can adopt more than one standard. The reason for doing this is because multinationals adopting two standards will be paying two full costs but receiving only part of the benefits of each standard. It is therefore assumed that the costs of adopting the standards are the same and denoted by F. The gross benefit of a standard s is now given by $G_s - F$, where it is assumed that $G_s \geq F$.

4.3.1 Equilibrium Conditions

An equilibrium now consists of eleven probabilities. The probabilities describe the likelihood that each type of supplier chooses one of their available actions when they have their decision-making opportunity. Denote the probability that a type j supplier takes action q as Z_q^j.

The following system of equations describes the equilibria of the model,

$$Z_r^A = exp\left[\beta\left(1-\lambda\left(\frac{n^A z_r^A + \alpha n^C (z_r^C + z_b^C)}{n^A + \alpha n^C}\right)\right)(G_r^A + \mu)\right]/C^A\,, \tag{4.7}$$

$$Z_r^B = exp\left[\beta\left(1-\lambda\left(\frac{n^B z_r^B + (1-\alpha) n^C (z_r^C + z_b^C)}{n^B + (1-\alpha) n^C}\right)\right)(G_r^B + \mu)\right]/C^B\,, \tag{4.8}$$

$$Z_r^C = exp\Bigg[\beta\Bigg(\alpha\left(1-\lambda\left(\frac{n^A z_r^A + \alpha n^C (z_r^C + z_b^C)}{n^A + \alpha n^C}\right)\right)(G_r^A + \mu) + (1-\alpha)$$
$$\left(1-\lambda\left(\frac{n^B z_r^B + (1-\alpha) n^C (z_r^C + z_b^C)}{n^B + (1-\alpha) n^C}\right)\right)(G_r^B + \mu)\Bigg)\Bigg]/C^C\,, \tag{4.9}$$

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[2] See Small (1993) and Dransfield and Forrester (1994).

$$Z_a^A = exp\Big[\beta\left(1-\lambda\left(\tfrac{n^A Z_a^A + \alpha n^C(Z_a^C + Z_c^C)}{n^A + \alpha n^C}\right)\right)\Big(G_a^A - F +$$

$$\psi_a^A(n^A Z_a^A + \alpha n^C(Z_a^C + Z_c^C)) + \mu\Big)\Big]/C^A, \tag{4.10}$$

$$Z_b^B = exp\Big[\beta\left(1-\lambda\left(\tfrac{n^B Z_b^B + (1-\alpha)n^C(Z_b^C + Z_c^C)}{n^B + (1-\alpha)n^C}\right)\right)\Big(G_b^B - F +$$

$$\psi_b^B(n^B Z_b^B + (1-\alpha)n^C(Z_b^C + Z_c^C)) + \mu\Big)\Big]/C^B, \tag{4.11}$$

$$Z_a^C = exp\Big[\beta\Big(\alpha\left(1-\lambda\left(\tfrac{n^A Z_a^A + \alpha n^C(Z_a^C + Z_c^C)}{n^A + \alpha n^C}\right)\right)\Big(G_a^A - F/\alpha + \psi_a^A$$

$$(n^A Z_a^A + \alpha n^C(Z_a^C + Z_c^C)) + \mu\Big) + (1-\alpha)\Big(1-\lambda$$

$$\left(\tfrac{n^B Z_r^B + (1-\alpha)n^C(Z_r^C + Z_a^C)}{n^B + (1-\alpha)n^C}\right)\Big)(G_r^B + \mu)\Big)\Big]/C^C, \tag{4.12}$$

$$Z_b^C = exp\Big[\beta\Big(\alpha\left(1-\lambda\left(\tfrac{n^A Z_r^A + \alpha n^C(Z_r^C + Z_b^C)}{n^A + \alpha n^C}\right)\right)(G_r^A + \mu)$$

$$+ (1-\alpha)\left(1-\lambda\left(\tfrac{n^B Z_b^B + (1-\alpha)n^C(Z_b^C + Z_c^C)}{n^B + (1-\alpha)n^C}\right)\right)\Big(G_b^B + F/(1-\alpha) + \psi_b^B$$

$$(n^B Z_b^B + n^C(Z_b^C + Z_c^C)) + \mu\Big)\Big)\Big]/C^C, \tag{4.13}$$

$$Z_c^C = exp\Big[\beta\Big(\alpha\left(1-\lambda\left(\tfrac{n^A Z_a^A + \alpha n^C(Z_a^C + Z_c^C)}{n^A + \alpha n^C}\right)\right)\Big(G_a^A - F/\alpha + \psi_a^A$$

$$(n^A Z_a^A + n^C(Z_a^C + Z_c^C)) + \mu\Big) + (1-\alpha)\Big(1-\lambda$$

$$\left(\tfrac{n^B + Z_b^B + (1-\alpha)n^C(Z_b^C + Z_c^C)}{n^B + (1-\alpha)n^C}\right)\Big)\Big(G_b^B - F/(1-\alpha) + \psi_b^B$$

$$(n^B + Z_b^B + n^C(Z_b^C + Z_c^C)) + \mu\Big)\Big)\Big]/C^C, \tag{4.14}$$

$$Z_g^A = exp\Big[\beta\left(1-\lambda\left(\tfrac{n^A Z_g^A + \alpha n^C Z_g^C}{n^A + \alpha n^C}\right)\right)\Big(G_g^A - F + \psi_g^A$$

$$(n^A Z_g^A + n^C Z_g^C) + \mu\Big)\Big]/C^A, \tag{4.15}$$

$$Z_g^B = exp\Big[\beta\left(1-\lambda\left(\tfrac{n^B Z_g^B + (1-\alpha)n^C Z_g^C}{n^B + (1-\alpha)n^C}\right)\right)\Big(G_g^B - F + \psi_g^B$$

$$(n^B Z_g^B + n^C Z_g^C) + \mu\Big)\Big]/C^B, \tag{4.16}$$

$$Z_g^C = exp\Big[\beta\Big(\alpha\left(1-\lambda\left(\tfrac{n^A Z_g^A + \alpha n^C Z_g^C}{n^A + \alpha n^C}\right)\right)\Big(G_g^A - F + \psi_g^A$$

$$(n^A Z_g^A + n^B Z_g^B + n^C Z_g^C) + \mu\Big) + (1-\alpha)\Big(1 - \lambda$$
$$\left(\frac{n^B Z_g^B + (1-\alpha) n^C Z_g^C}{n^B + (1-\alpha) n^C}\right)\Big)\Big(G_g^B - F + \psi_g^B$$
$$(n^A Z_g^A + n^B Z_g^B + n^C Z_g^C) + \mu\Big)\Big)\Big] / C^C, \tag{4.17}$$

where C^A, C^B, and C^C are scale factors which ensure that the relevant probabilities sum up to one for each type of supplier. Computational methods are again used to solve for equilibrium adoption shares. Appendix 4.2 presents a selection of figures which show adoption patterns for different values of the parameters. A detailed explanation of each figure is also contained in the beginning of this appendix.

4.3.2 Effects of Including Multinationals

Including multinationals in the standards adoption environment has three pronounced effects. First, it substantially increases the adoption shares of the generic standard. This occurs because multinationals incur only one set of adoption costs if they adopt the generic standard, instead of two sets of costs if they adopt both country-specific standards. Second, there are far fewer cases of multiple equilibria compared to an environment where multinationals are absent. Third, if countries have the same structure (for example, they each have the same number of suppliers) then there are far fewer cases where the countries exhibit different adoption patterns. When multinationals are absent, or there are few of them, then there are more parameter values for which countries exhibit different adoption patterns, even when they have the same basic structure. The latter two effects are related to the first result. Multinationals have a strong incentive to adopt the generic standard to reduce the associated adoption costs. This dominates the other factors, except for extreme values of the other parameters.

There are two key parameters driving the above results: the proportion of the population that are multinationals, and the size of the adoption costs. Larger adoption costs increase the number of adopters of the generic standard, as more multinationals act to avoid paying the two sets of costs associated with adopting the country-specific standards. Increases in the proportion of the population of suppliers that are multinationals n^C, can increase or (counter-intuitively) decrease the proportion adopting the generic standard, depending on the strength of the bargaining externality. This depends on which of two opposing forces is stronger. Higher values of n^C mean that there are proportionately more multinationals, and multinationals favour adopting the generic standard to economise on adoption costs. On the other hand, increases in the proportion of adopters of the generic standard lower the fraction of the benefits associated with it that are captured by the multinationals. This reduces the proportion of multinationals that adopt the generic standard.

4.4 Conclusion

Moving to multiple countries or industries has emphasized that it is important how interaction effects between agents are incorporated in a model. Interactions using proportions of agents who are in each state is perfectly acceptable when we are looking at only one country or industry. But this is not necessarily the case when we are looking at multiple countries or industries. In this situation, some types of agents or firms, such as multinationals, are affected by a greater population than non-multinationals. Not incorporating this economic feature in relevant models can produce misleading results. This again highlights the danger of making assumptions for technical convenience (particularly if they have no empirical support), since "markets" are just one way of modelling agents interactions. One particular form of assumption made for technical convenience, the representative agent, seems particularly prone to this criticism.

When the positive interaction effects are local, higher levels of integration between countries (say through increased trade) causes adoption patterns to differ between countries. The behaviour of suppliers is determined by their desire to reduce the impact of the negative bargaining externality. In contrast, high levels of integration between countries leads to them having the same adoption patterns when positive interaction effects are global, and the negative bargaining externality is sufficiently weak. When this situation holds, higher levels of integration increase the proportion of suppliers adopting the generic standard. Both effects occur because higher levels of integration increase the benefits of the positive interaction effects associated with the generic standard between adopters from different countries. Including multinationals and multiproduct firms increases the adoption of the generic standard as they act to avoid paying two sets of costs from adopting country-specific or industry-specific standards. Surprisingly, increases in the proportion of the population that are multinationals can reduce the adoption of the generic standard for some sets of parameter values. This occurs because the effect of the negative bargaining externality dominates any associated savings in adoption costs.

Appendix 4.1

Examples of Equilibrium Adoption Patterns when there is More than One Country or Industry

Two Countries

The same rules used in interpreting the figures in Appendix 3.3 hold for the figures in this appendix. The only change is that each figure now consists of two parts; one set of adoption shares for country A, and one set for country B.

As would be expected, each of the parameters studied in Chapter 3 when there is only one country have the same basic effects when looking at two countries. For instance, a sufficiently large value of β, which implies a sufficiently low degree of agent heterogeneity, results in multiple (with some possibly inefficient) equilibria.

When the negative bargaining externality (measured by λ) is strong, implying strong decreasing returns to adopting the standards, then ϵ has no effect (see Figure 4.1 and $\lambda \geq 0.55$ in Figures 4.7 and 4.8). In this case the dominant factor driving the adoption shares is the negative externality, and only the actions of local suppliers influence them. Similarly, if agents are relatively heterogeneous ($\beta < 4.2$ in Figures 4.5 and 4.6), then the main factor influencing suppliers' adoption decisions are their idiosyncratic circumstances. The location of suppliers is of little consequence in determining what action they take.

Similarly, if λ is small ($\lambda < 0.175$ in Figures 4.7 and 4.8 when $\beta = 3.5$), and agents are relatively homogeneous, then ϵ also has no effect (see also Figure 4.2 for another set of parameter values consistent with this scenario). In this case the dominant factor driving the adoption shares is the increasing returns, and as a result, only the actions of local suppliers influence the adoption shares in a country.

The parameter ϵ does influence the adoption shares of the standards when the variable returns to adoption are not dominating the adoption decisions of suppliers and heterogeneity is not too large or too small. This is graphically shown in Figures 4.5, 4.6, 4.7, and 4.8.

Consider also Figure 4.3, where $\beta = 3.5$, $\lambda = 0.65$, $G = 1$, $\psi_a^A = \psi_b^B = 2.5$, and $\psi_i = 3.5$. When $\epsilon < .58$ then there exists a single unique equilibrium where the adoption patterns are the same for both countries. But for $\epsilon \geq 0.58$ there exist three equilibria. Interestingly, it is still possible that the countries may have the same adoption patterns. But there also exist equilibria where the countries have different adoption patterns. The latter equilibria occur because for sufficiently high values of ϵ, or linkages between the countries, the global negative externality is strong enough to cause suppliers in different countries to want to standardise on different standards. The latter type of equilibria are Pareto superior to those in which countries have the same adoption patterns. As ϵ tends to one, the adoption patterns of the countries in these two equilibria become polarised. All suppliers in one country adopt one standard, while all suppliers in the other country adopt the other standard. It is worth noting that the country which standardises around the generic standard, for the parameter values in Figure 4.3, experiences higher welfare than the other country. This suggests that there may be examples where there is a motive for countries to engage in policy actions to ensure that their suppliers standardise on the "better" standard.

The influence of ϵ on the effects of G and ψ (parameters measuring the gross benefit and positive pecuniary externality of a standard) are similar to those on λ and β. Small values of ϵ do not influence the affects of G and ψ. But sufficiently high linkages between the countries does influence their impact. Compare, for instance, Figures 4.9 and 4.10. When $\epsilon = 0.25$, it has no impact on the effects of G. But when $\epsilon = 0.5$, there exist a range of values of G_i ($0.8 \geq G_i \leq 1$) for which multiple equilibria appear. The same pattern holds if the gross benefit of the country-specific standards are varied. A similar pattern also holds for ψ_i, ψ_a, and ψ_b.

What effect does G_r, the gross benefit associated with the alternative action, have on the above results? When G_r is sufficiently small then it does not change the qualitative nature of the results. When G_r is sufficiently large, then ϵ has no effect and suppliers in both countries all choose the alternative action. Values of G_r in between these two extremes can result in multiple equilibria if ϵ is large enough (see Figures 4.13 and 4.14 for $\epsilon \geq 0.575$). This example again shows that the welfare of one country can be higher than the other in the resulting equilibria. In this case the country where more suppliers adopt the generic standard, compared to the other country, experiences a higher level of welfare.

Global Positive Externalities

When both the externalities are global, and the bargaining externality is sufficiently small ($\lambda = 0.4$ in Figure 4.11), then increases in the linkages between countries increases adoption shares of the generic standard. This is evident in Figure 4.11. The increase in ϵ increases the positive external effects relatively more than the negative external effects associated with the generic standard. This means that increases in ϵ cause adopters of the generic standard in one country to more strongly raise the benefits of adopting the generic standard in the other country. This effect increases the adoption shares of the generic standard in both countries.

Two Industries

If suppliers are moderately heterogeneous ($\beta = 5$ in Figure 4.12) and the bargaining externality is not overly strong or overly weak ($\lambda = 0.4$ in Figure 4.12), then increases in the linkages between industries causes an increase in the adoption shares of the generic standard, in both industries. If the bargaining externality is strong and agents are heterogenous, then local conditions determine the adoption patterns. Similarly, local conditions drive the adoption patterns when the bargaining externality is weak and agents are relatively homogeneous.

Multinational and Multiproduct Firms

The effect of varying n^C, the proportion of all suppliers who are multinationals, is evident in Figures 4.13 and 4.14. When the bargaining externality is large ($\lambda = 0.5$ in Figure 4.13) then increases in n^C reduce the adoption shares of the generic standard. The impact of the negative bargaining externality in this instance outweighs economising on the adoption costs. Hence more multinationals find it in their interests to adopt the country-specific standards if n^C increases. When the bargaining externalitv is small ($\lambda = 0.4$ in Figure 4.14), then economising on adoption costs dominates the effects of the negative bargaining externality in the decisions of multinationals.

The impact of varying the costs of adopting the standards is clearly shown in Figures 4.15 and 4.16. The adoption shares of the generic standard increase with increases in the costs of adopting the standards, as we would expect. An increase in the cost of adopting the standards causes some multinationals who would have adopted the country-specific standards, because they best suited their idiosyncratic requirements, to adopt the generic standard to save on the adoption costs.

Figure 4.1: Country A
β=1 λ=0.9 G=1 φ_a=φ_b=2 φ_g=3

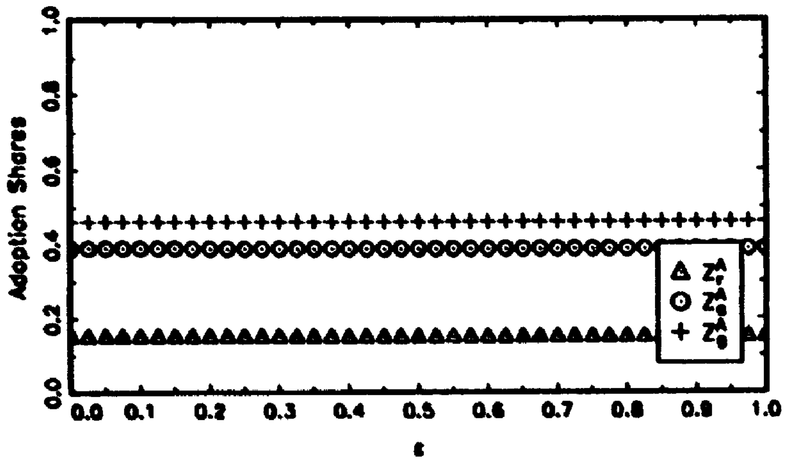


Figure 4.1: Country B
β=1 λ=0.9 G=1 φ_a=φ_b=2 φ_g=3

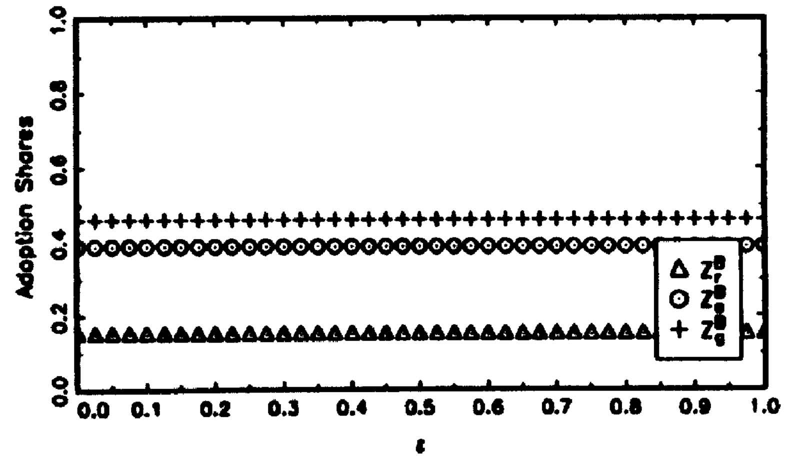


Figure 4.2: Country A
β=5 λ=0.4 G=1 φ=3

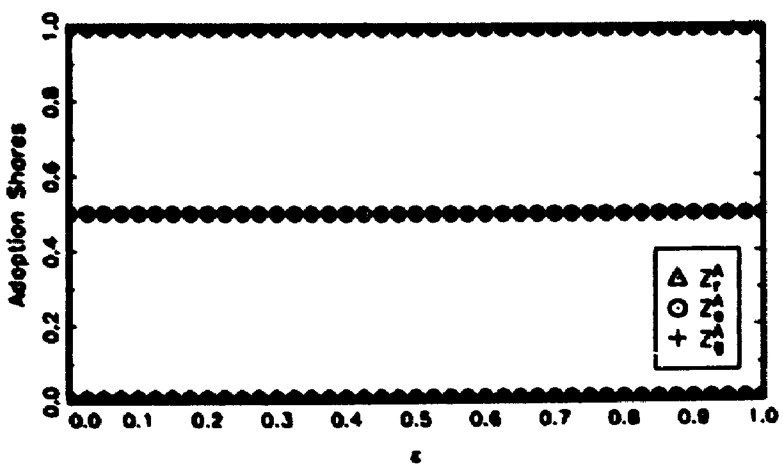


Figure 4.2: Country B
β=5 λ=0.4 G=1 φ=3

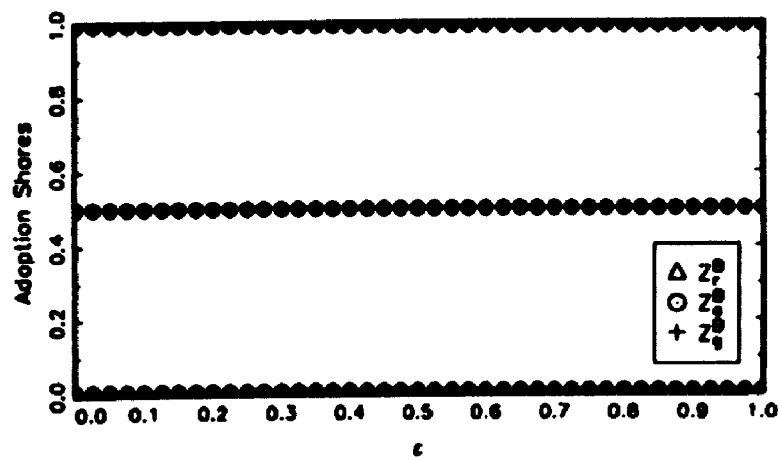


Figure 4.3: Country A
β=3.5 λ=0.65 G=1 φ_a=φ_b=2.5 φ_g=3.5

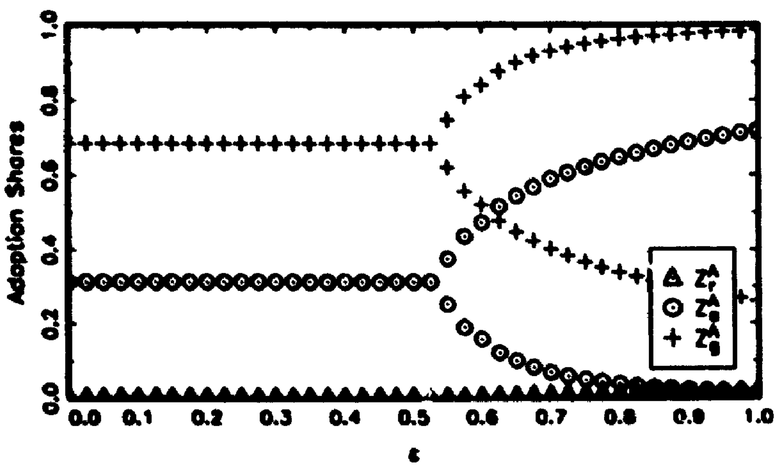


Figure 4.3: Country B
β=3.5 λ=0.65 G=1 φ_a=φ_b=2.5 φ_g=3.5

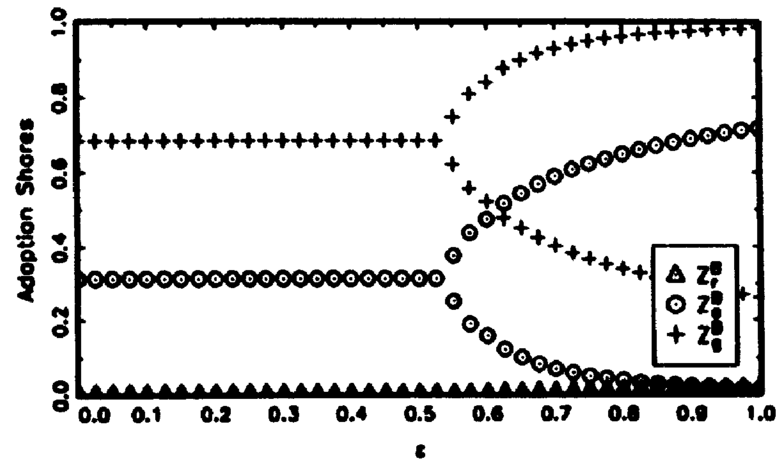


Figure 4.4: Country A
β=5 λ=0.5 G=1 φ_a=φ_b=2.5 φ_g=3.5 G_r=3.5

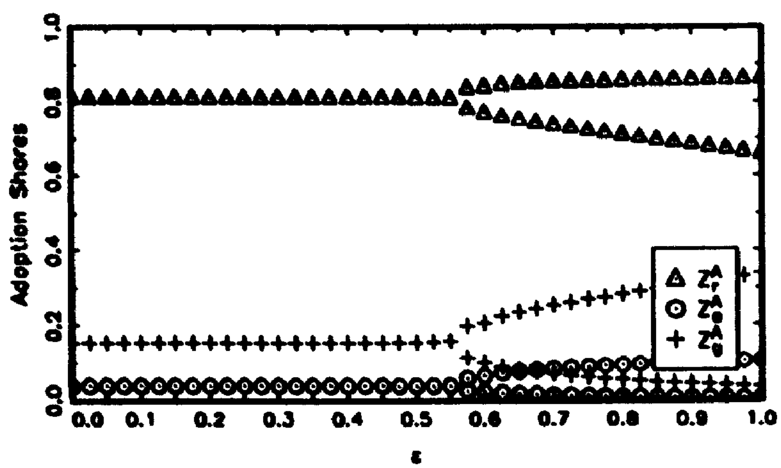
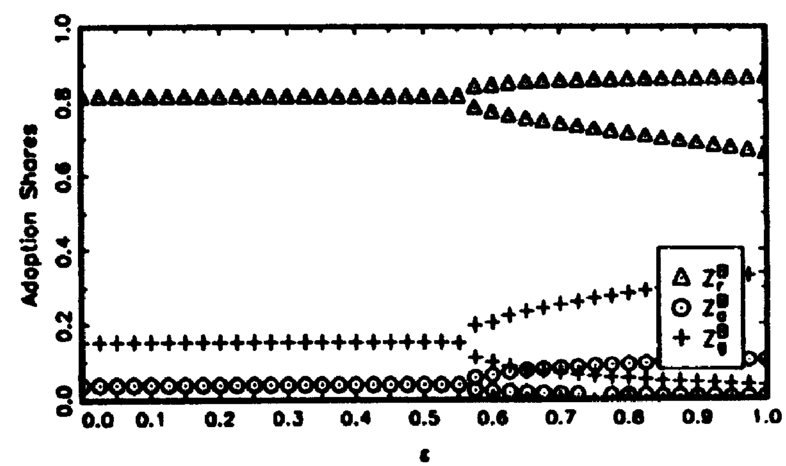


Figure 4.4: Country B
β=5 λ=0.5 G=1 φ_a=φ_b=2.5 φ_g=3.5 G_r=3.5



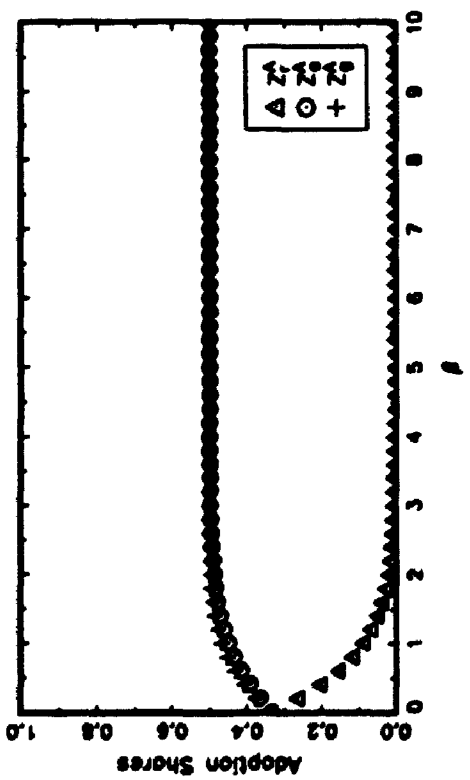


Figure 4.5: Country A
$\epsilon=0$ $\lambda=0.5$ $G_a=G_b=1$ $G_g=1.5$ $\varphi_a=\varphi_b=3$ $\varphi_g=2$

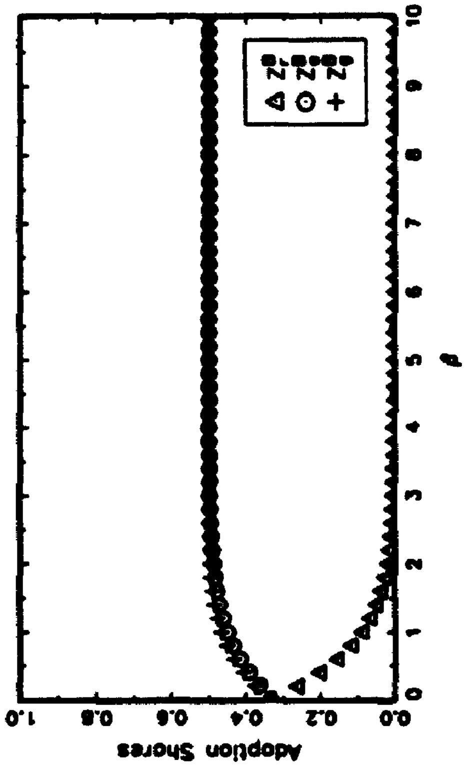


Figure 4.5: Country B
$\epsilon=0$ $\lambda=0.5$ $G_a=G_b=1$ $G_g=1.5$ $\varphi_a=\varphi_b=3$ $\varphi_g=2$

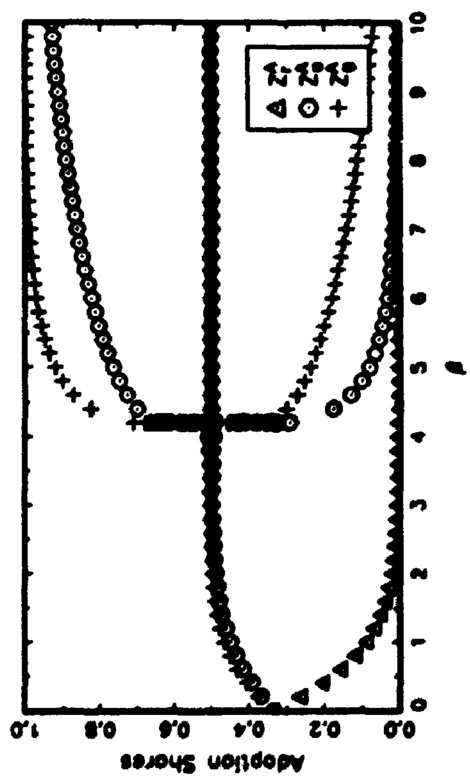


Figure 4.6: Country A
$\epsilon=0.25$ $\lambda=0.5$ $G_a=G_b=1$ $G_g=1.5$ $\varphi_a=\varphi_b=3$ $\varphi_g=2$

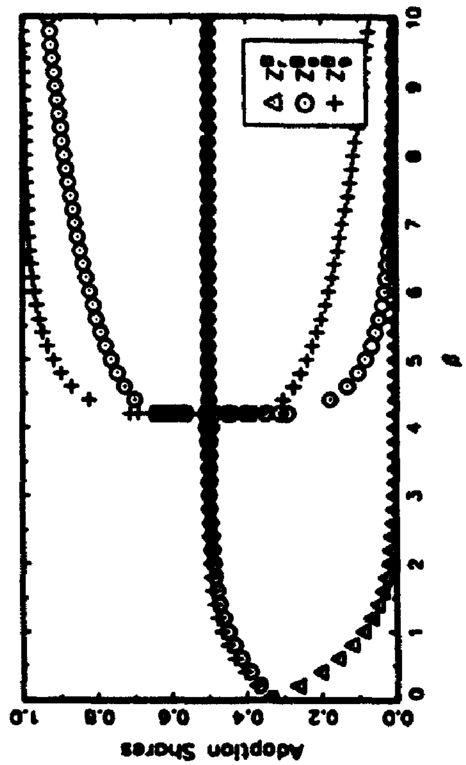


Figure 4.6: Country B
$\epsilon=0.25$ $\lambda=0.5$ $G_a=G_b=1$ $G_g=1.5$ $\varphi_a=\varphi_b=3$ $\varphi_g=2$

Figure 4.7: Country A
$\varepsilon=0$ $\beta=3.5$ $G_a=G_b=0.5$ $G_g=1$ $\varphi_a=\varphi_b=2$ $\varphi_g=1.5$

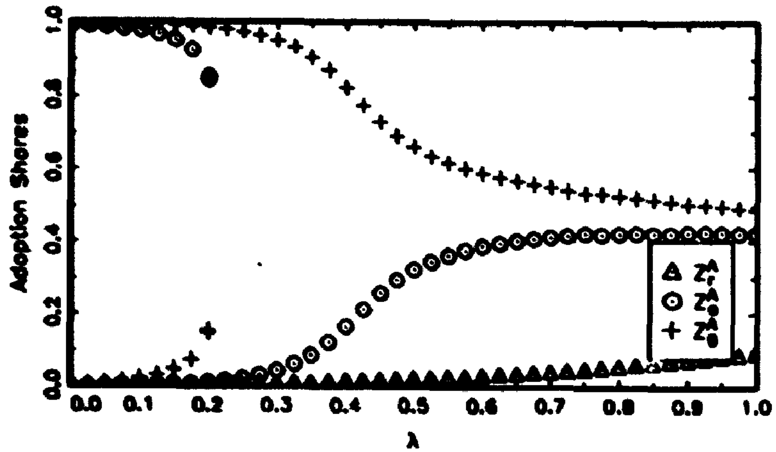


Figure 4.7: Country B
$\varepsilon=0$ $\beta=3.5$ $G_a=G_b=0.5$ $G_g=1$ $\varphi_a=\varphi_b=2$ $\varphi_g=1.5$

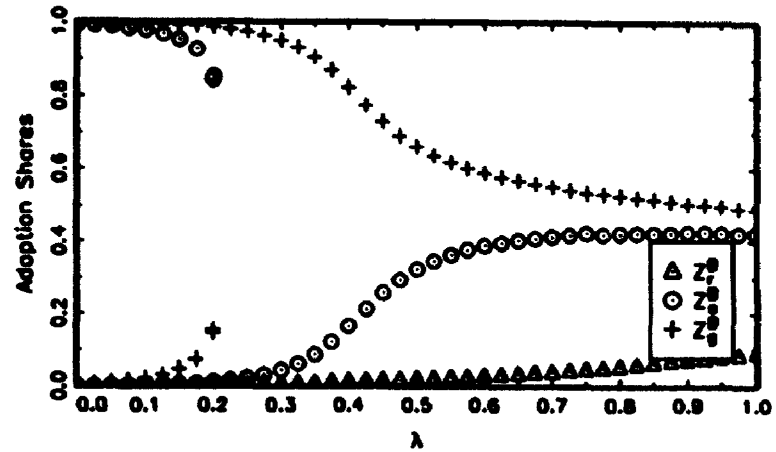


Figure 4.8: Country A
$\varepsilon=0.75$ $\beta=3.5$ $G_a=G_b=0.5$ $G_g=1$ $\varphi_a=\varphi_b=2$ $\varphi_g=1.5$

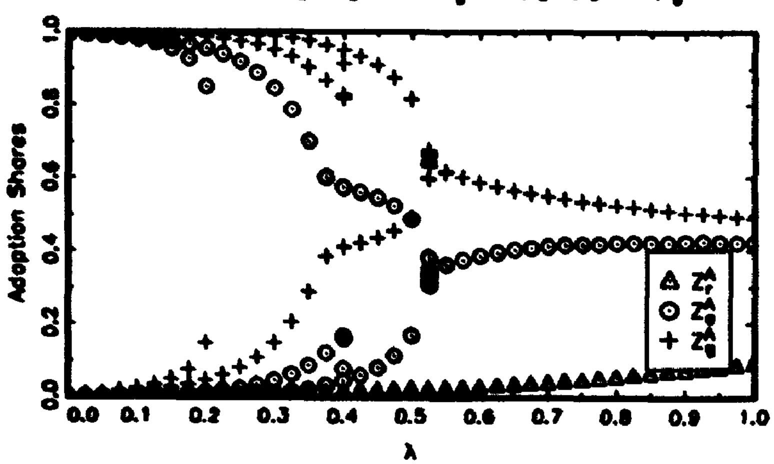


Figure 4.8: Country B
$\varepsilon=0.75$ $\beta=3.5$ $G_a=G_b=0.5$ $G_g=1$ $\varphi_a=\varphi_b=2$ $\varphi_g=1.5$

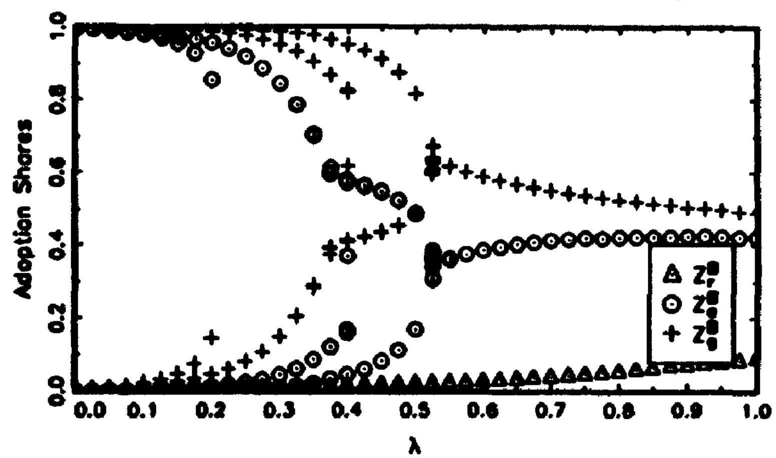


Figure 4.9: Country A
ε=0.25 β=5 λ=0.5 G_a=G_b=1 φ=2

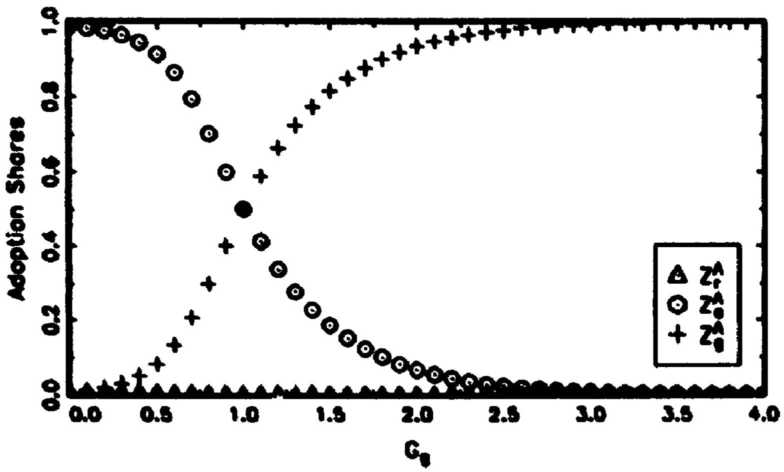


Figure 4.9: Country B
ε=0.25 β=5 λ=0.5 G_a=G_b=1 φ=2

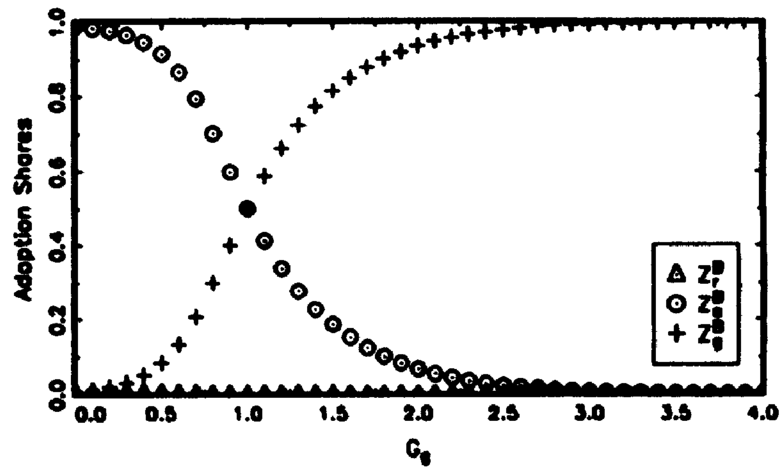


Figure 4.10: Country A
ε=0.5 β=5 λ=0.5 G_a=G_b=1 φ=2

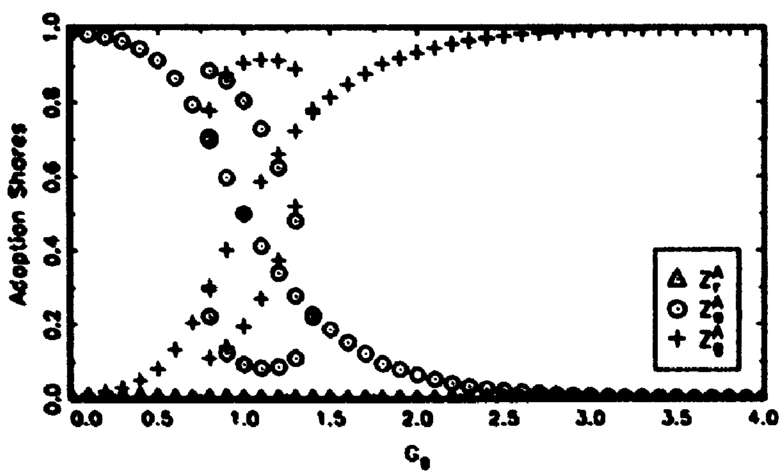


Figure 4.10: Country B
ε=0.5 β=5 λ=0.5 G_a=G_b=1 φ=2

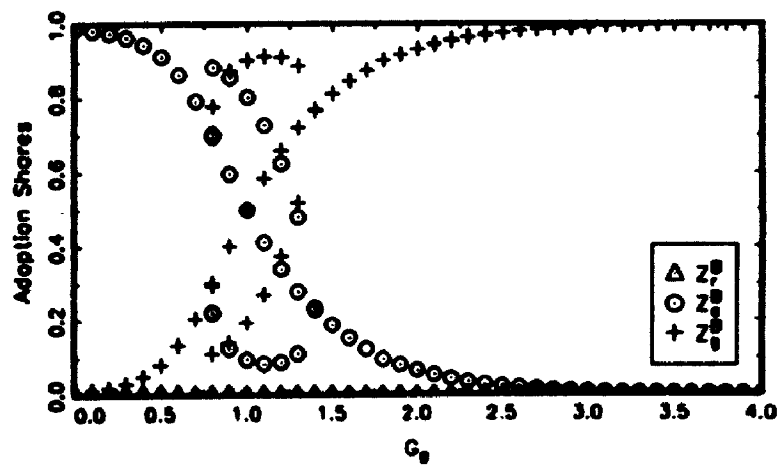


Figure 4.11: Country A
β=5 λ=0.4 G=1 φ_a=φ_b=3 φ_g=2

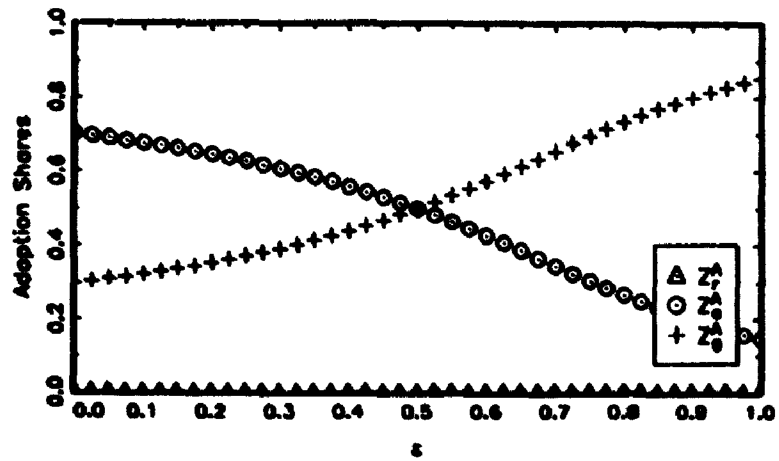


Figure 4.11: Country B
β=5 λ=0.4 G=1 φ_a=φ_b=3 φ_g=2

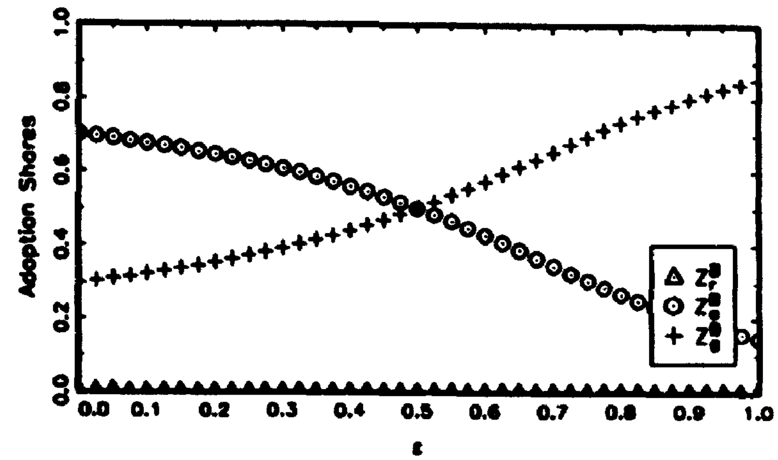


Figure 4.12: Country A
β=5 λ=0.4 G_a=G_b=1.5 G_g=1 φ=2

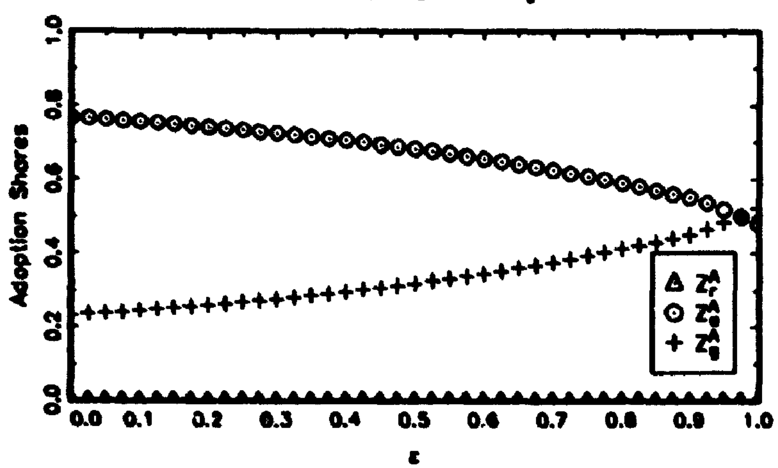


Figure 4.12: Country B
β=5 λ=0.4 G_a=G_b=1.5 G_g=1 φ=2

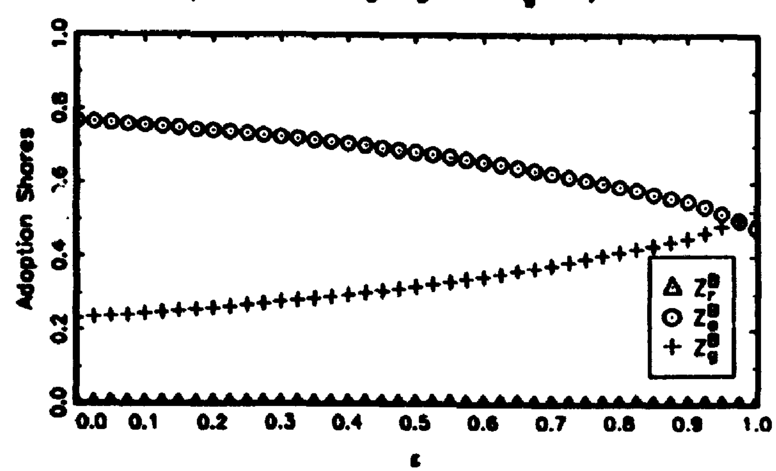


Figure 4.13: Country A
$\alpha=0.5$ $F=0.2$ $\beta=5$ $\lambda=0.5$ $G=1$ $\varphi=3$

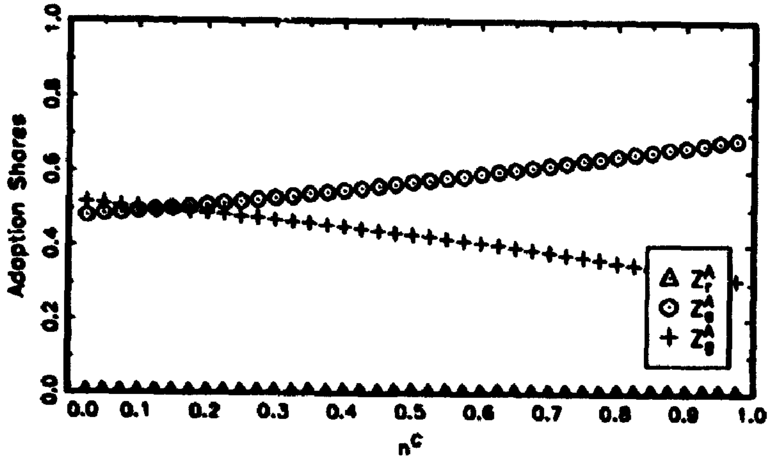


Figure 4.13: Country B
$\alpha=0.5$ $F=0.2$ $\beta=5$ $\lambda=0.5$ $G=1$ $\varphi=3$

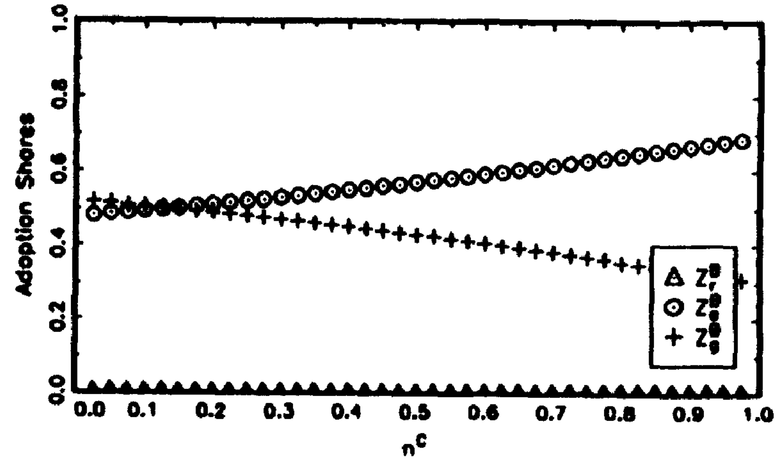


Figure 4.14: Country A
$\alpha=0.5$ $F=0.2$ $\beta=6$ $\lambda=0.4$ $G=1$ $\varphi_a=\varphi_b=2$ $\varphi_g=3$

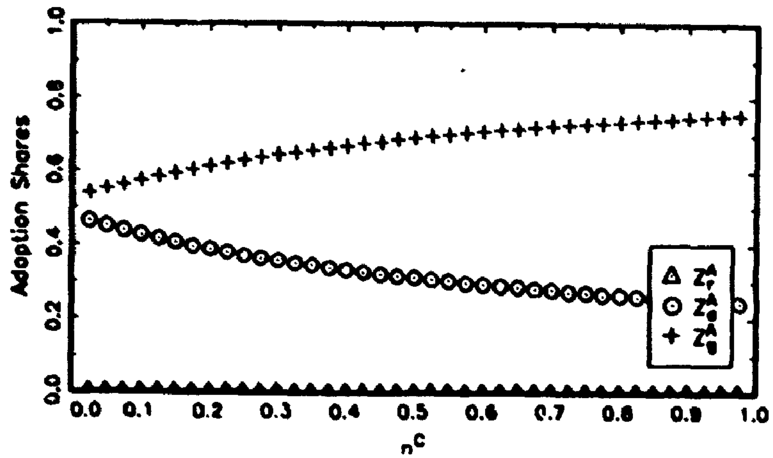


Figure 4.14: Country B
$\alpha=0.5$ $F=0.2$ $\beta=6$ $\lambda=0.4$ $G=1$ $\varphi_a=\varphi_b=2$ $\varphi_g=3$

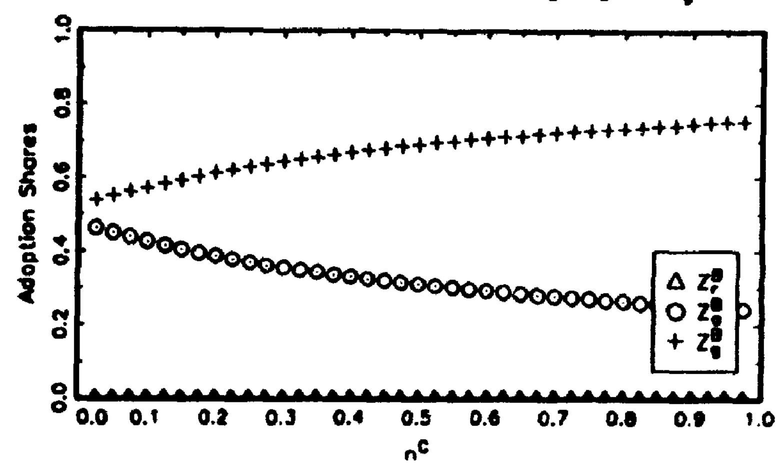


Figure 4.15: Country A
α=0.5 n^C=0.2 β=6 λ=0.4 G=1 φ=3

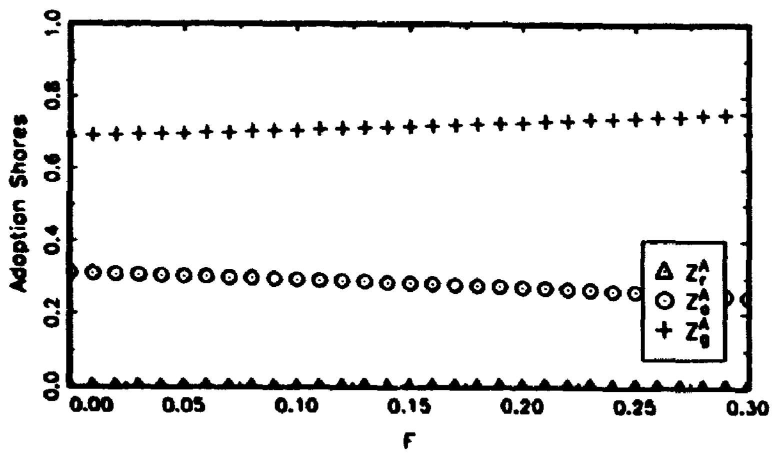


Figure 4.15: Country B
α=0.5 n^C=0.2 β=6 λ=0.4 G=1 φ=3

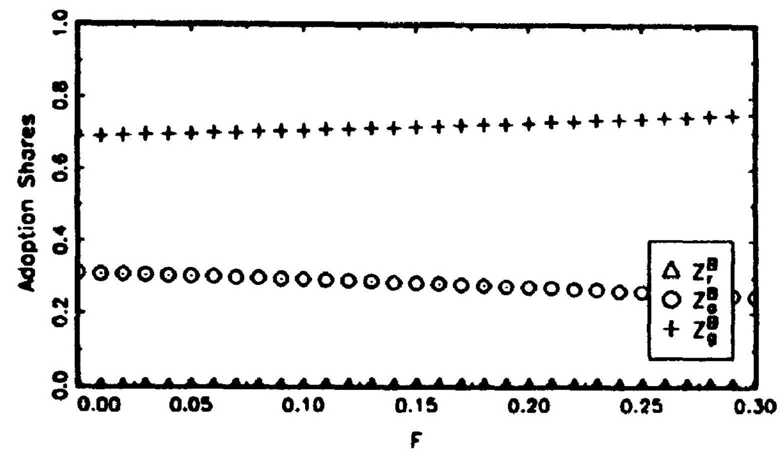


Figure 4.16: Country A
α=0.3 n^C=0.4 β=6 λ=0.4 G_a=G_b=1.5 G_g=1 φ_a=φ_b=3 φ_g=3.5

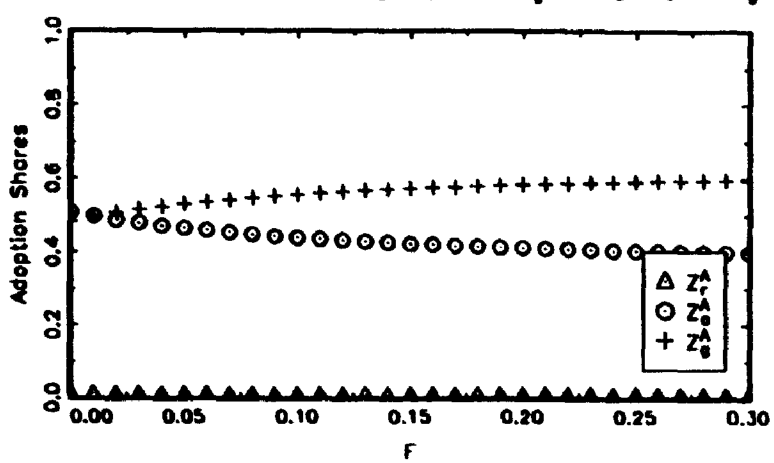
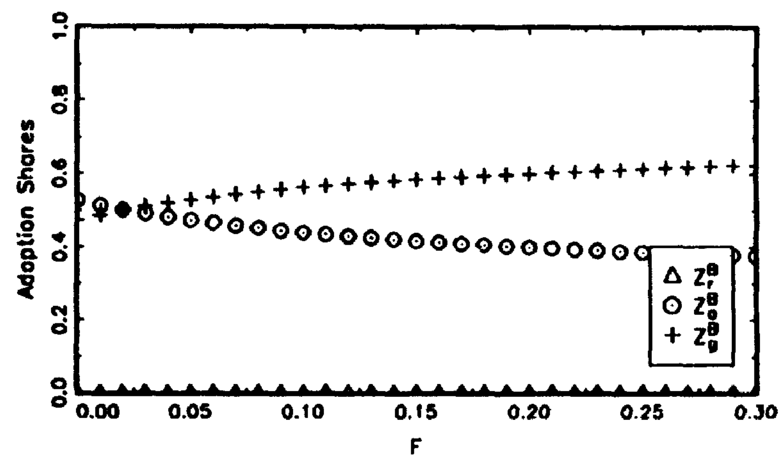


Figure 4.16: Country B
α=0.3 n^C=0.4 β=6 λ=0.4 G_a=G_b=1.5 G_g=1 φ_a=φ_b=3 φ_g=3.5



Chapter 5

Bug Control: Analysing The Adoption Of Process Standards In The United States Software Industry

5.1 Introduction

As was mentioned in the introduction, there are many examples of different adoption patterns of process standards. But there have not been any empirical studies concerning the adoption of these standards. This is unsatisfactory, especially since process standards have several features which differ from those present in compatibility standards (for which a number of empirical studies are available). These differences imply that the factors affecting the adoption of process standards are quite different from those affecting the adoption of compatibility standards. This chapter presents a case study of the adoption of process standards in the United States software industry. In particular, the adoption patterns in bespoke and packaged software will be contrasted. Theoretical results from Chapters 3 and 4 are used to explain the observed patterns. This will increase our knowledge about the adoption of them in general.

The software industry is also the scene of an intense debate about the merits of developing and using process standards. Currently there are over 250 standards applicable to producers in this industry.[1] Many of them were developed to "solve" a crisis that has been seen as plaguing the industry for the last twenty-five years — the crisis being a preponderance of "bug-ridden", over-budget, and excessively late software.[2] The development of software process standards was recommended in a study by Price Waterhouse (1988), and has been pushed by (among others) the Computing Services and Software Association in the United Kingdom and the United States Department of Defence (DoD).[3] In response to these concerns, the International Organization for Standardization (ISO) and the International Electrical Commission (IEC) are developing a series of international software process assessment standards to harmonise software process assessments throughout the world. The expectation of the ISO and the IEC is that these standards will supplant other software process standards.[4] They expect that this will increase the benefits of standardisation. To judge the likely success or failure of this approach requires that we understand the standards adoption environment of the software industry, the properties of the standards, the adoption pattern we currently observe, and the factors that are causing the current pattern to occur.

The rest of this chapter is structured as follows. The next three sections present detailed overviews of the software industry, the standards adoption environment, and the main competing process standards. The large amount of detail present in these sections is, in part, a response to the assumption in the theoretical work of

[1] Pfleeger, Fenton, and Page (1994, p. 71).

[2] Gibbs (1994).

[3] Although Jones (1994a) raises doubts about the ability of them to solve the industry's problems, while Buetow (1994) adamantly opposes their use on the grounds that they do not fix any problems. He even suggests that they may aggravate the existing crisis.

[4] International Organization for Standardization (1992).

the independence of irrelevant alternatives. To accurately characterise the adoption patterns for any industry, we first have to ensure that any actions available to software producers that are similar are treated as a single action. In order to do this it is necessary to gain a thorough understanding of the software industry and the choices available to software producers. Hence the large attention to detail. Then the pattern of process standard adoption in the software industry is analysed using the theoretical results developed in Chapters 3 and 4. Finally, conclusions are drawn from the case study.

5.2 Software and the Software Industry

It is important to realise that there are two general types of software. The first is the well known package software bought at a local computer store. An example is *Wordperfect*. The second is bespoke software, typically purchased, or produced internally, by medium to large sized organisations such as government departments, telephone companies, aircraft manufacturers, and hospitals. Bespoke software is used in most information systems in the industrial world, including many "safety-critical" systems. It is used to control telephone networks, nuclear power stations, elevators, air-traffic control systems, military weapons and defence systems, automobiles, medical equipment and many other products and services. It is also being increasingly used in common consumer products.[5] Most electric shavers contain 2000 bytes of software, televisions contain on average 500,000 bytes of code, and different parts of automobiles (such as anti-lock braking systems) can contain 30,000 lines of code.[6] Projections are that society will increasingly depend

[5] Commonly referred to as embedded software in these contexts.

[6] Gibbs (1994).

on software to control many of its economic activities.[7] Both types of software can be either final goods or intermediate inputs.

While package software is more well known, over ninety percent of all software produced, and over sixty percent of the $147 billion worth of traded software in 1993, was bespoke. Approximately eighty percent of all software is produced in-house, all of which is bespoke. Manufacturers of electronic, computer or telecommunication equipment produce ten percent, and software houses such as Microsoft or Novell produce the remaining ten percent. In 1993, firms in the United States produced 48.5 percent of all software, with another 33.5 percent produced by Japan, the United Kingdom, Germany and France. Producers in the United States supply much of the internationally traded software, both package and bespoke.[8]

5.2.1 Concerns about Software Quality

There are many definitions of software quality. Three commonly used dimensions are: the number of defects; the degree to which a program meets the requirements of its users; and the level of maintenance costs. Maintenance costs are a function of the ease with which software can be altered to meet the changing requirements of users, to convert it to different hardware (usually to take advantage of technological changes in computer equipment), and to fix defects. Obviously these three factors are interrelated. High maintenance costs are more likely if a program

[7] For example, computer systems are being increasingly used in buildings and automobiles. See *The Independent*, (1994), 20 June, p. 25; and *The Economist*, (1995), 28 January, pp. 76 and 78. Typically, embedded software represents only a small fraction of the value of a product, but it is almost always *the* critical component determining whether a product functions or not. See Yourdon (1992, p. 2).

[8] The information in this paragraph can be found in Gibbs (1984) and Organisation for Economic Co-operation and Development (1991 and 1994). This suggests that linkages between the United States and other countries is large, at least in the software industry. In Chapter 4, this would imply that ϵ, the parameter measuring the strength of the links between countries, is large.

has a high number of defects. Equally, high maintenance costs are more likely if a program does not meet the requirements of its users. Finally, there is one significant difference between low quality package and bespoke software. A defect in a spreadsheet program may cause a loss of data, resulting in additional costs of data being re-entered. A defect in a program controlling an automobile's breaking system, or a program controlling a nuclear power plant, may have more drastic consequences.

The importance of bespoke software, and the consequences of defects in it, are highlighted in many recent examples of software system failures. In the United Kingdom a software defect allowed a washing machine to overheat in 1992. The washing machine then caught fire which spread throughout the rest of the house, causing a fatality.[9] In June and July of 1991 over ten million telephone customers in California, Maryland, Pennsylvania, Virginia, West Virginia and Washington D.C. experienced service outages for approximately seven hours. Similarly, a software error in January 1991 caused outages for fifty percent of AT&T's network traffic.[10] In early 1991, software written to prevent aircraft collisions falsely reported four aircraft in the vicinity of a United Airlines passenger aircraft and instructed the pilot to climb. This caused the aircraft to move into the flight path of other nearby jets. Luckily an aircraft controller was able to warn the pilot of the situation before an accident occurred.[11] The destruction of an Iranian civilian airliner in July 1988 by the USS Vincennes was blamed on software that was not programmed to report the altitude of the approaching aircraft. Instead, it was designed to report whether

[9] *The Independent*, (1994), 20 June, p. 26.

[10] In response to these and other software defect induced disruptions to the United States telephone system, representative Robert Wise introduced a bill in the United States House of Representatives which would make the Federal Communications Corporation responsible for reliability and quality standards for the telecommunications industry in the United States. For details about problems caused by software defects in the United States telecommunications industry see Burgess (1991), Fordahl (1991), and Fordahl (1992).

[11] Sims (1992).

the aircraft was hostile, and if so, whether the ship was under attack. The software system falsely reported that the airliner was descending to attack. The software had to be reprogrammed.[12] Between 1985 and 1987, a Therac-25 radiation therapy machine emitted massive overdoses of radiation on seven different occasions due to a software defect. Four people died as a result.[13] These incidents represent only the tip of the iceberg.[14]

It is also the case that many development projects result in bespoke software that is never used, is not delivered to the user, or has to receive extensive modifications after it is delivered to be of any use. A United States Federal Government survey of software contracts found that in value terms, forty-seven percent was not used, twenty-nine percent was not delivered to the user, and nineteen percent needed extensive modifications after delivery to be used.[15] An IBM survey of twenty-four leading companies that develop large bespoke software systems found similar results.[16] Price Waterhouse (1988, Chapter 4) estimate that United Kingdom software users in 1987 incurred costs of $690 million due to defects and maintenance costs from domestically produced software. The value of software sold by United Kingdom producers was only $900 million.

There are also concerns about the low quality of package software. Many projects are behind schedule. Programs such as DBase IV, Lotus 1-2-3, OS/2 and

[12] Gruman (1989).

[13] Leveson (1994).

[14] For instance, see Lee (1991). In addition, there is a regular column in the software engineering journal *Software Engineering Notes* devoted to incidents and accidents caused by computer systems.

[15] Davis (1990).

[16] Gibbs (1994, p. 89).

Windows 95 have all been released years after their target dates.[17] There are complaints that they are excessively complex, requiring substantially more computing power than necessary.[18] The programs also contain many defects. Michael Miller, a regular columnist for *PC Magazine*, recently wrote, "Will Windows 95 have bugs? Yup. Every newly released operating system or application has bugs. It is unavoidable.". He later commented that Microsoft have already planned to ship a series of "fixes" on a regular basis.[19] This practice is commonly used by package producers. The initial version of *Netware* released by Novell was found to be unreliable and incomplete.[20] Software Productivity Research (SPR) has found that thirty percent of package software bought by firms and government agencies does not meet enough of the users needs to be effective, twenty percent duplicates the functions of existing software, twenty-five percent suffers from a lack of use, and fifteen percent is incompatible with existing software and requires substantial modification.[21] Some industry experts, howe' ., believe that the practices of large package producers, in particular, may be appropriate for their market. Though they also believe that there are major problems with the practices of bespoke producers.[22]

There is no dispute that software contains defects. Jones (1994a, p. 9) estimates that software produced in the United States has an estimated average of five defects per function point.[23] Yourdan (1992, p. 199) reports that software produced in the United States has an average of four defects per thousand lines of

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[17] Buckley (1990, p. 75).
[18] Reiser and Wirth (1992, pp. 5-6).
[19] *PC Magazine*, (19^5), August, p. 75.
[20] *The Economist*, (1995), 13 May, pp. 63-64.
[21] Jones (1994a, p. 235).
[22] *IEEE Software*, (1995), 12 (8), pp. 105-106.
[23] A function point is an abstract metric developed to give a measure of the functional output of a program that is invariant to the programming language used to code it.

code. It is also unlikely that defect free software can be produced with the technology currently available. It may even be inefficient from an economic perspective.

While we would expect software to contain some defects, require maintenance costs, and fail to perfectly match the needs of users. There are indications, however, that the quality of software, particularly of the bespoke type, is suboptimal. There are three reasons for taking this claim seriously. First, there is widespread concern by both users and producers that the quality of software is suboptimal. Second, the average quality of software appears to be considerably below that of other products, especially those of comparable complexity. Yourdan (1992, p. 199) estimates that on average, software is 99.98 percent reliable. In contrast, the products and services of other industries, such as the airline industry, are estimated to be 99.9999998 percent reliable. For the software industry to attain the same level of reliability as the airline industry would require decreasing the number of defects from an average of four per thousand lines of code to four per million lines of code. [24] In addition, it has to be realised that a defect is defined as the failure of a program to perform to the *producer's* specifications. There is evidence that most software also fails to meet the requirements of the *user*. Of course this is harder to quantify and much harder to correct.[25] Third, as will be argued, there are strong reasons to believe that asymmetric information and moral hazard are present in the trade of software, which adversely affect its quality. This results in a "lemons" problem as analysed by Akerlof (1970).

[24] Yourdan (1992, p. 199) and Jones (1994e, pp. 25-26).
[25] Price Waterhouse (1988).

5.2.2 Asymmetric Information and Moral Hazard

The quality of a program is predominately determined by the processes with which it is designed. Over eighty-five percent of all defects on average are introduced in the design stage.[26] The amount of resources expended on coding or testing a program will increase its quality, but only moderately.[27] This means that emphasis needs to be placed on the processes used to design it. But, the design process is where customers have the least information about what producers are doing. It is straightforward to see that a producer uses an object-orientated language such as C++, which has been linked to lower maintenance costs. It is considerably more difficult to ascertain whether a producer used requirements analysis, hazard analysis, mathematical verification, or even simple planning procedures, in designing the same program.

Even if producers were to employ better processes and tools, users may not be sure what has caused the software to have fewer defects and/or to better fit their requirements. This is due to the characteristics of software, which is both an experience and a credence good; package software being more of an experience good, while bespoke software is more of a credence good. Experiencing few defects may be the result of higher quality software, or it may be that it contains a large number of defects but the user has not experienced any of these to date. It is not unheard of for firms to claim that they want to produce high quality goods, yet fail to carry out any appropriate actions. For example, a Gallup survey for the American Society for Quality Control (ASQC) reported that over half of the 1,237 corporate employees surveyed reported that their companies say that increasing the

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[26] Poston (1985a, p. 83).

[27] The next section describes why testing in general has only a moderate affect on software quality.

quality of their goods and services is a top priority. Only a third of those surveyed reported that their companies actually did anything to improve the quality of their goods and services.[28] It could take many years of use before users would attribute the increase in quality to better processes used by the producers.

This is the basis for Price Waterhouse (1988) arguing that producers do not employ better production techniques because the benefits of higher quality software, a lower number of defects and smaller maintenance costs, only show up on average after it has been in use for a number of years. In contrast, the costs of improving its quality are immediate.[29] As a result there is a large gap between when firms incur the costs to increase the quality of their software and when they receive the benefits from the higher quality. Discounting clearly reduces the incentive in this situation. The temporal mismatch experienced by producers is not by itself a major impediment to the implementation of techniques that result in higher quality software. There are economic mechanisms which can overcome such a temporal mismatch of benefits and costs, even in the presence of asymmetric information.

But, there are other characteristics of software that reduce incentives for producers to develop high quality software. It is common for users to alter the software they have purchased. Partly this reflects dissatisfaction with the ability of it to fit their needs. It also reflects the fact that most software systems last for a long time and require maintenance to fix discovered defects, or require updating to fit the users' changing environment. These changes undermine the integrity of the

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[28] *The Wall Street Journal*, (1990), 4 October, sec. B, p. 1.

[29] Price Waterhouse (1988) give a detailed analysis of the costs and benefits of improving software quality for an average producer in the United Kingdom.

software system as well as introducing defects.[30] Users may also apply programs to tasks for which they were never intended. Finally, a major determinant of the quality of bespoke software is the quality of the program requirements set by the users. The program requirements establish what the software is supposed to do, how it is supposed to do it, what it is not supposed to do, and any other features of the program needed by the users. The dependency of the quality of software on the users, as well as the producers, creates a problem of moral hazard. High quality software may be due to high quality requirements provided by the user. It could also be due to the producer, in spite of low quality requirements provided by the user. This makes it very difficult to determine the contribution of the producer to the quality of a program.

In general, there is strong evidence that the processes of producers are indeed in a low quality equilibrium. The Software Engineering Institute (SEI) assessed 323 (mainly United States) software producers between 1987 and 1991 and found that eighty-eight percent of them used processes that are unpredictable and poorly controlled. See Table 5.1.

Similar outcomes were also found in comparable studies of producers in Europe and Japan.[31] In contrast, observable characteristics, such as whether the latest tools are being used, do not appear to be in such a state. There have been many tools developed in recent years designed to aid producers, such as Computer Aided Software Engineering programs. These are becoming widely used.[32] Economic

[30] Lee (1991, pp. 101-103) discusses the likelihood of introducing a defect into a program through changes to its requirements. Zave (1993) documents the difficulty of adding features to complex software systems in the telecommunications industry.

[31] Bannert (1991), Bicego and Kuvaja (1993), and Humphrey, Kitson and Gale (1991).

[32] Curtis (1994) and Yourdan (1992, p. 293).

Table 5.1
Types of Organisations Assessed Under the CMM and their Maturity Profiles

Organisation Type	% of Organisations
Commercial	29
DOD/Federal Contractor	36
Military/Federal Organisation	22
Other	13
Maturity Level	
1 — Initial	76
2 — Repeatable	15
3 — Defined	8
4 — Managed	0
5 — Optimising	0.5

Source: SEI.

theory would predict that this would happen since the use of these tools is directly observable. Unfortunately, they have little impact on the quality of software without sound production processes, particularly design processes.[33]

The importance of sound production processes is heightened by the inability of testing to eradicate many software defects. It is usually impossible to test any program comprehensively for defects; the state space of computer software is huge and computing resources are finite. Software is an exceedingly complex product, with some systems containing over forty million object instructions.[34] Lee (1991, p. 100) reports that a program consisting of 160 lines of code would imply an

[33] Curtis (1994) and Yourdan (1992). A common joke in the software industry is that a producer which uses these tools will be able to produce more low quality software faster.
[34] Norris and Rigby (1992) and Davis (1990).

average of forty million possible outcomes. Air traffic controllers in the United States use software that consists of 16,000 lines of code, which is tiny by modern standards. The number of possible outcomes from this program is greater than the total number of atoms in the universe! Pressman (1992, p. 599) estimates that a 100-line PASCAL program would take 3,170 years to be exhaustively tested. He also goes on to say that there is no technology at present able to do this, even if we wanted to. To make matters worse, at least a third of the defects contained in a program are called 5,000 year bugs. A program would have to be run for many multiples of 5,000 years before all of these defects would be discovered.[35] As a result, the cost of testing for defects increases exponentially, not only with the size of the state space, but also with the number of defects found. Even when a barrage of tests are thrown at a program they will on average find less than fifty-five percent of the defects.[36] Furthermore, even if a defect is found, fixing it has a twenty to fifty percent chance of introducing another defect. In some cases they are not fixed because the likelihood of introducing a new defect is considered too high.[37] More problematic, if a fix does not introduce another defect, often it will destroy the system integrity of the program. This reduces its effectiveness and robustness.[38]

This situation is worse for bespoke software than it is for package software. Package software tends to be sold to a large number of users, so the cost of testing and fixing defects is substantially less expensive for each user than for bespoke software which only has one user. For example, Microsoft typically distributes prototypes of its programs to 20,000 volunteers who use them and report any defects

[35] Littlewood and Strigini (1992, p. 64).
[36] Jones (1994e, p. 26).
[37] Lee (1991, p103).
[38] Brooks (1975, p. 122).

found. The volunteers get a free copy of the program for their troubles.[39] Corel has even started paying its beta testers.[40] This is obviously an expensive method to eradicate software defects. First, fixing defects in software code is typically 100 times more expensive than fixing them in the specifications stage.[41] Second, employing 20,000 people to test each program is costly. This method is not economically feasible for many producers of package software since large numbers of such testers are required. It is considerably less applicable to producers of bespoke software since each program is sold to only one user.[42] It is also worth pointing out that beta testing will also be an inadequate method for users of embedded software, even though they may sell large quantities of products which contain the software. First, the software typically makes up a small fraction of the cost of the product. Second, in some cases, for instance automobiles, it would be very risky to let 20,000 customers drive around with defective software controlling ignition, power, steering, and braking systems in order to find the defects!

The previous discussion strongly suggests that trade in software is affected by the presence of asymmetric information consistent with economic theories such as Akerlof (1970). Users cannot judge the quality of software until they have used it, if they can judge it at all. As Michael Miller commented, "How serious will the Windows 95 bugs be? No one knows."[43] Even if users could eventually judge the quality of software through repeated use, incentives faced by producers to increase quality are small. Trade in bespoke software, in particular, is also heavily affected by moral hazard. Uncertainty by users about the source of the lower number of

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[39] Gibbs (1994, p. 90).
[40] *IEEE Software*, (1995), 12 (7), p. 104.
[41] See Boehm (1991, p. 40).
[42] Jones (1994e, pp. 16-17).
[43] *PC Magazine*, (1995), August, p. 75.

defects, as well as the temporal mismatch between the flow of costs and higher benefits arising from higher quality, reduces even further the discounted benefits to increasing quality by producers. Economic theory would suggest that trade in these circumstances will in general be inefficient. The next section evaluates the potential of various mechanisms to alleviate the effects of asymmetric information.

5.2.3 Possible Responses

There are several economic mechanisms available to alleviate the effects of asymmetric information.[44] This section discusses the main mechanisms (except for the applicable process standards which will be analysed later in Section 4), their use in the software industry, and the likelihood that they can overcome the asymmetric information. From analysing these mechanisms we will be able to establish an estimate of the gross benefits (this is the parameter G_r in Chapters 3 and 4) that a firm may expect to receive from using them.

An Imperfect Testing Mechanism

Heinkel (1991) has suggested that the negative effects of asymmetric information can be overcome if consumers have an imperfect testing mechanism available. The discussion in the previous section suggests that such a mechanism, while available to consumers, is very "noisy" and suffers from large decreasing returns. As shown by Heinkel, mechanisms that are noisy have little effect in situations where asymmetric information is present. The presence of high decreasing returns also implies that such a mechanism will be little used, since there is only a small range of intensity of use for which the net benefit is positive. In other words, testing

[44] See Chapter 2 for a discussion about these mechanisms.

of software products by consumers has at best a minor impact on the practices of producers.

Warranties

Warranties may be effective at signalling the quality of a good to consumers as shown by Grossman (1981). Warranties, however, are virtually never offered for software products and only cover the media on which the programs are stored.[45] One reason for this is that producers know that their software will contain defects, but do not know how serious the defects will be. It only takes a defect in one character to cause a serious accident and there is no method available at present to identify defects by the seriousness of their potential for disaster. For instance, there was a single incorrect character in the control program for the Atlas rocket carrying the first interplanetary spacecraft, Mariner 1. The incorrect character caused the rocket to veer off into space. Both the rocket and the spacecraft were destroyed.[46] Finally, there is the dependence of software quality on the requirements and use of users. As Utton (1986) argues, when moral hazard is present, warranties will be at best partial, and at worst non-existent. In the case of software, warranties are virtually non-existent.

Legal Liability

Producer liability schemes have the potential to overcome the effects of asymmetric information as shown by Spence (1977). Legal liability has until recently

[45] Thomas (1993).

[46] Littlewood and Strigini (1992, p. 63).

had little impact on software producers.[47] Producers of defective bespoke software have rarely been sued since the bulk of it is covered by contract law and not laws concerning product liability and negligence. The circumstances under which bespoke software is produced means that it is difficult to win cases brought against producers of it under contract law. This is changing, however, as complex bespoke software is contained in more consumer products. This trend, however, does not affect the large value of bespoke and package software that is sold to business users and is embedded in non-consumer goods. Finally, Spence has shown that a government has to know a lot of information about both consumers and producers to be able to implement a welfare improving liability scheme. Since consumers alone come from very different industries, it seems extremely unlikely that a government could possibly gather sufficient information about them to do this.

Reputations

A producer always has the option of "investing" in its reputation by producing high quality software today. This would enhance the reputation of the producer once consumers realised that it produced consistently high quality software. The producer would then be in a position to earn a return from its "reputation capital" as shown by Shapiro (1983). As Tirole (1990) points out, reputations about the quality of a seller are likely to form if a good is repeatedly purchased from a seller, a large number of consumers buy the good, and quality is measured more by vertical product space characteristics than durability. These characteristics seem to apply to some types of package software. Large numbers of consumers purchase programs such as *Lotus 1-2-3*. Although purchases of a single version are not repeated by

[47] Trubow (1991), Armour and Humphrey (1993), and Sprague (1995).

consumers, they can be by businesses. Quality of package software is measured by its durability (number of defects), but it is also measured by its features. In contrast, bespoke software is purchased by one user. Purchases of bespoke systems by a user also tend to be infrequent. Durability (number of defects and maintenance costs) takes on more prominence in measuring the quality of bespoke software, compared to its usability. This is because bespoke software is normally expected to be in use for many years. Furthermore, much of the bespoke software produced is large and complex. This is precisely the area in which software technology is changing the most rapidly.[48] This feature will quickly depreciate any reputation capital. The use of reputations does seem to be used by at least some producers of package software, especially large producers such as Microsoft, Novell, Borland, and Corel. Unfortunately, as argued, this option seems far less applicable for bespoke producers. This is not to say that reputations about bespoke producers do not mitigate some of the effects of the asymmetric information. Simply, that we would expect their effects in general to be weak.

Summary

The discussion in this section suggests that the average bespoke producer who chooses a mechanism, other than a process standard, to alleviate the effects of asymmetric information, will experience only a small gross benefit from doing so. Thus the value of G_r is likely to be small for the average producer of bespoke software. In contrast, it is likely that G_r is large for the average producer of package software. Characteristics of trade in package software suggest that reputations about firms will serve to alleviate many of the effects of asymmetric information.

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[48] Leveson (1994).

5.3 Software Process Standard Adoption Environment

The number of process standards which apply to the software industry has followed two trends. First, they have increased in number with increases in the fraction of total costs of an information system that are accounted for by software.[49] In 1955, software costs accounted for an average of seventeen percent of the life cycle costs of an information system. By 1985, this had risen to eighty-five percent.[50] Second, the number of process standards has increased with the complexity and increased use of information systems. These trends are not independent. The cost of software has increased relative to hardware because the cost of a unit of computing power has fallen by considerably more than a unit of software functionality.[51] Falling real costs of computing power have caused a substantial increase in the use of information systems. They are now used in a much wider variety of applications than in 1955, as well as having become more complex. The increased complexity has occurred because users of information systems have wanted them to perform a wider variety of tasks, for a given application.

The increased use and complexity of information systems has resulted in a dilemma for the organisations that use them. On the one hand organisations want to employ information systems since computing power is cheap and they are very useful. On the other hand, the users want to know that their systems are reliable, and do what they want them to do. This is unlikely to be the case. Virtually all of

[49] An information system consists of computer hardware, computer software, personnel, and other resources that together collect, store, manipulate, and distribute data.

[50] These figures are in Boehm (1981) and Gruman (1989b).

[51] It must be pointed out that this remark contains a high degree of uncertainty. It is easy to measure a unit of computing power. It is exceedingly hard to measure a unit of software functionality, especially since there is considerable controversy over what is meant by a unit of software functionality. But there is substantial evidence that the productivity of software producers has significantly lagged that of hardware producers. See Gibbs (1994, p. 93), Jones (1991, Chapter 2), and Reiser and Wirth (1992, Preface).

the functionality of an information system is derived from its software. We also know that trade in software is strongly affected by asymmetric information. As a result, organisations can either refuse to purchase computerised information systems and forgo the large number of features they contain, or they can purchase these systems, but be unsure of their reliability. Process standards have been developed to reduce the effects of asymmetric information and rid users of this dilemma.

Until the 1980s, the only process standards used in the software industry were organisation specific, predominately developed by military and government agencies. This is not surprising, since the use of complex programs in this period was limited mainly to these organisations. The military and the National Aeronautics and Space Administration (NASA), especially, had need of high quality software since they used it for safety-critical applications. These organisations still encountered programs with many defects. But complex software was restricted to only a small number of users and therefore concerns about its quality were not widespread.[52] In the 1980s and 1990s concerns about the quality of software have become more prevalent since its use has become widespread, and information systems have become more complex, as a result of the falling real cost of computing power. Other factors accounting for concern with the quality of goods and services in general include increases in global trade, and an apparent trend for firms to purchase a higher fraction of the value added of the goods and services they produce as parts from suppliers. These latter two trends have made firms more susceptible to the

[52] That the organisations that used software intensively were concerned about its quality during this period is amply demonstrated by the fact that North Atlantic Treaty Organization (NATO) held a conference in 1968 trying to come up with solutions to the 'software crisis'. See Gibbs (1994, p. 87). The title and content of Gibbs' article, "Software's Chronic Crisis", indicates that the problems plaguing the software industry in 1968 still exist today.

effects of asymmetric information. [53] As a result, it is after about 1980 that the majority of the formal process standards, including those applicable to the software industry, have been developed. These trends seem to hold for the software industry as well as for other industries.[54]

The adoption of process standards has many of the features which are present in recent theoretical models describing the adoption of competing standards. There are many alternative process standards in the software industry and firms repeatedly choose which of these to adopt. Some firms have adopted one standard, some firms have adopted multiple standards, and some firms have chosen not to adopt any.

5.3.1 Heterogeneity Among Software Producers

There is substantial heterogeneity in the environments that firms experience in the software industry. Firms can produce bespoke or package software, or both. Firms producing bespoke software experience a large amount of heterogeneity due to the different contracts they work on. Software produced for say a telecommunications firm is substantially different from that produced for a financial institution, or for a company producing medical equipment. Even firms producing package software experience heterogeneity. They may produce programs for households, businesses, or government. The product may be exported. The product may be a

[53] See *Purchasing*, (1994), 117 (6), pp. 18-19; and Martin (1994).

[54] Bespoke software produced by domestic producers cost an average ten to fifteen percent less than producing it in-house. Offshore vendors offer average savings of fifty percent. The average cost incurred to produce a function point is $1200 in most industrial countries compared to less than $250 in countries like India, Poland, Malaysia and Hungary. Offsetting these lower outsourcing costs are increased costs resulting from service degradation and slower response times to requests for changes. Producing software offshore also results in increased monitoring and, notably for less developed countries, infrastructure costs. Purchasing package software results in costs of between $0.25 and $15 per function point. See Jones (1994b) and Jones (1994d). Dedene and De Vreese (1995) provide two examples of organisations in Belgium which used a software producer in the Philippines. Using the Filipino software producer resulted in net savings of thirty-five percent over domestic Belgian firms.

simple wordprocessor, or a complex network operating system. New features are also frequently introduced by producers of package software. Finally, both package and bespoke developers are experiencing change in the technologies they use.[55] Furthermore, producers of bespoke software spend a significant proportion of their programming 'maintaining" existing computer systems. There are over 400 computer languages, and many languages are incompatible with others and have their own nuances. This is not to mention the different vintages and makes of computers, each of which also tend to be incompatible and have their own nuances.[56] As a result, each program has a different set of problems and there is only a small overlap between their solutions.

There are many examples of this heterogeneity. IBM produces package software such as OS/2 Warp or PC-DOS, bespoke software for many different organisations, and operating systems and applications for its mainframe computers. A similarly broad range of software is produced by companies such as DEC, Hitachi, NEC, and ITT.[57] Texas Instruments produces software for the defence industry, consumer electronics products, and machine tools. Raytheon produces software for common household appliances, aircraft and missiles, while E-Systems (recently taken over by Raytheon) produces military space-based imaging and communications software, as well as commercial and medical imaging software.[58] There also exist many smaller companies which create many different types of programs. An example is American

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[55] Leveson (1994) and Jones (1994a).

[56] Examples are provided in Brooks (1975), Curtis, Krasner and Iscoe (1988), Stix (1994), and Dedene and De Vreese (1995).

[57] Cusumano (1991).

[58] *The Wall Street Journal*, (1995), 3 April, sec. A, pp. 3 and 15.

Management Systems which produced $213 million worth of productivity tools and applications software in 1990.[59]

5.3.2 Uncertainty of Tasks

Software producers typically find themselves in situations where they do not fully know the tasks that need to be done to produce a program.[60] Producing software is similar to consuming an experience good; the exact nature of the tasks to be performed are not known at the outset and are only learnt after the previous tasks in the production sequence have been completed. In part this reflects the fact that producers know how to develop software, but they do not know the nature of the environment of the user. There is substantial learning involved on the part of the producer about the needs of the user.[61] Producers of package software frequently use potential customers to test prototype versions of their programs. They then change the specifications of the program to incorporate points of dissatisfaction. Producers of bespoke software also have to learn about their customer's needs. In addition, bespoke producers experience many changes in a program's requirements from the users, because initially at least, the user knows very little about the technologies involved. External factors, such as changing technology, also cause changes throughout the production cycle of both bespoke and package software.

It has been estimated that the fundamental requirements of an average software project change by one percent per month.[62] A study by IBM found that twenty-five percent of the total requirements of an average software project change over

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[59] Juliussen and Juliussen (1990) contain entries for a vast number of hardware and software producers in the computer industry.

[60] See Curtis, Krasner and Iscoe (1988), Dedene and De Vreese (1994), Gibbs (1994), Stix (1994), and *The Wall Street Journal*, (1995), 18 May, sec. A, pp. 1 and 9.

[61] Carmel and Keil (1995).

[62] Jones (1994e, p. 21).

its life-cycle.[63] Consider the project to overhaul United States air-traffic control equipment. Both the Federal Aviation Administration and the IBM subsidiary handling the project have had to alter program requirements dealing with information input and output involving air-traffic controllers. The IBM subsidiary also found that its original requirements for handling data interchange between mainframes and workstations had to be changed due to unforeseen data inconsistencies. There have been many other such changes.[64] BAE Automated Systems, developer of software for the Denver International Airport baggage handling system, was issued with $20 million worth of software changes by the airport's planners. The contract was only worth $193 million.[65] The development of *Windows NT* proved to be something which Microsoft had never dealt with before and its previous experience proved to be of little use in writing this exceedingly complex program. This is in spite of having considerable experience with what appear to be, at least to the casual observer, very closely related products.[66] Microsoft experienced frequent requirements changes when developing its operating system *Windows NT.* In part this was due to Microsoft's desire to add new features. Feedback from potential customers who used partially completed versions of the program also led to changes in its requirements. Both Novell and Microsoft have been separately trying to introduce networking software into common electronic devices such as fax machines, copiers, and televisions. They have found this project to be unlike anything they have each experienced before.[67] Even small changes to the requirements of a program can have very large consequences for its development. The components of a program are highly inter-related so that a small change in the requirements in

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[63] Boehm (1981, p. 484).
[64] Stix (1994) and Gibbs (1994).
[65] Gibbs (1994).
[66] *The Wall Street Journal*, (1993), 26 May, sec. A, pp. 1 and 12.
[67] *The Economist*, (1995), 13 May, pp. 63-64.

Table 5.2

Number of Registrars by Standard and Region

	Number of Registrars			
Year	TickIT International	ISO 9000 United Kingdom	ISO 9000 North America	ISO 9000 North America*
1987	na	6	0	0
1988	na	9	0	0
1989	na	13	0	0
1990	na	15	1	0
1991	5	18	6	3
1992	6	25	8	4
1993	6	34	19	12
1994	6	41	50	25

Sources: United Kingdom National Accreditation Council for Certification Bodies, CEEM Information Services and Registrar Accreditation Board

* Accredited to the RAB

what appears to be a small piece has a cascading effect and can lead to many other changes. It is also likely that altering a program will introduce defects, as well as destroy its integrity.

5.3.3 Life Cycle of a Competitive Auditing Industry

Conformance to some process standards is checked by third-party auditors (typically called registrars). The cost of being audited by a registrar tends to fall over time as more organisations adopt a standard. As more organisations adopt a standard, more registrars are certified to conduct audits and assessments. The increase in the number of registrars increases competitive pressures in the supply of registrar services which lowers the cost of being audited (see Tables 5.2 and 5.3).

This time path is consistent with theoretical models of the life cycle of competitive industries such as Spence (1981), Jovanovic (1982) and Jovanovic and MacDonald (1994). Technological innovation seems unlikely in this industry, so the learning by doing modelled in Spence or the weeding out of inefficient firms in Jovanovic are the likely causes of the time path of auditing prices, number of registrars and number of registrations in this industry. This effect is evident in the adoption of the ISO 9000 standards.

Table 5.3
ISO 9000 Registration Success Rates and Fees in the United States

	Jan. 93	Nov. 93	Oct. 94
first time success rate	40%	58.5%	71.6%
lowest registration fee	$7,800	$4,000	$4,000
highest registration fee	$30,000	$18,000	$20,000
average registration fee	$13,128	$11,452	$11,300

Source: *Quality Progress* (1994).
Based on survey of thirty-one registrars.
Costs are for an automotive supplier located at a single site with 250 employees.

5.3.4 Marshallian Externalities

An additional way in which the benefits of adopting a process standard increase with the number of adopters occurs through reductions in auditing and implementation costs. When only a few organisations have adopted a process standard, each has little knowledge about it and how to apply it to the organisation. Acquiring this knowledge can be expensive. When many organisations have adopted a standard, knowledge about how to adopt it is widely available through conferences, books, and magazine and journal articles (see Tables 5.4 and 5.5). Firms also produce tools, like computer programs, to help an organisation prepare and maintain registration to a standard. There have been numerous conferences about various process standards that are relevant to the software industry. For example, there are twenty regional Software Process Improvement Networks in the United States that organise regular meetings to discuss issues concerning software production processes. The ASQC Software Division also regularly organises conferences about software issues. As can be seen by reading the bibliography there have also been numerous magazine and journal articles written about these standards. Of course the bibliographic references only cover a small fraction of all published sources. Computer tools for many standards are also readily available. For example, see the advertisements in *Quality Progress* particularly the March issue which includes a special report on available programs. An increase in the number of organisations who adopt a process standard also tends to increase the number of consultants who offer their services to help organisations adopt the standard (see Figure 5.1). The increase in consulting services increases the success rate of organisations who are attempting to adopt the standard as well as decreasing the costs of preparing for the audits (see Table 5.3).

There is also intra-organisation learning for a site-specific process standard. The cost of any site adopting a process standard decreases as more sites within an organisation adopt it. This is clearly evident in the experience of IBM adopting ISO 9000. Initially IBM sites had average first time failure rates of sixty-five percent and took an average fifteen months before attaining registration. The average failure rate of an IBM site is now less than ten percent and each site takes an average of ten months to become registered.[68]

[68] See Small (1993, p. 87).

Table 5.4

Article Content in *IEEE Software*

Primary Focus of Articles	Number of Articles 1987	1994
Feature Articles:		
IEEE Software Standards	0	0
Military Standards	5	3
ISO 9000	0	7
CMM	0	7
TickIT	0	1
Other Process Standards	0	8
Total Process Standards	5	26
Total Articles	42	59
Secondary Articles:		
IEEE Software Standards	23	0
Military Standards	1	2
ISO 9000	0	8
CMM	0	14
TickIT	0	0
Other Process Standards	0	6
Total Process Standards	24	30
Total Articles	77	130

Note: Secondary articles consist of the editorial column and the columns of the regular journal departments.

Table 5.5

Article Content in *Quality Progress*

Primary Focus of Articles	Number of Articles 1987	1994
Military Standards	7	4
ISO 9000	1	36
Malcolm Baldrige	0	22
Other Process Standard	3	9
Total	11	71
Total Articles	228	292

Note: Consists of feature articles as well as the editorial column and the columns of the regular journal departments.

5.3.5 Bargaining Between Users and Producers

Any contract that is agreed to by a supplier and a firm involves some form of bargaining. The bargaining is over both price and quality conditional on the future states of the world, where quality is usually measured across many different facets of the product. Dobler, Burt and Lee (1990) characterise such a process and Scrupski (1994) briefly discusses bargaining as it applies to the software industry. See Dedene and De Vreese (1994), Jones (1994d) and Sprague (1995) as examples of the presence of bargaining between producers and users of bespoke software. Producers of package software also bargain when selling to businesses. The bargaining involves factors such as price, installation and maintenance of the program, training, repairs, and licensing terms.[69]

Since software process standards are developed to lower transaction costs, increase quality, or lower development costs, there is a question of who obtains the

[69] Frankel (1986, Chapter 6).

resulting rents. T'- . appropriate framework is that of a bargaining game between two agents that have outside options. As Osborne and Rubinstein (1990, pp. 54-63) point out, the question then becomes how credible is the threat of opting out.

There are indications that adopters of these standards are able to gain an advantage in bargaining with their customers, compared with firms that have not adopted the standards.[70] This advantage is through suppliers being able to offer lower prices, higher quality, or more reliable information about their production capabilities at a lower cost, than others who do not adopt a standard. Over sixty-nine percent of adopters of ISO 9000 gave their main reason for adopting ISO 9000 as the ability to bid for tenders from which they were otherwise excluded.[71] Initial adopters of TickIT have also cited their ability to increase or maintain their market shares as one of the main reasons they adopted this standard.[72] It also appears that the bargaining strength of adopters of the standards is affected by the number of adoptions. The developers of the yet to be released Software Process Improvement and Capability Evaluation (SPICE) series of international software process standards conclude that widespread adoption of these standards should result in substantial benefits passed on to the users of software.[73] The United States DoD expects a similar effect with the CMM. The reasoning behind this conclusion seems to be that if large numbers of producers adopt these standards then purchasers of software will have the bargaining power to extract most of the rents associated with the standards.

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[70] Of course in some cases firms adopt process standards that are mandatory so that they can be considered for an order. This motivation for adopting a process standard is also consistent with wanting to maintain or increase a firm's market share.

[71] DeCarlo (1993, p. 10).

[72] *TickIT News*, (1993), November.

[73] International Organization for Standardization (1992, p. 11).

A further point to note is that most process standards differ widely in their coverage of the production activities of firms.[74] As Diebler (p. 2) notes in comparing ISO 9000 and the CMM, "The two models are independent: complying with either model does not predict compliance with the other. Each model address unique aspects of the software development organisation...". This means the threat point of a firm involved in bargaining with a supplier who has adopted a standard is primarily affected by the number of adopters of the same standard. There may be affects from adopters of other standards, but these would only be of second order.

This section highlights the key features of the standards adoption environment. Producers of software, particularly bespoke software, face substantial heterogeneity in the projects they work on. They also face considerable uncertainty about future tasks that they need to perform to complete these projects. Their adoption decisions are influenced by what others decide to do. The benefit of adopting a standard increases with the number of adoptions, because of lower auditing and implementation costs. On the other hand, they receive less of the overall benefit from adopting a standard with increases in the number of adoptions, because their bargaining power is weakened. Such an environment is studied in Chapters 3 and 4.

Using the material presented in this section we can also obtain a rough estimate of the parameters characterising the models of Chapters 3 and 4 which affect the decisions of software producers. A large amount of heterogeneity translates into a small value of β. It also seems likely that there is a smaller degree of heterogeneity among package producers than bespoke producers. This implies a larger β (or less

[74] See Tingey (1994), Diebler (1994), Price Waterhouse (1988) and Computing Software and Services Association (1995).

heterogeneity) for the package industry than the bespoke industry. The existence of significant positive pecuniary externalities implies that ψ is moderate to large. The parameter affecting the negative bargaining externality, λ, seems likely to be non-zero. But there is little indication of its value other than this.

5.4 The Main Competing Software Process Standards

As was mentioned in the introduction to this chapter, there are over 250 process standards applicable to the software industry. Some of these are country (or even firm) specific, while others are internationally recognised; some are software-specific while others are generic. The theoretical results of Chapters 3 and 4 suggest that there are two key parameters which characterise process standards: the gain associated from their adoption; and the affect that other adopters have on their net benefit. This section presents some of the more important standards that are relevant to the software industry, and discusses the likely values of these parameters for each of them.

5.4.1 ISO 9000

Probably the most well known process standards are the ISO 9000 series developed by the International Organization for Standardization (ISO) in 1987, and updated in 1994. This series establishes a generic framework for any organisation that wishes to adopt an internationally recognised quality management and assurance program.[75] Both ISO 9001 and ISO 9000-3 are pertinent to the software

[75] The standards are: ISO 9000-1, ISO 9000-3, ISO 9001, ISO 9002, ISO 9003 and ISO 9004-1. They are known by different names in different countries reflecting each country's convention for naming standards. In the European Community they are known as the EN 29000 series, although each country in the European Community has a separate naming convention for them. They are known as the ANSI/ASQC 90 series in the United States and as the JIS Z9900 series in Japan. See Lamprecht (1992, p. 2).

industry: ISO 9001 specifies how a firm (in any industry) that designs and develops, produces, installs and services a product or service is to establish a quality management and assurance program; ISO 9000-3 provides guidelines on how to implement ISO 9001 if a firm produces software.[76]

The ISO 9000 series was developed by a committee consisting of standard setting bodies of virtually all of the world's nations.[77] The original motivation for developing them was to reduce the costs of second-party auditing in two party contractual situations. They were intended to be voluntary and were not intended to certify process systems. They were also designed to be used in conjunction with an industry specific standard, and by themselves, they specify only the minimal requirements for a process system.[78] An organisation wishing to adopt ISO 9000 has three basic tasks to carry out to become registered: the organisation has to state what it does, the organisation has to document what it does, and the organisation has to be able to prove that it does what it claims that it does. There is no

[76] The standards ISO 9000-1 and ISO 9000-2 provide a generic set of guidelines on how to select, interpret and implement ISO 9001, ISO 9002, ISO 9003. ISO 9002 specifies how a firm that produces and installs products is to establish a quality management and assurance program. If a firm only inspects and/or tests products then ISO 9003 is the relevant standard. ISO 9004-1 provides general guidelines on how to establish a quality management system (distinct from a system assuring quality of a firm's products to external organisations). The three standards ISO 9004-2, ISO 9004-3 and ISO 9004-4 provide guidelines on how to interpret ISO 9004-1 for services, process materials, and to ensure continuous quality improvements.

[77] The standards are the responsibility of ISO Technical Committee 176 and are based on earlier military examples. In 1959, the United States DoD published the process standard MIL-Q-9858. It was the basis, with some additions, for the AQAP1, AQAP4 and AQAP9 standards published by NATO in 1968. In 1979, the British Standards Institute (BSI) modified the NATO standards so that they could be used by commercial organisations. These were published as BS 5750: parts 1, 2 and 3. The ISO 9000 series are based on BS 5750. See Bamford and Diebler (1994).

[78] These issues are discussed in Jacques (1990) and Price Waterhouse (1988). As noted in Chapter 1 the function of the standards is generally misperceived by most people.

requirement in the ISO 9000 series that a firm has to produce a good of high quality, only that it produce a good of a level of quality that it has stated.

A final feature of the ISO 9000 standards is the process by which organisations become registered. When an organisation decides to adopt one of them it is audited by a certified third-party registrar, who verifies that the organisation has fulfilled the necessary requirements. If the registrar is satisfied, then the organisation is entered into the national records of registered organisations. The organisation can then use the official logo on its advertising, though not on its products. The organisation undergoes periodic audits to check that it is still adhering to the standard; these audits are normally biannual. After two or three years the organisation loses its certificate of registration and has to decide if it wants to undergo a full audit again and be re-registered to the standard. The registrar decides how frequently to audit the organisation, and the expiry date of the organisation's certificate of registration.

The registrars are themselves subject to process standards, in this case to the ISO 10000 series.[79] Organisations who wish to conduct third-party audits are required to adopt these standards. This is to ensure that there is a high level of confidence in the auditing and registration of firms to ISO 9000. It is almost always the case that a government standards body 'audits the auditors', the exception being the United States where an affiliate of the American National Standards Institute (ANSI) is responsible for auditing registrars.[80]

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[79] There are four such standards: 10011-1, 10011-2, 10011-3 and 10012-1. The first three specify how organisations are to audit process systems. The last provides requirements for measuring equipment used by auditors. Two additional standards are being developed; 10012-2 concerns the measuring equipment used by auditors and 10013 provides requirements for the development of quality manuals.

[80] ANSI is a non-profit private standards setting body and it is the sole national standard setting body recognised by the United States Federal Government. It therefore sits on

While the process by which organisations adopt an ISO 9000 standard seems highly controlled, with a tightly controlled certification process, there is one fly in the ointment. While the standards are internationally recognised, the certification of the registrars is not. The fact that an organisation has been accepted by one country's standards body as a registrar does not mean that the organisation is recognised by other countries. In this case, the firms that are certified by that registrar may have to be certified by a registrar from another country, if they want to claim ISO 9000 certification in that country. There have been attempts to harmonise the certification of registrars through 'memoranda of understanding' between national standard bodies throughout the world. The coverage of these memoranda is by no means comprehensive, and registrars may still not be recognised by organisations even in countries that sign the memoranda.[81] The fact that recognition of registrars is not harmonised internationally, obviously limits the potential of the ISO 9000 standards to lower transaction costs.

A survey of 620 firms by *Quality Systems Update* and Deloitte & Touche who adopted ISO 9000 in North America found that on average they experienced a present value net gain of approximately $271,400 from this action.[82] They incurred adoption costs of $245,200 on average, with smaller firms paying considerably less than and larger firms paying considerably more than this. The average benefit from adopting ISO 9000 was $179,000 per annum.

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international standard setting organisations as the representative of the United States. ANSI is responsible for the ISO 9000 series in the United States.

[81] See Marash and Marquardt (1994), Neville (1994) and Hutchins (1993, p. 5).

[82] This uses an annual interest rate of four percent and a registration period of three years. The figures on the average costs and benefits of adopting ISO 9000 are from *Quality Systems Update — Special Report*, (1993), September.

There are two main reasons why adopting ISO 9000 provides benefits. The first is lower transaction costs. Westvaco's Chemical Division experienced a decline in the number of customer audits, from twelve to two per year, after adopting ISO 9000. AMP has also experienced a decline in the number of audits by its customers. GE Plastics, Du Pont and Phillips 66 have all reduced the number of audits they perform on their suppliers who have adopted ISO 9000. AMP, Phillips 66 and Quality Plus Engineering also use ISO 9000 to reduce the cost of searching for suppliers.[83] In addition, over thirty-three percent of the firms in the *Quality Systems Update* and Deloitte & Touche survey reported that their most important external benefit was higher perceived quality. By acting as a credible signal of higher quality, at least for suppliers in some industries, ISO 9000 alleviates the effects of asymmetric information. This is another source of lower transaction costs. A second source of the reported benefits is from an increase in quality, or from lower costs. Higher quality from adopting ISO 9000 typically occurs because firms with more consistent processes have fewer defects. Edgecomb Metals experienced a thirty percent reduction in customer claims and their on-time delivery improved.[84] Square D experienced a twenty percent increase in on-time delivery and a forty percent reduction in their product cycle time.[85] Of course, in some cases it is hard to tell whether the stated benefits of adopting ISO 9000 were due to the adoption of the standards or were due to other factors. Some firms were also undertaking other actions to raise quality and lower costs.

[83] These examples are in Avery (1994). Peach (1992, Chapter 11) presents other examples.

[84] Avery (1994b, p. 45).

[85] Avery (1994a, p. 103). Other examples can be found in Avery (1994b, p. 45), Peach (1992, Chapter 11), and Clark and Starkweather (1993, p. 106).

Software producers who adopt ISO 9000 are likely to experience a much smaller benefit than a firm in another industry. Software Productivity Research has conducted a study of twenty software producers that have adopted ISO 9000 and another twenty software producers that have not adopted ISO 9000. It found that adopting ISO 9000 had no effect on the quality of the software produced by the firms, or in lowering their production costs. But firms that adopted ISO 9000 experienced a dramatic increase in their costs. The firms attributed this to the documentation they needed to maintain to conform to the standard.[86] It is thus unlikely that software producers would experience lower costs or higher quality from adopting ISO 9000. Of course, this study does not measure transaction costs savings. But we would expect that ISO 9000 would not significantly lower transaction costs in the software industry. The generality of the ISO 9000 standards is a strength in that they can be applied to a myriad of industries. This generality, however, also means that there is a lot of latitude in how they are interpreted and applied, especially since auditors of the standards do not need industry-specific training. This is one of the main criticisms of these standards and is why the United States auto industry has developed the QS 9000 standard and the United Kingdom Department of Trade and Industry (DTI) instituted the TickIT standard.[87] Unlike the production of say chemicals, the production of software is still very much in a state of flux. In such a situation it seems unlikely that a very general standard would provide much information to firms purchasing software since there is essentially no standard industry practice(s). The standards may not even be as general as is claimed. They appear to have a manufacturing bias which means that they may have little value for producers of services and software which involve fundamentally different technologies. This criticism of ISO 9000 seems especially pertinent for software. By far the ma-

[86] Personal communication with Capers Jones, Chairman of SPR.

[87] Avery (1994b), Zuckerman (1995), and Price Waterhouse (1988).

jority of manufacturing processes take the following form: develop requirements the product has to satisfy; validate the requirements; design the product according to the requirements; validate the product design; manufacture the product according to the design; test the manufactured product to see that it satisfies the design and requirements; and ship the product. This is called a waterfall production process. In contrast, one commonly used life cycle model of software development is the spiral model. This model treats the requirements as fluid and instead of software development proceeding in a sequential fashion, it evolves in a spiral fashion by repeatedly returning to requirements specification, design, prototype coding and testing. Only after the software requirements and design are stable does final coding and testing take place.[88]

In addition to the gain from adopting ISO 9000, we are also interested in how the adoption and implementation costs are affected by the number of adoptions. There is strong evidence that third-party auditing services are also provided by a competitive industry, and as seen in Table 5.3, the cost of the audits is seen to decline over time with increases in the number of adopters. There are also a myriad of consultants available which help firms to implement and adopt the standards (see Figure 5.4). Finally, there are many different books, videos, conferences, magazine and journal articles about adopting the standards.[89] Overall, these factors suggest that the adoption and implementation costs will be strongly affected by the number of ISO 9000 adoptions.

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[88] Matsubara (1994) and Coallier (1994) discuss the relevance of ISO 9000 to software producers. Boehm (1988) and Gruman (1989b) contrast the spiral and waterfall production processes.

[89] For example, Peach (1993, pp. 341-474) provides a substantial list of resources for firms that wish to adopt ISO 9000. See also Tables 5.4 and 5.5.

5.4.2 TickIT

The United Kingdom DTI developed and published a software process standard in 1991 called the TickIT Scheme. TickIT is based on ISO 9001 and ISO 9000-3. However, TickIT also contains modifications which mean that if an organisation is registered to ISO 9001, even if it uses ISO 9000-3 to become registered, it is not registered to TickIT. Registrars have to undergo special training to be certified to audit software producers under TickIT. The registration process is exactly the same as for ISO 9000, apart from the special training of the registrars. The United Kingdom DTI implemented TickIT as they concluded that the software industry required more specialised standards than the generic ISO 9000.[90]

There is no hard data available concerning the gain from adopting TickIT. Thomson and Mayhew (1994), however, estimate that in 1992 a software firm with an annual turnover of $5.3 million would likely experience a present value net gain between $269,000 and $1 million. This is solely from decreases in defects due to better production processes.[91] Of course the accuracy of these estimates is highly questionable. Given that TickIT is based so heavily on ISO 9000, this estimate seems to be substantially higher than we would expect. On the other hand, we could expect TickIT to reduce transaction costs by substantially more than ISO 9000. While TickIT is based on ISO 9000, the guidelines in ISO 9000-3 are specific to the software industry. Of more importance is the fact that the auditors are required to have experience in the software industry, as well as specialist training.

[90] The software industry is not the only industry to customise ISO 9000. The automotive industry in North America have also altered ISO 9000 by incorporating three existing firm-specific process standards. See Pritchard (1994).

[91] A firm that adopts TickIT incurs registration costs of $17,650 and surveillance costs of $7,950 per annum. Potential benefits of adopting TickIT are estimated to be $265,000 to $530,000 per annum. The total cost of implementing TickIT could be expected to be around $422,000 based on the costs of implementing ISO 9000. Using an interest rate of four percent gives the estimated range of the benefits in present value terms.

This means that the information generated by a supplier being found to conform to TickIT is more credible than for ISO 9000. A survey conducted by the CSA (now the CSSA) reported that the number of second-party audits for firms adopting TickIT in the survey had been drastically cut.[92]

Since TickIT is based on ISO 9000 we would expect the cost of adopting it to be strongly influenced by the number of adoptions. There is some evidence supporting this claim. Logica has adopted TickIT in nineteen separate production sites in five countries. It found that the cost of adopting the standards in the last site was twenty percent lower than for the first site.[93] As with ISO 9000, there are many books, journal articles, videos, and conferences about TickIT.

5.4.3 Capability Maturity Model

A software-specific standard is the Capability Maturity Model developed by the SEI in 1987.[94] The CMM is not a formal process standard in the sense that it has national recognition by a government recognised standard setting body such as ANSI or the BSI. The CMM was originally designed to help software producers increase their quality. However, some purchasers, notably the military, have required that their suppliers adopt it.[95] The CMM is also being used by the ISO and the International Electrotechnical Committee (IEC) as a basis for a series of

[92] Computer Services Association (1994).

[93] *TickIT International*, (1994), 4Q94, pp. 20-22.

[94] The SEI is a part of Carnegie Mellon University and is funded by the United States DoD. The primary objective of the SEI is to improve the average process of producing software in the United States. A revised version, Version 1.1, of the CMM was released in 1993. A wholesale revision of the CMM, Version 2, is expected in 1996. There are other process assessment models such as the SPR Assessment Method developed by Software Productivity Research, a private United States consulting and research firm.

[95] In 1998, the United States Air Force will require that all Air Force software organisations will be at level 3 of the CMM. There are indications that the United States DoD intends to use level three of it as the minimum requirement for producers to be allowed to bid on some types of its contracts. Both Bell Canada and British Telecom have developed process standards modelled after the CMM which they require their suppliers to adopt.

international process standards that will be used to assess the production processes of software producers.[96]

The CMM measures the production processes of producers using five levels. Assessment is voluntary. Level 1 (called the Initial Level) is applicable if a producer uses processes that are unpredictable and poorly controlled. In contrast, a producer assessed as being at level 5 (called the Optimising Level) not only has extremely well controlled and predictable production processes, but also has detailed programs in place which continually improve them. Obviously, levels 2, 3 and 4 fall in between these two extremes. Initially the only assessments carried out were by employees of the SEI. However, the SEI introduced an Appraiser Program in 1990 to train people outside of the SEI to conduct CMM assessments. Only people with eight to ten years experience in the software industry are accepted for this program. These assessors have authorisation to conduct CMM assessments for two years, after which their performance is evaluated. If this is satisfactory, then their authorisation is renewed. The SEI also conducts random audits of the assessors during their period of authorisation.[97]

What evidence is available suggests that firms adopting the CMM experience substantial benefits. The software engineering division of Hughes Aircraft estimated a present value net benefit of $1,555,000 from adopting the CMM, after incurring auditing costs of $45,000 and implementation costs of $400,000. Schlumberger ex-

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They use them as the basis for assessing their software suppliers. See Herbsleb et al (1994) and Jones (1994b, p. 239).

[96] This is called the SPICE series and is being developed by five working groups under Subcommittee 7 of ISO/IEC Joint Technical Committee 1. There are expected to be approximately twenty standards ready by 1996 and they will be more comprehensive than the CMM. See Edelstein et at (1991) and Paulk and Konrad (1994).

[97] Software Engineering Institute (1994) and Tingey (1994).

perienced a present net value gain of $1,326,000. Other companies such as Texas Instruments, and Bull HN Information Systems also report large present value net benefits.[98] These benefits are solely from lower production costs and higher software quality. As with ISO 9000 and TickIT, some of these firms were also taking other actions in combination with adopting the CMM. The reported net benefits may therefore overstate the gain from adopting the CMM. Lower transaction costs have also been reported by the United States Air Force and United States Army since they required their suppliers to undergo CMM assessments as part of their procurement procedures. Prior to this, they had major difficulties in judging the quality of their suppliers and used to award contracts purely on the basis of cost. They now are able to more accurately judge the quality of their suppliers, and cost is only one consideration in awarding a contract.[99]

The CMM appears to provide substantial benefits from lower production costs and higher quality. If so, why did the firms not implement the relevant procedures earlier? There are two reasons. The CMM is software specific and highly detailed. It allows buyers to accurately assess the quality of producers, as shown by the experience of the United States Air Force and United States Army. It provides a great deal of information about the state of a firm's production technology. In addition, auditors of the CMM are required to have considerable software experience and undergo extensive training. This means that the accuracy of the information provided by an assessment is highly credible. Before the CMM, buyers did not have cost effective ways of judging the quality of producers. Producers had no incentive to produce higher quality software since they would not be rewarded for their extra expenses. Producers now have an incentive to increase their quality,

[98] See Humphrey, Snyder and Willis (1991) and Herbsleb et al (1994).

[99] Brotherton (1992).

because the CMM allows buyers to see what they have done and reward their actions. One further point to note about the CMM is that it may be biased in favour of production technologies used for larger software projects.[100] This reflects the needs of the United States DoD. Adopting the CMM would probably provide a much smaller relative benefit to producers of smaller projects.[101] The technologies embodied in the standard seem to be less relevant, and the assessments would be less informative.

The costs of adopting the CMM can be expected to be moderately affected by the number of adoptions. Initially, the SEI was solely responsible for auditing producers. The Appraiser Program introduced in 1990 increased considerably the number of trained auditors. But there is still no auditing industry as such, and therefore, the cost of being audited is unlikely to fall very much with increases in the number of adoptions. There also seems to be little in the way of a consulting industry for the CMM. This may reflect the fact that relatively few firms have adopted the CMM. Uncertainty about the future direction of it may also be a factor. Unlike ISO 9000 and TickIT, the CMM is not under the jurisdiction of an organisation which is accountable to the general public, and which incorporates input from all interested parties. The SEI is sponsored solely by the United States DoD, and the main focus of the SEI is to meet their specific needs. The potential cost decreases of adopting the CMM through inter-organisation learning and information generation in trade journals, magazines, books, and conferences, however, seems to be large (see Table 5.4).

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[100] Yourdan (1992, p. 84), and Thomson and Mayhew (1994).

[101] Yourdan (1992, p. 74).

5.4.4 IEEE Software Engineering Standards

Another series of voluntary software specific process standards are those developed by the Institute of Electrical and Electronics Engineers (IEEE), a United States-based international organisation for engineering professionals. They have released twenty-three process standards since 1983, which together cover the complete process by which software is developed and maintained.[102] The IEEE began this effort in 1976 as an alternative to organisation specific standards, such as those developed by the United States DoD and NASA. The standards specify how producers should perform each part of the production process. There is also a standard that defines software engineering terminology. It is important to note that there is no third-party assessment scheme for the IEEE standards. Of course, a producer can adopt the standards as the basis for second-party audits if it so wishes.[103]

There is no available quantitative data concerning the net benefit of adopting the IEEE standards, but their features indicate that it would be small. It is true that they are specific to software and have been developed by a large number of professional engineers representing an equally large number of producers and users. Unfortunately, the same process that ensures widespread participation in their development also means that they are dated when released. They are estimated to be three to five years behind the state of the art, which markedly decreases their relevance in an industry experiencing significant technological change.[104] There is no structure in place, such as an auditing industry with training and competency testing of auditors, to aid in the use of the IEEE standards in third-party audits. The lack of a formal structure for third-party auditing would make it unlikely that

[102] Most of these standards have been jointly released with ANSI.

[103] More details about the IEEE standards can be found in Branstad and Powell (1984), Poston (1985a), Poston (1985b), Tice (1988a), Tice (1988b) and Tice (1989).

[104] Personal communication with Capers Jones, Chairman of SPR.

the IEEE standards significantly lower transaction costs. Their seeming obsolescence when released also means that they are unlikely to lead to lower production costs and/or higher quality software.

The cost of adopting the standards should be moderately affected by the number of adoptions. The lack of a third-party auditing industry limits the likelihood that auditing costs will be affected by the number of adoptions. There is also no evidence that a consulting industry exists for firms that wish to adopt them. This may reflect the fact that few firms have adopted these standards. More likely it reflects the fact there is no formal structure associated with the standards. The IEEE has simply developed them and left it at that.[105] The potential cost decreases of implementing the standards through inter-organisation learning and information generation in trade journals, magazines, books, and conferences seems to be no different than for other software standards (see Table 5.5).

5.4.5 Military Standards

There are also a number of other process standards which apply to software producers. Before the 1980s, most of these were developed by the military. The United States DoD, in particular, has published a number of them. As has been previously mentioned, the United States DoD published MIL-Q-9858 in 1959, which was a precursor to ISO 9000. Two other well known military process standards are DoD-STD-2167A and DoD-STD-2168, published in 1985. Producers are required to adopt these, and other military standards, if they wish to bid on a software contract. The military organisation awarding the contract conducts second-party audits to ensure that the producers conform to the applicable standard(s). They

[105] This is not quite true as the IEEE reviews the standards every five years. If the they are seen to be unneeded or unwanted then they are phased out, otherwise they are revised.

cover less of the production process than a standard such as ISO 9000. But, the military standards specify considerably more detailed requirements for those areas that they do cover, than more general standards such as ISO 9000.

Other countries also have military process standards. For instance, the German Federal Armed Forces published the Software Development Standard (SDS) in 1986. The SDS is a set of three separate standards (the V-Model standard, the Methods standard and the Functional Tools Requirement standard) which provide a comprehensive and detailed treatment of the process by which software is produced. In addition, the SDS can serve as a basis for implementing the ISO 9000 series, and fulfils the requirements of the NATO standards AQAP-13 and AQAP-150. The SDS was developed to increase the quality of software supplied to the German military. There is no established third-party assessment under the SDS. This requires that purchasers use second-party assessments to verify that their suppliers have adopted them.[106]

There is no published quantitative evidence concerning the benefits of the military standards, but we would expect that most of the analysis concerning the IEEE standards can be applied with some additional comments. Military software standards are estimated to be five to seven years out of date and not as thoroughly developed as the IEEE standards.[107] The cost of conforming to them has been estimated to be very large, chiefly from creating and maintaining documentation about software production activities. For instance, conformance to DoD 2167 creates an average of 400 English words for every Ada statement. The cost of creating

[106] Further details about the SDS can be found in Industrieanlagen-Betriebsgesellschaft (1993a, 1993b, and 1993c).

[107] Personal communication with Capers Jones, Chairman of SPR.

and maintaining this documentation is estimated to be greater than fifty percent of all other software production costs.[108] Jones (1994e, p. 16) reports that a firm that adopts a military standard experiences a positive impact on the quality of its software. But, the increased costs arising from adopting them would seem to more than outweigh the improved quality of the software. Overall there seems to be little if any net benefit from adopting a military software standard.

5.4.6 Comparing the Standards

The main competing standards in the United States software industry consist of one general standard, twenty-five industry specific standards (twenty-three of these from the IEEE), and the organisation specific military standards. There are two characteristics of the standards which we can use to compare them: the gain an adopter experiences ; and the affect that the number of adoptions has on the net benefit of adopting a standard. These are the parameters G_s and ψ_s for standard s in Chapters 3 and 4. We would expect on average that a firm adopting the CMM would experience the highest gain. Adopting TickIT would provide the next highest gain, with the other standards providing small if any gains from their adoption. The costs of adopting the CMM (F in Chapter 4) are higher than those for ISO 9000 and TickIT. There is little information about the costs of adopting the other standards, other than the military standards create large paperwork costs. We can expect that the net benefit of adopting ISO 9000 or TickIT is most affected by the number of adoption of each of these. Net benefits of the CMM and the IEEE standards would be moderately affected, while the net benefit of adopting the military standards will be little affected, by the number of their adoptions. See Table 5.6 for a summary.[109]

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[108] Jones (1994c).

[109] For some of these standards there is a substantial amount of published data concerning their costs and benefits. For others, an investigation of their properties has been used to give a rough idea of their economic characteristics.

Table 5.6
Economic Features of the Main Competing Process Standards in the United States Software Industry

	Gross Benefit	External Effects on Costs: Auditing Industry	External Effects on Costs: Marshallian Externalities
ISO 9000	Small	Large	Large
TickIT	Moderate	Large	Large
CMM	Large	Moderate	Large
IEEE Software Standards	Small	Small	Large
Military Process Standards	Small	Small	Moderate

5.5 Adoption Patterns in the United States

By the end of 1994, 160 and forty-five software producing organisations had adopted ISO 9000 in the United States and Canada respectively. See Figures 5.2 and 5.3.[110] There had also been forty-six organisations in the United States that had adopted TickIT by the end of September 1994. This represents seven percent of TickIT adoptions, with the United Kingdom accounting for over eighty-one percent of the 655 adoptions in total. (see Table 5.7). By August 1994, 273 organisations had been assessed using the CMM in the United States (and another fifty-two organisations worldwide). See Figure 5.4.[111] A European software assessment method called Bootstrap, which is based on the CMM, was adopted by twenty-three European organisations between 1991 and 1993.[112] It is highly likely that only a handful of firms have adopted the IEEE standards. There are roughly 5000 copies of the software standards collection sold worldwide over their life cycle of five

[110] Unfortunately there appear to be no figures on the number of software producers who have adopted ISO 9000 outside of North America.

[111] There is no register available of firms who continue, or discontinue, using the CMM. As a result, this figure mentioned may overstate the number of adoptions of it at any one moment in time.

[112] *IEEE Software*, (1993), 10 (3), pp. 93-95.

Table 5.7

Number of TickIT Certifications

Date		Number
May	92	65
Dec.	92	149
Nov.	93	300
Sept.	94	655

Sources: Thomson and Mayhew (1994) and *TickIT International 4Q94*.
Note: For September 1994: 81.2 % were in the United Kingdom; 8.4% were in Continental Europe; 7% were in North America; and 3.3% were in the rest of the world.

years.[113] But, surveys in the United States and the United Kingdom indicate that they garner little use. Tice (1988) conducted a survey of *IEEE Software* readers to see how many organisations used the IEEE software standards. He received twenty replies (eleven from the United States) and most of these replies indicated that the standards were only used as reference material rather than being fully invoked. Price Waterhouse (1988, p. 49) found in a survey of United Kingdom software firms that none used the IEEE standards. While both surveys were undertaken in 1988, it seems unlikely that there has been much change in the adoption and use of the IEEE standards, even with their revision. By 1988, most of them had already been around for five years and they had obviously garnered little interest over that period. There is also no evidence that military standards are used by other than producers who work for the United States DoD.

It has been estimated that there are over 30,000 software producers in the United States alone, which would mean that just over one and a half percent (or

[113] Personal communication, IEEE. The IEEE does not keep a record of the sales of individual standards.

479) of them have adopted one of ISO 9000, TickIT, or the CMM.[114] This estimate is roughly consistent with the results of a survey by Price Waterhouse in 1993 that found four percent of the 929 firms surveyed had adopted either ISO 9000, the CMM, or the Malcolm Baldrige National Quality Award.[115] The degree to which software process standards have been adopted in countries outside the United States seems to be slightly higher. There have been 532 software producers in the United Kingdom that have adopted TickIT. This implies that a greater percentage of software producers have adopted a standard in the United Kingdom than the United States. First, the raw number of adoptions of the standards is higher in the United Kingdom. Second, there is a smaller number of software producers in the United Kingdom than the United States, since the United Kingdom industry is considerably smaller than in the United States.[116]

There are three points to note about the above adoption figures. First, they only capture adoptions of standards where they are used between different firms. It is possible that a firm can use a standard solely for transactions between its different operating divisions. In this case a standard has been adopted, it has lowered transaction costs, and it may have increased quality or lowered costs. Such an adoption, however, is not measured by the figures presented in this study. Second, some adoptions will go unreported, even when they are used for transactions between firms. Only TickIT and ISO 9000 have a registration scheme which involves centralised record-keeping. Third, there is no systematic way of measuring multiple adoptions of the standards by an organisation. IBM Toronto Laboratories has adopted TickIT, the CMM and the Malcolm Baldrige National Quality Award.[117]

[114] The number of software producers in the United States is from Jones (1994e, p. 25).
[115] *IEEE Software*, (1994), 11 (1), pp. 101-102.
[116] Price Waterhouse (1988).
[117] *IEEE Software*, (1994), 11 (1), pp. 114-115.

Schlumberger has adopted both TickIT and the CMM. These two examples, however, are not readily attainable using the adoption figures and were discovered in a trade journal article. The SEI usually does not release the names of firms assessed using the CMM, unless they give permission, for reasons of confidentiality . While these three factors reduce the quality of the data, the trends in the adoption of the standards is still very much evident, as will shown in the rest of this section.

The fraction of firms that have adopted a process standard in the United States software industry is small.[118] This raises the question, why did most producers decide not to adopt the standards? This pattern of standard adoption also seems inconsistent with the interest and hype surrounding these standards which was mentioned in the introduction. Why is there so much interest in these standards when they seem to be used by a small fraction of producers? Answers to these questions can be obtained by using theoretical results obtained in Chapters 3 and 4 concerning the adoption of process standards, as well as remembering that there are two distinct software markets. We will now investigate the adoption pattern of the standards in each of these two markets. This approach also has the advantage of highlighting the different features which influence adoption decisions, and how they combine to determine adoption patterns of standards.

5.5.1 Bespoke Software

While the number of producers that have adopted a standard is small, most of them produce bespoke software. Furthermore, each bespoke producer usually produces a large amount of software by value. In 1992, 3.7 percent of the 12,001 computer services and software firms produced over seventy-eight percent of Cana-

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[118] This is the sum of the Z_ss in Chapters 3 and 4, where Z_s is the proportion of suppliers who adopt standard s.

dian bespoke software.[119] These figures do not even include software produced by firms in the telecommunications, banking. and computer manufacturing sectors. These sectors produce a considerable amount of bespoke software, and a few firms produce most of their output. Less than 275 organisations produced over seventy-five percent of all software traded in the United Kingdom by value, with several thousand producers accounting for the other twenty-five percent.[120] These firms include bespoke producers such as the Sema Group, Logica, British Telecom and ICL, as well as United Kingdom subsidiaries of firms such as IBM, EDS, Anderson Consulting, AT&T, Olivetti, Praxis, and Bull. These firms have all adopted TickIT.[121] The Sema Group, Logica, and ICL had combined software revenues of over $1,272 million in 1990 compared to total software sales of $5,927 million in the United Kingdom.[122] Similarly, some very large United States bespoke software producers such as IBM, EDS, Motorola, AT&T, Raytheon and Texas Instruments have adopted a process standard.[123] In 1991, IBM alone sold $10.5 billion worth of software, most of it bespoke, compared to total sales of software of almost $63 billion by all United States firms.[124] The same pattern of dominance of the bespoke market by a few firms also seems to hold in Japan.[125]

We know that there is very strong evidence that the market for bespoke software is affected by asymmetric information. In addition, it is highly unlikely that conventional economic mechanisms, such as warranties, are able to alleviate its af-

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[119] Statistics Canada (1994).

[120] Price Waterhouse (1986, p. 37).

[121] The companies who have adopted TickIT can be found in the quarterly publication *List of TickIT Certified Organisations* produced by the DISC TickIT Office.

[122] See Juliussen and Juliussen (1993, p. 392) and Siwek and Furchtgott-Roth (1993, pp. 37-38).

[123] Herbsleb et al (1994).

[124] Siwek and Furchtgott-Roth (1993, pp. 30 and 32).

[125] Humphrey, Kitson and Gale (1991).

fects. We also know that *firms who adopt a standard* experience substantial benefits from this action. This means that the gain from adopting a process standard (G_s for standard s in Chapters 3 and 4) is high relative to alternative actions (G_r in Chapters 3 and 4). We would therefore expect that many producers of bespoke software would adopt a process standard. This has indeed occurred, as previously argued. It also explains why there is so much interest in these standards - the firms that have adopted them produce a large amount of software. What is not expected is the dispersion in the adoption shares of the standards (in Chapters 3 and 4, this would mean that the Z_ss are non-zero for each standard s). Consider the United States. Of the 479 software producing organisations that have adopted a process standard, 33.4 percent have adopted ISO 9000, 9.6 percent have adopted TickIT, and fifty-seven percent have adopted the CMM. These figures are only approximate, as there is little data available on multiple adoptions of process standards, but this does not alter the fact that the adoption shares are dispersed. Conventional economic theories on standards adoption, where the benefits are affected by the number of adopters, predict that one standard will completely dominate the others. The dispersion of adoption shares is unexpected since we know that the benefits of most of these standards are strongly affected by the number of adopters. Explaining this pattern requires the use of theoretical results developed earlier.

The theoretical results of Chapters 3 and 4 suggest that dispersion in the adoption shares of standards can occur, even when their benefits are strongly influenced by the number of adopters. This can happen in one of three ways. First, producers can experience considerable heterogeneity in their environments (a small β). Their adoption decisions would then depend to a large degree on their idiosyncratic benefit from a standard, rather than the actions of other firms. Second, the share of the benefit accruing to an adopter of a standard may be heavily influenced by the total number of firms adopting it (a large λ). This implies strong decreasing returns to adopting a standard, swamping any of the positive externalities. Third, the net benefit from adopting a standard may be mainly determined by its gain rather than the external effects (G_s is large relative to ψ_s for standard s). In this case the external effects carry little weight in the decisions of the firms. Of course, this explanation also requires that firms are moderately heterogeneous. Otherwise they would all choose the standard with the highest gain.

When there are strong decreasing returns to adopting a standard, the adoption shares are evenly split between the standards. Theory suggests that to get a divergence of the adoption shares with this type of characteristic requires extremely large differences in the gains associated with the standards. While the CMM seems better on average than ISO 9000 or TickIT, their differences do not seem to be of the required magnitude. Besides, there is strong evidence of increasing returns to adoption, at least for low adoption levels. This also rules out the possibility that the gains alone determine the adoption pattern because the external effects are weak. The evidence concerning the increasing returns to adoption suggests that they are strong, especially for ISO 9000. The most probable reason for the dispersed adoption shares is that firms experience considerable heterogeneity. This argument is supported by the description in Section 3.1 of the standards adoption environment in the software industry. When there is substantial heterogeneity, the results of Chapter 3 predicts that even strong positive external effects will have little impact in determining the adoption shares of the standards. The adoption shares will be mainly determined by the gains associated with adopting the standards. We would thus expect that the CMM would be the most adopted by the producers of bespoke software and ISO 9000 the least adopted. We would also expect that a substantial number of producers would not adopt a standard if there existed alternative actions, even if on average they provided lower gains than the standards.

Clearly the CMM has been the most adopted in the United States and while 479 producers have adopted a standard, it is likely that there are still many producers of bespoke software that have not adopted one. The fact that the number of United States producers that have adopted ISO 9000 is substantially higher than those that have adopted TickIT would seem to contradict the above predictions. Three important details, however, have been left in the background in the preceding analysis.

The first such detail is that many producers of bespoke software operate in more than country, and more than one industry (a large value of n^C in Chapter 4). Most software producers in the United States operate in other countries, notably Western Europe. These companies include IBM, EDS, DEC, Unisys, AT&T, Anderson Consulting, and Hewlett Packard. In practice, most bespoke firms also operate in other industries. Texas Instruments, which has adopted the CMM, produces semiconductors, consumer electronic products, computers, and metallurgical materials, as well as software. Schlumberger, which has adopted the CMM, produces not only software, but also metering products, and testing and electronic transaction products. Motorola, which has adopted ISO 9000, produces telecommunications equipment, semiconductors, and consumer equipment, in addition to software.

Second, the theoretical results mentioned previously depend on the degree of integration between countries and between industries. The United States is not isolated; it has significant links with the rest of the world (a large value of ϵ in

Chapter 4). This is especially so for the software industry where the United States dominates the world market for both package and bespoke software. In 1990 United States producers accounted for fifty-seven percent of world software sales.[126] Five of the top ten independent software and service vendors in Western Europe by revenue in 1991 were United States based firms.[127] It has been estimated that forty percent of all software used in the world originated in the United States.[128]

Another important factor in the adoption of ISO 9000 is the impact of government policies concerning process standards. The European Community has been promoting the adoption of the ISO 9000 standards since their release in 1987 In part, their adoption has been promoted as one way of achieving a unified market for the European Community by ensuring that firms in all member countries have a quality management system that attains a minimally acceptable level. The European Community has also held the belief that if its firms adopted ISO 9000, they would achieve a competitive advantage over the firms of other countries by producing higher quality products.[129] Regardless of whether this belief is actually correct, it has led to the formation of policies by some European Community national governments that encourage their domestic firms to adopt ISO 9000. Many European government departments have required that their suppliers adopt ISO 9000 and software suppliers have been no exception to this type of policy. This policy effectively raises the net benefit of adopting ISO 9000.[130]

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[126] Siwek and Firchtgott-Roth (1993, p. 28).

[127] *The Economist*, (1992), 10 October, p. 82.

[128] Jones (1994b, p. 235).

[129] Zuckerman (1994) reports that this view may have changed and that some European Community officials now believe that their is no international competitive advantage to be gained by having all European Community firms adopt ISO 9000.

[130] In contrast to the policy situation in Europe regarding ISO 9000, North American firms, including software producers, have not been pressured (yet) by their domestic government agencies to adopt these two standards.

The three previously mentioned factors, explain why ISO 9000 has been adopted by more producers in the United States than TickIT. The results of Chapter 4 show that multinational and multiproduct firms have an inherent preference for generic standards such as ISO 9000, as opposed to industry-specific standards such as TickIT. By adopting a generic standard they economise on adoption costs. This effect will increase the proportion of firms adopting the generic standard relative to the industry-specific one, even if the generic standard has a lower gross benefit. This effect explains why they have preferred ISO 9000 to TickIT - even though TickIT has a higher average benefit and can substitute for ISO 9000. Firms who produce many types of products, and who export a large amount of their output to Europe, will on average prefer ISO 9000 to TickIT, or the CMM. This explains why Motorola has adopted ISO 9000. It finds that the effective benefit of both TickIT and ISO 9000 has increased due to the actions of the European Community, compared to say the CMM. Since it produces large amounts of many types of products, not just software, it is preferable (at least at in its present environment) to adopt a general standard, rather than one which is software specific. It produces a significant amount of software, but for this firm other products matter more. In contrast, at least fifty percent of Schlumberger's output by value is software.[131] It is also a critical factor in its products. The effective benefit of ISO 9000 and TickIT has also increased in this case, since Schlumberger is a multinational with a substantial presence in Europe. It has therefore adopted TickIT. We also know from Section 3.5 that most process standards differ widely in their coverage of the production activities of firms. In addition, we know that on average adopting the CMM produces a large gain, particularly for producers of complex software such as Schlumberger. This is why it has adopted the CMM as well as TickIT.

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[131] Herbsleb et al (1994, p. 27).

The European Community policy of promoting, and in many cases requiring, firms to be registered to ISO 9000 effectively increased its average gross benefit.[132] United States multinationals or firms that export to the European Community would experience the same effect and would thus adopt ISO 9000 in higher numbers than would be the case if the European Community policies were absent. The procurement policies of various European Community governments which require ISO 9000 adoption by their suppliers is one of the key reasons that IBM has adopted TickIT (since it is recognised by various European governments as equivalent to ISO 9000).[133] This impact of government policies that promote a standard in one country which impacts on the adoption decisions of firms in another interconnected country, is consistent with the theoretical results of Chapter 4. In such an environment, if the links between countries (ϵ in Chapter 4 is large) are extensive, and the positive pecuniary externalities are global in nature, and the bargaining externality is sufficiently small, then we would expect higher adoption of ISO 9000 due to the policy actions in the European Community, increasing the adoption of it in the United States.

5.5.2 Package Software

Trade in package software, like bespoke, is subject to asymmetric information. We also know that producers of it are subject to the same sort of environment as bespoke producers. They experience some heterogeneity in the projects they work on, and many of the tasks that make up each project are uncertain. The gains associated with the standards are as relevant for package producers as they are for bespoke producers. Furthermore, the affect that the number of adoptions has on reducing the adoption costs of each standard is not a function of which type of

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[132] In Chapter 4 this would amount to an increase in $G^{EC}_{ISO9000}$.

[133] Personal communication with David Sheir, Software Quality Assessment Group Manager, IBM Toronto Laboratories.

software the adopters produce. Many of these producers also sell their programs to businesses, and bargain with them about price and quality. However, the market for package software is different from that for bespoke. It is hard to imagine an ordinary household ordering a custom wordprocessing program from say DEC! The bargaining power of package producers, over splitting the benefits associated with the standards, will be only weakly affected by the number of adoptions by bespoke producers. This does not, however, inhibit the adoption of the standards by package producers. The question is, why have very few package producers decided to adopt a standard?

To answer this question we need to understand three key differences between the markets for package and bespoke software. First, package software, unlike bespoke, is not subject to moral hazard. This raises the benefits of other mechanisms, in particular, the use of reputation capital. Warranties are still not used by package producers, however, because they know that their product will have defects, and they do not have any idea about their seriousness. Second, package software is sold to many buyers. Third, the features of each program are more important in measures of their quality compared to bespoke software. These three characteristics allow producers to invest in their reputations since they are informative to customers. They also allow the production of information about the quality of package software by consumer computing magazines such as *PC Magazine*. As has also been mentioned, some firms that sell large quantities of package software employ large numbers of beta testers which can be an effective method of finding and removing defects. In contrast, bespoke software has considerably fewer mechanisms available for the reasons previously mentioned. As Roger Sherman, test manager at Microsoft, was quoted as saying, "Our world is completely different from a contract-supplier situation, ... This [bespoke software] is the world of ISO 9000 and the Capability Maturity Model."[134]

The three factors mentioned do not affect the gain from adopting a process standard, nor do they affect the degree to which the actions of other producers affect the benefits of adopting a standard. What they do affect are the gross benefits of alternative actions (G_r in Chapters 3 and 4). The results from Chapter 3 suggest that when an action, or combination of actions, has a very large gross benefit, it will be chosen by most firms. This will happen even if other actions provide moderate gross benefits and their net benefits increase greatly with the number of adopters. The results from Chapter 3 also predict that unless the degree of heterogeneity of firms is very small and/or the benefit of the alternative action is overwhelmingly large, some firms will decide to adopt a standard. Most firms will choose the alternative, but some will experience projects where the idiosyncratic gain from adopting a standard is as large as the alternative action. This prediction of the theory explains why most package producers have not adopted a standard. It also explains why a few package producers have adopted a standard, such as Apoloco, a small United Kingdom producer of software for the bioscience industry.[135] In this case, Apoloco adopted TickIT. It sells its software to businesses, it does not sell many programs since they are highly specialised, and durability is more of an issue because output from the software is used to check the safety of medical drugs. These factors increase the benefit of adopting a standard relative to alternative actions for this particular firm its present environment.

[134] See *IEEE Software*, (1995), 12 (1), pp. 110-111.

[135] Department of Trade and Industry (1993, p. 4).

5.6 Conclusion

Software is a classic case of a good whose trade is subject to asymmetric information between buyers and sellers. Process standards are one mechanism used to alleviate its effects. These standards have been adopted by a small fraction of software producers, yet they have aroused considerable interest and controversy. These seemingly contradictory facts can be reconciled by treating the bespoke and package software markets separately. On doing this, it is evident that most adopters of software process standards produce bespoke software. They also account for a considerable amount of the output of this type of software. It is therefore obvious why there is so much interest in software process standards, given that this type of software constitutes over ninety percent of all software produced and over sixty percent of all software traded. In contrast, very few package producers have adopted a standard. Three other observations are also worth noting. The shares of the standards adopted by bespoke producers are dispersed. In addition, some bespoke producers have not adopted a standard at all. There is also strong evidence that there exist increasing returns to adopting these standards, at least for early adopters. Conventional theoretical models, such as Farrell and Saloner (1985) or Arthur (1989), are not able to explain the adoption patterns given these features. The results from Chapters 3 and 4, however, give results that are consistent with the adoption patterns displayed in the software industry. The basic characteristics of the software industry are also consistent with the assumptions of these models.

One prediction of Chapter 3 is that adoption shares of standards can be dispersed when producers experience substantial heterogeneity. In this case, the gains from adopting the standards will dictate the adoption shares. External effects from the actions of other adopters will have little impact. In addition, some producers will not adopt any standard. This seems to explain the adoption pattern in the bespoke market, particularly since there is strong evidence that producers in this market experience considerable heterogeneity. One feature of the adoption pattern which is initially puzzling, is why have more producers adopted ISO 9000 compared to seemingly superior TickIT? This puzzle can be explained by incorporating spatial aspects and the effects of government policies. Both geographic and product space matter in firms adoption decisions. There exist large software trade flows between the United States and Western Europe, and many United States software producers are multinationals. These two facts suggest a connection between software industries in the United States and the European Community. The policies of many European Community governments which promote the adoption of ISO 9000, effectively raising its net gain, impact on the decisions of United States firms. In addition, many bespoke producers also operate in other industries. The gain from adopting a general standard is more attractive to these producers, than firms who produce mainly software, or firms for which software is a critical input in other products they sell.

Few producers of package software have adopted a standard. This has occurred even though its trade is subject to asymmetric information, many features of its production are the same as for bespoke software, and the benefits of the standards apply equally to them as to bespoke producers. This pattern reflects the fact that there are three different features between package and bespoke software: an absence of moral hazard on the part of the users; typically large sales of each program; and features of the programs, as opposed to durability, matter more in measuring their quality. These features mean that the gains from alternative actions, such as investing in reputation capital, are much higher on average for package compared to bespoke producers. As would be expected, and is predicted by the models developed in Chapters 3 and 4, most producers will choose the alternative actions instead of adopting a standard. This occurs even with standards that provide significant positive gains and have strong increasing returns to their adoption. The models developed in Chapters 3 and 4 also predict that a few package producers will adopt a standard given their particular idiosyncratic environment. This prediction explains why a few package producers have adopted one of the standards, even though the alternative actions appear to have substantially higher gains on average.

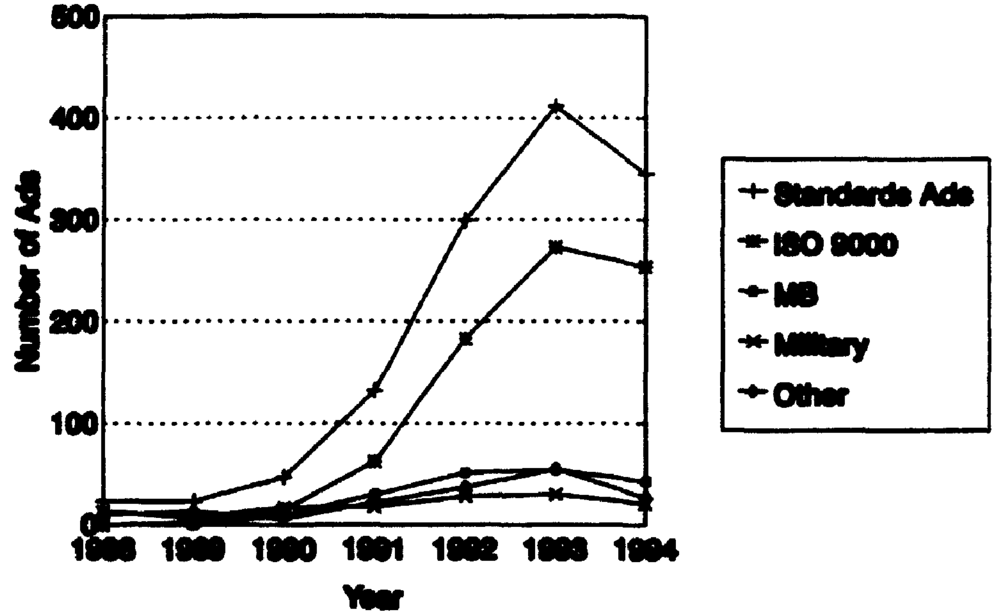
The results of this study provide strong evidence that there is a substantial level of heterogeneity experienced by producers of software. It also suggests that the development of the international software process standard by the ISO and the IEC will not realise substantial benefits from increased standardisation. It also suggests that process standards, particularly those that are industry specific, do have a role to play in the market for bespoke software by alleviating the impact of asymmetric information. These standards will not by themselves raise the quality of software, nor solve the crisis the software industry is facing. They may, however, provide an environment in which firms who wish to increase their quality are rewarded for their efforts. The market will then be in a position to provide bespoke software of a quality that buyers want and are willing to pay for. This already seems to occur in the market for package software.

Appendix 5.1

Related Figures

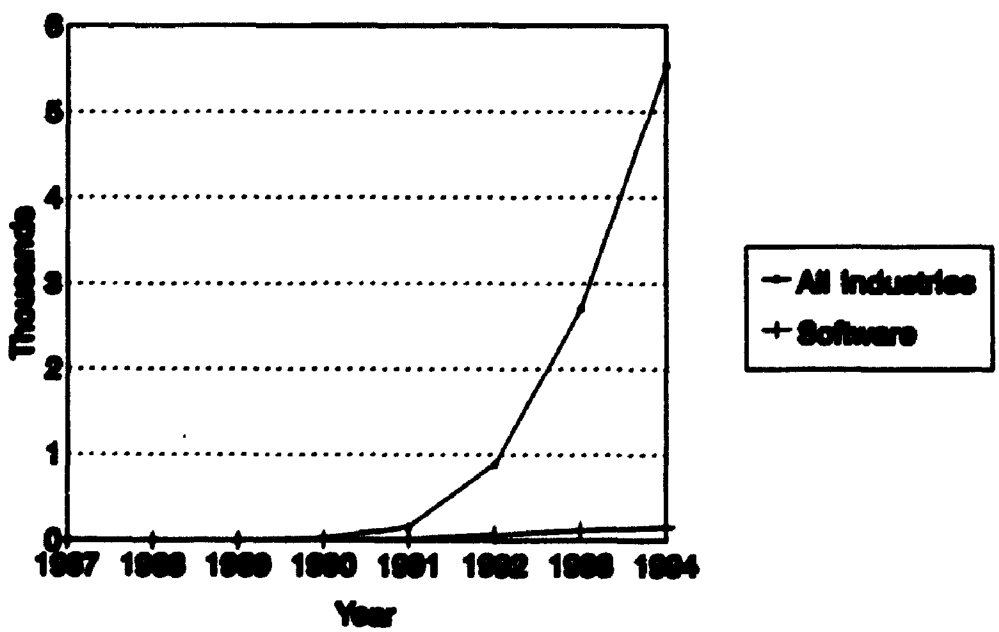
This Appendix presents four figures. The first figure provides one form of evidence suggesting that Marshallian externalities exist in the adoption of process standards. The next two figures show the number of organisations that have adopted the generic ISO 9000 standard, in the United States, and in Canada. The number of adopters is broken up into software organisations, and non-software organisation. The fourth figure shows the number of software producers that have adopted the industry-specific CMM standard.

Figure 5.1: Number of Consultants Ads by Standard



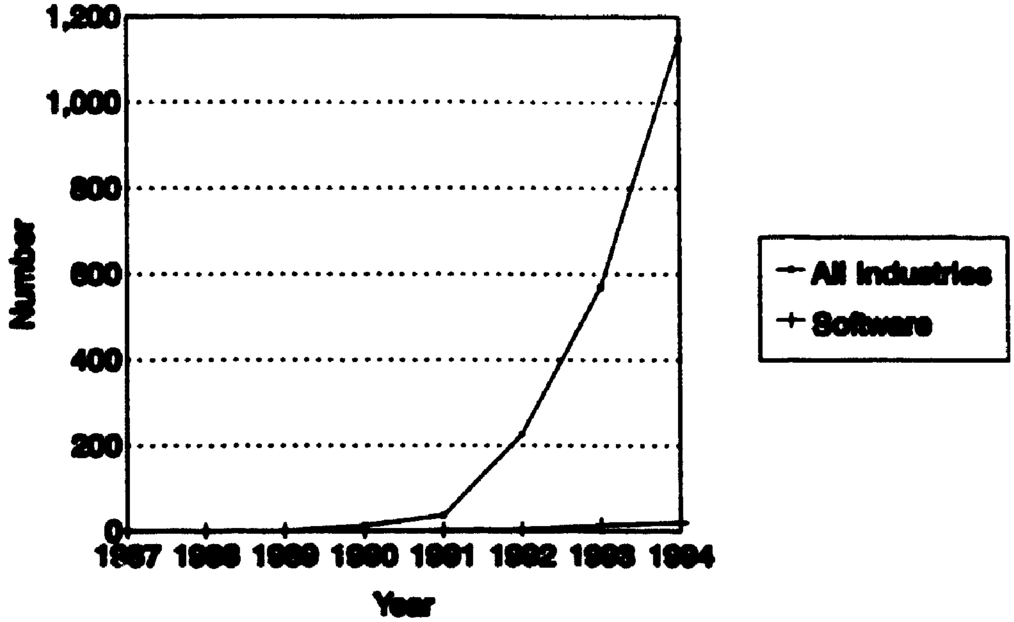
Source: Quality Progress, August issue

Figure 5.2: Total ISO 9000 Registrations in the US



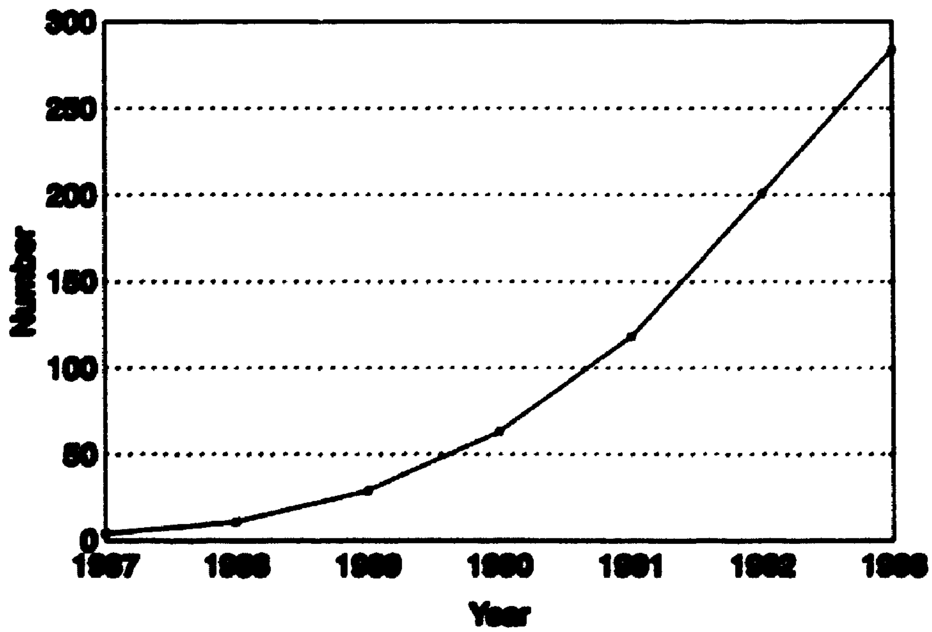
Source: CEEM Information Services

Figure 5.3: Total ISO 9000 Registrations in Canada



Source: CEEM Information Services

Figure 5.4: Cumulative First Time CMM Assessments



Source: SEI

Chapter 6

Conclusion

In the introduction to this thesis, two issues were raised concerning the adoption of process standards. The first issue involves the expectation by the International Organization for Standardization that a generic standard would increase the benefits of standardisation, by supplanting the many firm-specific, industry-specific, and national process standards that have traditionally existed. Both Chapters 3 and 4 have shown that this may not occur for three reasons. First, different firms may do very different things, for which they need very different standards. Second, there may be strong negative returns associated with adopting the available standards. In this situation firms have an incentive to choose standards that are less heavily adopted, so no one standard becomes "the standard". Third, firms in different countries will adopt different standards when negative externalities are mainly global, and positive externalities are mainly local. Firms act to standardise locally to exploit the positive externalities associated with the standards. But countries standardise on different standards to minimise the impact of the associated negative externalities.

This thesis also provides empirical evidence suggesting that there will be seemingly "chaotic" situations where many standards will coexist, even when a generic standard is available for adoption. The case study presented in Chapter 5 strongly indicates that the bespoke software market in the United States is one such example. Multiple standards coexist in this market because there is considerable heterogeneity in the tasks that different producers perform. The "chaotic" situation in this market serves a purpose, firms are doing very different things so many different standards are required to meet their needs. Taken together, the results of Chapters 3 and 4, and the evidence presented in Chapter 5, suggest that the expectations of the ISO may not be met. That for some industries at least, we can expect multiple standards to coexist, even when there is a generic standard available for adoption. Furthermore, we can expect situations where any standards that exist will not be adopted by most firms. The package software industry is one such instance. Actions such as the use of reputations, seem to be superior to adopting process standards for most producers of pacakge software. This example suggests that governments should be wary of mandating that firms have to adopt a standard without first examining the applicable standards adoption environment.

This thesis also addresses a second issue; under what conditions can we expect to observe different adoption patterns between countries, and between industries? When there are global negative externalities associated with adopting standards, and local positive externalities, then countries will increasingly adopt different standards as their economies become more integrated. In contrast, different industries will exhibit similar adoption patterns if adopters of generic standards in one industry confer positive externalities (for example, because of the existence of Marshallian externalities) on adopters of the standard in other industries. The presence of multinationals and multiproduct firms causes adoption patterns in different countries or industries to become similar. This is because these types of firms favour adoption of generic standards to economise on adoption costs, and they have the same effect on adoption patterns in each of the countries or industries that they operate in.

Finally, there are two themes that underlie the work in this thesis. The first is that the presence of heterogeneous agents matters in determining the values of aggregate variables. Using techniques such as the "representative agent" to sweep aside issues of aggregation is likely to produce misleading results, as is shown in Chapters 3 and 4. The second theme concerns the importance of including spatial considerations in economic analysis. What is assumed about the spatial structure of an economy, such as assumptions about what interactions can occur between firms in different places, and what types of firms exist, can produce drastic changes in the results that are derived. Moving from a single country or industry to multiple countries or industries, causes very different patterns of aggregate behaviour to occur. Including multinationals in the model of Chapter 4 also produces different adoption patterns than a model in which they are absent.

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