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A Spatiotemporal Analysis of the Global Diffusion of ISO 9000 and ISO 14000 Certification

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We study the global diffusion of ISO 9000 and ISO 14000 certification using a network diffusion framework. We start by investigating the presence and nature of contagion effects by defining alternative cross-country networks and testing their relative strength. Second, we study how the rate of diffusion differs between the two standards and between early- and later-adopting countries. Third, we identify which countries had more influence on diffusion than others. Empirically, we build a diffusion model which includes several possible cross-country contagion effects and then use Bayesian methods for estimation and model selection. Using country by year data for 56 countries and nine years, we find that accounting for cross-country influences improves both the fit and the prediction accuracy of our models. However, the specific cross-country contagion mechanism is different across the two standards. Diffusion of ISO 9000 is driven primarily by geography and bilateral trade relations, whereas that of ISO 14000 is driven primarily by geography and cultural similarity. We also find that the diffusion rate of ISO standards is higher for later-adopting countries and for the later ISO 14000 standard. We discuss several implications of our findings for the global diffusion of management standards.

Key words: global diffusion; management practice; ISO 9000; ISO 14000; spatiotemporal analysis; Bayesian estimation
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1. Introduction

Managers in many leading firms are increasingly concerned about practices in place at their suppliers and other trading partners. Poor management systems at suppliers can lead to poor quality of incoming products, which in turn will cause problems for the firm and its own downstream customers. Firms are also concerned about unreliable shipments from suppliers with poor internal procedures, and about the potential damage to a firm's reputation if its suppliers do not behave responsibly in an environmental or social context. These concerns, combined with the difficulty involved in monitoring suppliers' internal processes, led to the emergence of, at first, the ISO 9000 series of quality management systems standards, later followed by standards for issues that are not immediately related to quality, such as the ISO 14000 environmental management systems standard.

The ISO management standards are intended to be adopted globally but, partly due to their relative youth, little is known in the literature about how they diffuse across countries. Our goal in this paper is to contribute to knowledge about the mechanisms underlying their global diffusion, about how the adoption rate differs between the two standards and between early- and later-adopting countries, and about the influence that different countries have on the global diffusion process.

Our approach is to use a framework of network diffusion and apply concepts from social interaction theory (e.g., Granovetter 1978) to the understanding of how and why firms in different countries influence each other's adoption behavior. This allows us to formalize the nature and speed of diffusion and to determine cross-country influence in global diffusion processes as a function of between-country proximity and of past adoption behavior.

Empirically, we propose and estimate a diffusion model, in which cross-country influences can follow: (1) geography, where adoption spreads to neighboring countries, (2) trade, where adoption spreads to exporting countries, and (3) culture, where adoption spreads to culturally similar countries, or (4) any combination of these. We estimate the model using Bayesian methods on data tracking the diffusion of ISO 9000 and ISO 14000 certification across countries and years.

Our results indicate that cross-country influence is important for ISO 9000 and ISO 14000 certification. Interestingly, however, the underlying mechanisms are different. Diffusion of ISO 9000 follows bilateral trade flows and geographic proximity, while for ISO 14000 certification, cultural similarity is also important. This suggests that the diffusion mechanism is driven in part by the nature and objectives of the standard. We also find that ISO 14000 diffuses faster than ISO 9000 and that both standards diffuse faster in later-adopting countries. We argue that the difference in the amount of evidence about the usefulness of ISO standards available to different countries and at various stages in the diffusion process is a driving factor for these findings. Finally, we find that a country's relative influence on the diffusion varies between the ISO standards. For instance, while the United Kingdom is the most influential nation in both cases, Japan and Sweden are more influential in the diffusion of ISO 14000 than ISO 9000. These findings can partly be explained by the different nature (economic versus cultural) of the network along which the ISO standards are found to spread.

Our results are hopefully useful to the wide range of policy makers and institutions involved in ISO standards, specifically in determining where to focus their resources in launching future management standards.

In §2, we briefly describe the ISO standards. Section 3 formulates research questions on diffusion of ISO 9000 and ISO 14000. Section 4 introduces the temporal and spatial aspects of the model; the data are presented in §5. Section 6 covers estimation and model selection. Section 7 focuses on the results and §8 concludes.

2. ISO Management Standards

ISO 9000 refers to a series of quality management systems standards (introduced in 1986), while ISO 14000 refers to the series of environmental management systems standards (introduced in 1996). A "management system standard" is a set of requirements that a management system must meet to receive certification of compliance, usually from a third-party auditor.[1] A firm that has ISO 9000 certification has a well-documented and consistent quality management system; the certification does not, in itself, say anything about product quality. Similarly, an ISO 14000 certification indicates that a firm has a well-documented consistent environmental management system, but again does not in itself say anything about a firm's environmental impacts. Audits are performed by independent firms, that in turn are accredited by various independent agencies worldwide. Firms must be re-audited every three years to keep their certification current.

[1] See, for instance http://www.iso.org/iso/en/iso9000-14000/understand/inbrief.html (last accessed June 10, 2006) for more detail.

It is important to note the fundamental difference in scope between the two standards. ISO 9000 focuses on quality management, which makes it relevant primarily for buyer-seller relationships. On the other hand, ISO 14000 is explicitly aimed at a much broader audience, including governments, communities, nongovernmental organizations (NGOs), and others. Both standards have been updated since they were first introduced. As of December 2004, there were 670,399 ISO 9000 certifications outstanding in 154 countries, and 90,569 ISO 14000 certifications in 127 countries (ISO 2004).

3. Research Framework

3.1. Theoretical Background

In this section, we consider how the diffusion patterns of the ISO 9000 and ISO 14000 standards differ from each other and across countries. Research in economics (e.g., Bikhchandani et al. 1992), sociology (Valente 1995, Granovetter 1978), and marketing (Bass 1969) focuses on descriptions of adoption behavior as a contagion process. This contagion is often portrayed as the result of communication between agents via social interaction networks (Granovetter 1978). In this view, adopting firms are receptive to evidence about the usefulness of an innovation, in our case about the usefulness of adopting the ISO standards. Different firms have different "evidentiary" thresholds that represent the minimum amount of evidence to convince the adopter to act, such as a minimum number of past adopters in one's reference group (e.g., Granovetter 1978). Adoption takes place once the amount of supporting evidence collected by the firm surpasses its threshold. Factors affecting firms' reception of evidence or their evidentiary thresholds can therefore affect the nature of diffusion, the speed of diffusion, and the extent of influence of certain countries in propagating standards. The following sections identify these factors and consider how they affect the diffusion process of the ISO 9000 and ISO 14000 standards.

3.2. Nature of Diffusion

The degree to which firms are exposed to evidence is governed by their proximity, on an inter-firm network, to firms that have already adopted. The nature of the diffusion mechanisms is then related to the definition of proximity. Below, we speculate on whether certification is subject to cross-national influences and, if so, when and why proximity to past adopters in terms of culture, geography, or trade relations carries more weight.

First, it is well documented that geographic proximity to past adopters affects the decision to adopt a new product or service. Geographical proximity of rivals is shown to be linked to knowledge spillovers, innovative activity, and firm development (Audretsch and

Feldman 1996, Glaeser et al. 1992), thereby facilitating the transmission of ideas, imitation, and improvement. There is also strong networking between firms of geographic clusters (Baptista 2000), leading to pressures from social contacts and localized competitive environments. Hence, geographic closeness facilitates contacts between any pair of firms, regardless of their sector, but proxies primarily for contacts between rival firms, i.e., for horizontal connectedness.

Because this effect is independent of the specific scope of the standard, geographic proximity of countries is expected to be important to both ISO 9000 and ISO 14000 certification.

Second, another dimension of proximity on an inter-firm network is defined by economic relations, i.e., bilateral trade. It is likely that a stronger business relationship between firms, even across national borders, will lead to a stronger pressure to adopt. "Economic" proximity may therefore be different from geographic proximity. Because it focuses on buyer-seller relations, the bilateral trade mechanism represents vertical connectedness.

Economically-oriented reasons to adopt are commonly found in the diffusion of ISO 9000 but less so for ISO 14000. For ISO 9000, export considerations, quality improvements, and cost reduction are reasons to certify (Anderson et al. 1999, Guler et al. 2002). Certification follows supply chains "upstream" (Corbett 2006) because buyers require foreign sellers to be ISO 9000 certified. Thus, we expect that bilateral trade is relatively more important in the decision to certify for ISO 9000 than for ISO 14000.

Finally, cultural similarity is a third dimension of proximity between firms. Culture plays a multi-faceted role in influencing firms' relations and in shaping cooperation between managers. For instance, culture impacts the importance given to cooperative solutions and creates social barriers to cooperation between people (Nakamura et al. 1997). In general, if groups have the same cognitive framework, they are more likely not to distort the information they receive from others. Thus, the greater is the cognitive and cultural similarity, the better is the flow of information (Triandis and Suh 2002). Culturally similar countries are therefore expected to have more contact.

ISO 14000 is relevant to communities, NGOs, regulators, and other noneconomic parties that need not have any business links with the certified firm (Neumayer and Perkins 2004). In that sense, ISO 14000 affects a broader set of stakeholders, and hence could reflect a country's cultural values more strongly than ISO 9000. For instance, Corbett et al. (2003) report that firms adopting ISO 14000 are more motivated by relations with authorities and communities than firms adopting ISO 9000. Consequently, we expect that cultural similarity is relatively more important in the decision to seek ISO 14000 than ISO 9000 certification.

3.3. Speed of Diffusion

Firms adopt when the current accumulated evidence exceeds their evidentiary threshold. Diffusion speed is therefore adversely affected by the gap between the accumulated evidence and the threshold. Due to the attenuation of adoption risk over time, the evidentiary thresholds of firms in later-adopting countries are generally lower (see, e.g., Valente 1995 for a discussion of the attenuation of adoption risk and its reducing effect on thresholds). In addition, firms in countries where certification starts late are exposed to more evidence of the usefulness of ISO standards in countries where certification started earlier. Using this logic, we speculate on differences in diffusion rates between early- and later-adopting countries, and between the ISO 9000 and ISO 14000 standards.

3.3.1. Differences Between Early- and Later-Adopting Countries. We expect firms in countries that start late to adopt faster. First, when the diffusion of an innovation has reached a critical mass, perceived risk of adoption decreases. As stated above, this decreases the "evidentiary" threshold and "less exposure is sufficient to persuade individuals to adopt" (Valente 1995, p. 92). In our case, the attenuation of risk is likely governed by decreased uncertainty about the usefulness of a particular ISO standard after many countries have started certification. For this reason, later-adopting countries are expected to show higher within-country diffusion rates. Second, even if all countries had the same firm-level distribution of thresholds, later-adopting countries benefit from supporting evidence about the usefulness of the innovation accumulated across earlier adopting firms. Therefore, firms in such countries start the adoption decision closer to exceeding their threshold.

Most of the literature suggests that diffusion in later-adopting countries is faster than in early-adopting countries and that later-adopting countries catch up with earlier-adopting countries. For instance, Takada and Jain (1991) find that the imitation coefficient will be greater for a country in which a product is introduced later. Comin and Hobijn (2004) compare diffusion patterns across countries and find that while economic leaders tend to adopt first, the rate at which lagging countries catch up is accelerating. Although there is no direct literature on acceleration of cross-country contagion effects, later-adopting countries may exhibit higher cross-country imitation rates. Later-adopting countries tend to be less economically developed (Lücke 1993, Comin and Hobijn 2004), more likely to be further upstream in supply chains, and hence subject to pressure from a larger number of downstream parties. Corbett (2006) finds that early-adopting firms in later-adopting countries are more heavily motivated by export considerations, which would also suggests a higher cross-country imitation rate.

3.3.2. Differences Between ISO 9000 and ISO 14000 Diffusion Rates. We predict that the adoption of the later ISO 14000 standard takes place at a faster pace than adoption of the earlier ISO 9000 standard because the installed base of ISO 9000 removed part of the uncertainty about the commercial value and relevance of management systems standards.

The literature on diffusion rates of successive innovations is mixed but on balance favors the prediction that later innovations diffuse faster than earlier ones, consistent with the statement above. Mahajan and Muller (1994) find that the imitation parameter is higher for diffusion in a unified (European Union) market than in individual countries. The globalization that has occurred between the introductions of ISO 9000 (1986) and ISO 14000 (1996) would suggest that ISO 14000 should have a higher imitation rate than ISO 9000. Grubler (1991) finds that first versions of a technology (in our case a management standard) may clash with implemented practices, be perceived as risky, and take considerable time to be accepted as valuable by the community. Van den Bulte (2000) also finds that diffusion of new consumer goods is accelerating over time.

3.4. Influential Countries

Finally, the degree to which firms are effective in transmitting evidence is dependent on their position in the network. Given the inferred structure of the network, firms in some countries are better positioned to have more influence in propagating certification while others are more susceptible to it. In our analysis of influence and susceptibility, we use the structure of this network defined by nodes (countries) and edges (relations between them) to propose a measure of how one country affects the adoption of ISO standards in another (for an in-depth discussion on measures of influence based on network structure, see Wasserman and Faust 1994 and Anderson et al. 1999). Based on this measure, we identify groups of countries that are influential in or susceptible to cross-country contagion.

4. Modeling the Global Diffusion Process

4.1. Background

Mansfield (1961) is perhaps the first to explicitly model the process of technology diffusion using the well-known logistic function and corresponding S-shaped growth curve. Teece (1980) shows that this model also describes the spread of an administrative innovation, hence making it applicable to the ISO 9000 and ISO 14000 standards. Bass (1969) shows that essentially the same model applies to the diffusion of consumer goods, and others have integrated the effects of management action into this model (e.g., Horsky and Simon 1983). Granovetter (1978) proposes that collective adoption behavior is driven by the distribution of individuals' adoption thresholds. Finally, Shaikh et al. (2005) show that the S-shaped diffusion model can be derived from network diffusion primitives so the use of, say, the Bass model is consistent with a network diffusion interpretation.

The international diffusion literature has focused on (1) heterogeneity in country-specific diffusion rates (e.g., Gatignon et al. 1989 and Talukdar et al. 2002), and (2) cross-country contagion (e.g., Kumar and Krishnan 2002, Neelamegham and Chintagunta 1999 and Putsis et al. 1997). Diffusion models are used in these papers to capture installed-base effects on subsequent adoption. Surprisingly, the existing literature on ISO 9000 and ISO 14000 rarely refers to this body of literature, despite the fact that the spread of management standards is probably subject to installed-base effects. In addition, diffusion models typically focus on certification growth rather than on certification levels. This is appropriate here because the investment in obtaining the initial certification is sunk and large compared to the costs of renewing it. The installed base will therefore predominantly affect the timing of the initial certification decision, not that of the renewal decision. Second, if most initial certifications are renewed (as is the case for ISO 9000 and ISO 14000), the yearly certification levels are cumulative variables. Newbold and Granger (1974) show that regressions among cumulative variables often yield statistically significant results where none are present. The standard solution to this spurious regression effect is to difference the time series, i.e., focus on certification growth rather than levels.

4.2. Features of the Diffusion Model

We focus on ISO 9000 and ISO 14000 certification levels by country and by year, particularly on the temporal and cross-sectional aspects of diffusion. Our model has four distinguishing features, each of which can be operationalized in several ways, discussed in more detail below. First, it accounts for differing degrees of cross-country influence, defined as the effect of past certifications in one country on current certification in another. We estimate two versions of the model, where only recent or all past certifications influence current new certifications.

Second, the model allows for alternative views of which countries influence each other. We consider four definitions of "influence sets" of nations based on geography, trade relations, cultural similarity, or a combination of these.

Third, the model includes an econometric control for omitted variables by allowing for contemporaneous correlation of unobserved factors across geography (see, e.g., Anselin 1988). For instance, some relevant factors that contribute to the diffusion of certifications may be at the level of economic regions such as the European Market (EU) or North American Free Trade Agreement (NAFTA). Any such factor that creates a multicountry "trend" in certification will cause contemporaneous correlation when omitted. We specify two models, with and without contemporaneously correlated errors.

Finally, to ensure that what we measure as cross-country influence is not simply a form of unobserved heterogeneity, we allow for random (country-specific) effects. We specify two models, one flexible with random effects and one more restrictive with nonrandom effects.

These four dimensions of model specification lead to a total design of $2 \times 4 \times 2 \times 2 = 32$ models, each of which is estimated for both ISO 9000 and ISO 14000.[2] The following subsections focus on each of these four model design dimensions. We present the model in the context of ISO 9000; the models for ISO 14000 are analogous.

4.3. The Multicountry Diffusion Model

We start by defining a multicountry Bass model where the cross-country imitation effects are based on the cumulative number of certifications in other countries. Here, firms are influenced by other firms, at home and abroad, that have received certification in past periods. We model the number of new certifications c_{kt} in country k at time t as

$$c_{kt} = \left(p_k + \sum_{k'=1}^{K} q_{kk'} \frac{C_{k',\,t-1}}{M_{k'}}\right)(M_k - C_{k,\,t-1}) + e_{kt}, \qquad (1)$$

where C_{kt} (c_{kt}) is the cumulative (incremental) number of certifications in country $k = 1, \ldots, K$ at time $t = 1, \ldots, T$. p_k is the coefficient of innovation, $q_{kk'}$ is the contagion effect of past adoption in country k' on current adoption in country k, M_k is the potential for the number of certifications, and e_{kt} is the error term. To allow for heteroskedastic errors, we assume that the e_{kt} are normally distributed with mean zero and variance proportional to the previous year's growth of certifications,[3]

$$e_{kt} \sim N(0, \sigma_e^2 \cdot |c_{k,\,t-1}|). \qquad (2)$$

The parameters to be estimated are p_k, $q_{kk'}$, M_k, and the error variance σ_e^2.

An alternative assumption is that a firm only exerts influence on firms in other countries soon after its own certification process. Cross-country contagion is then driven only by recent certifications in other countries. This would occur if managers in different countries are more likely to transmit information about recent or ongoing projects than about older events. Therefore, we also examine a model where the cross-country effects depend on recent rather than cumulative certifications in other countries:

$$c_{kt} = \left(p_k + q_{kk}\frac{C_{k,\,t-1}}{M_k} + \sum_{k'=1,\ldots,K;\,k'\neq k} q_{kk'}\frac{c_{k',\,t-1}}{M_{k'}}\right) \cdot (M_k - C_{k,\,t-1}) + e_{kt}. \qquad (3)$$

Note that the within-country contagion effects do still depend on cumulative adoption to maintain the structure and spirit of the traditional S-shaped diffusion curve.

4.4. Cross-Country Influence

In this section, we define the cross-country effects $q_{kk'}$, which depend on a country's "neighbor sets," i.e., the set of countries that are hypothesized to affect adoption in that country. According to our model of network diffusion and inter-firm contagion, we define neighbor sets based on geography, trade, and culture.[4]

4.4.1. Geographic Distance. This notion of influence is appropriate if a management standard's diffusion follows geographical patterns, for instance, starting in Western Europe, then spreading West, South, and East from there. For each country k, we define the neighbor set $G_k(n)$ as the n geographically closest countries, where distance between countries is measured as the surface distance between country capitals.[5] The contagion effects in Equations (1) and (3) are specified accordingly:

$$q_{kk'}^G = \begin{cases} \lambda_k^G & \text{if } k' = k \\ \gamma_k^G & \text{if } k' \in G_k(n) \\ 0 & \text{otherwise,} \end{cases} \qquad (4)$$

where $k' \in G_k(n)$ means that country k' is among the n closest geographical neighbors of k. λ_k^G is the usual coefficient of own-country imitation, while γ_k^G is the coefficient that measures the strength by which firms

[2] Using all combinations of random effects (yes/no) with omitted-variables control (yes/no), we additionally estimate four specifications without cross-country effects.

[3] We set $c_{k,\,t-1} = 1$ for the few cases where $c_{k,\,t-1} = 0$. This additive and heteroskedastic residual term is a simple and parsimonious way to account for the empirical patterns in our data: (1) the residuals in countries with more certifications have higher variance, (2) the absolute errors tend to increase over time as certification levels increase, and (3) in very rare occasions, reflecting measurement error and occasional decertification, c_{kt} can be zero or negative in the ISO data.

[4] For a clarifying example of different neighbor sets across these definitions, see the end of this subsection.

[5] We also tested a countinuous distance specification, with $q_{kk'} = \exp(-\gamma_k D_{kk'}^{-1})$, where $D_{kk'}$ is the geographical distance between country k and k'. This specification produced worse results in terms of fit.

in country k imitate firms located in countries $k' \in G_k(n)$. Testing for geographical cross-country influence is equivalent to testing that $\gamma_k^G > 0$. An appropriate value for n is determined empirically on the basis of model fit.

4.4.2. Bilateral Trade. If a larger share of country k's exports go to country k', then country k' likely has more influence on adoption in country k. We define the share of exports, $BT_{kk'}$, as follows:

$$BT_{kk'} = \frac{\text{Exports}_{kk'}}{\sum_{j=1}^{J} \text{Exports}_{kj}}. \tag{5}$$

Country k's neighbor set $B_k(n)$ consists of its n largest export markets, i.e., the n countries with highest $BT_{kk'}$. The cross-country effects are then operationalized as

$$q_{kk'}^B = \begin{cases} \lambda_k^B & \text{if } k' = k \\ \gamma_k^B & \text{if } k' \in B_k(n) \\ 0 & \text{otherwise.} \end{cases} \tag{6}$$

Again, n is specified empirically. This definition is not symmetric: for instance, the United States is a key export market for many countries which are not major export markets for the United States.

4.4.3. Cultural dimensions. To numerically represent the culture of a given country, we use Hofstede's (2001) four cultural dimensions: (1) power distance, (2) individualism, (3) masculinity, and (4) uncertainty avoidance.[6] These cultural dimensions have been used in other work on comparing innovativeness across countries. For instance, Shane (1993) finds a link between culture and the number of trademarks per country, while Van Everdingen and Waarts (2003) find that culture affects country-level adoption rates of enterprise resource planning systems. Each country k is represented by four scores sc_{ks}, with $s = 1, \ldots, 4$, one for each of Hofstede's dimensions. We define the cultural distance between countries k and k' using the distance measure

$$H_{kk'} = \sqrt{\sum_{s=1}^{4} (sc_{ks} - sc_{k's})^2}. \tag{7}$$

[6] These dimensions mean the following: (1) "power distance" focuses on the degree of equality versus inequality between different people in terms of power and wealth; (2) "individualism" focuses on the importance given to the individual versus the collective in terms of achievements and relationships; (3) "masculinity" deals with the traditional role played by the man in terms of control, power and achievement; and (4) "uncertainty avoidance" regards the level of tolerance for uncertainty and risk.

For each country k, $H_k(n)$ contains the n countries culturally closest to k. The cross-country effects are operationalized as

$$q_{kk'}^H = \begin{cases} \lambda_k^H & \text{if } k' = k \\ \gamma_k^H & \text{if } k' \in H_k(n) \\ 0 & \text{otherwise,} \end{cases} \tag{8}$$

with n determined empirically.

4.4.4. Combining the Neighbor Sets. Finally, neighbor sets can be defined as any combination of the three previous definitions, e.g., the union,

$$q_{kk'}^A = \begin{cases} \lambda_k^A & \text{if } k' = k \\ q_{kk'}^G + q_{kk'}^B + q_{kk'}^H & \text{if } k' \neq k, \end{cases} \tag{9}$$

where $q_{kk'}^G$, $q_{kk'}^B$, and $q_{kk'}^H$ are as defined previously in Equations (4), (6), and (8). These cross-country effects contain the parameters γ_k^G, γ_k^B, and γ_k^H, which are estimated concurrently. The γ's are identified because for any given n, the sets $G_k(n)$, $B_k(n)$, and $H_k(n)$ are not identical. Under the union of these sets, each country k may thus have more than n neighbors.

4.4.5. An Example: India. The countries in our sample that are considered India's neighbors, assuming $n = 5$, under each of the above definitions are:

- Geographical distance: Pakistan, United Arab Emirates, Iran, Thailand, and Saudi Arabia.
- Bilateral trade: United States, Japan, United Kingdom, Hong Kong, and United Arab Emirates.
- Cultural: Egypt, Jordan, Saudi Arabia, United Arab Emirates, and Kenya.
- Combined: the union of all 12 countries listed above.

The countries are listed in order of proximity under each measure; it is clear that the neighbor set and ordering of neighbors varies substantially across the different measures.

4.5. Country Heterogeneity

We use two alternative methods to account for heterogeneity in the country diffusion rates. The first uses country-specific covariates (see, e.g., Gatignon et al. 1989, Putsis et al. 1997). We make the parameters p_k, M_k, λ_k, and γ_k a linear function of country characteristics, $\mathbf{x}_k$:

$$M_k = \mathbf{x}_{Mk}\beta_M, \tag{10}$$

$$p_k = \mathbf{x}_{pk}\beta_p, \tag{11}$$

$$\lambda_k = \mathbf{x}_{\lambda k}\beta_\lambda, \tag{12}$$

$$\gamma_k = \mathbf{x}_{\gamma k}\beta_\gamma, \tag{13}$$

where $\mathbf{x}_{pk}$, $\mathbf{x}_{Mk}$, $\mathbf{x}_{\lambda k}$, and $\mathbf{x}_{\gamma k}$ are factors such as population, urbanization, and illiteracy ratings for each parameter. These expressions can be substituted in Equation (1) to get a nonrandom effects model of country heterogeneity. The resulting model captures observed heterogeneity across countries.

An alternative approach accounts for unobserved as well as observed differences across countries through a random coefficients model (e.g., Talukdar et al. 2002), where a hierarchical structure is placed on the parameters, which have a distribution of the following form:

$$M_k \backsim N(\mathbf{x}_{Mk}\beta_M, \sigma_M^2), \tag{14}$$

$$p_k \backsim N(\mathbf{x}_{pk}\beta_p, \sigma_p^2), \tag{15}$$

$$\lambda_k \backsim N(\mathbf{x}_{\lambda k}\beta_\lambda, \sigma_\lambda^2), \tag{16}$$

$$\gamma_k \backsim N(\mathbf{x}_{\gamma k}\beta_\gamma, \sigma_\gamma^2). \tag{17}$$

The first model produces a distribution for the parameter vectors $\beta = [\beta_p; \beta_M; \beta_\lambda; \beta_\gamma]$. The country-specific parameter values then result from Equations (10) to (13). The second model provides distributions of the final parameters M_k, p_k, λ_k, and γ_k for each country, capturing heterogeneity more flexibly.

We use the following covariates. For the potential number of certifications M_k, we choose population and gross domestic product (GDP) per capita as the main source of heterogeneity. Larger countries generally have more firms, while richer countries have a higher proportion of firms that can support the costs of ISO 9000 certification. Specifically for ISO 14000, we include the sum of the "social and institutional capacity" and "global stewardship" components of the environmental sustainability index (World Economic Forum 2002) as a covariate (this measure is broader than the measure based on the number of environmental treaties used in Corbett and Kirsch 2001).

We use literacy rates as an alternative measure of development. Studies in urban economics (Calem and Carlino 1991) show that urban centers offer better infrastructure and consequently facilitate faster diffusion of information about adoption of innovations, so we also include percentage of urban population. Empirically, variable selection for each model in (10)–(17) is based on model likelihood (corrected for overfitting) and prediction.

4.6. Omitted Variables

A final feature of our model is that it allows for contemporaneous correlation in the residuals e_{kt} across countries. This helps control for those omitted variables that cause multicountry trends in certification, such as business cycles that are common to a neighbor set of countries.

A parsimonious model of contemporaneous correlation can be specified as a spatial correlation on the residuals of Equation (1). Recall that these residuals are heteroskedastic with variance $c_{kt-1} \cdot \sigma_e^2$. For ease of notation, define the transformed residuals $\tilde{e}_{kt} = e_{kt}/\sqrt{c_{kt-1}}$. Instead of assuming that the error component $\tilde{e}_{kt}$ is independent across countries, we allow for a more general autocorrelated error process on the $[K \times 1]$ error vector $\tilde{\mathbf{e}}_t$. That is,

$$\tilde{\mathbf{e}}_t = \mu \mathbf{W} \tilde{\mathbf{e}}_t + \boldsymbol{\eta}_t, \tag{18}$$

where $\mathbf{W}$ is a $K \times K$ matrix whose elements $\mathbf{W}_{kk'}$ are $1/n$ for all $k' \in G_k(n)$ and 0 otherwise (recall that n is the number of neighbors). The interpretation of Equation (18) is that $\tilde{e}_{kt}$ is allowed to be a function of the average $\tilde{e}_{k't}$ in the spatial neighbor set. μ is a spatial autoregressive coefficient. Finally, the error term η_{kt} is distributed as $\eta_{kt} \sim N(0, \sigma_\eta^2)$.[7]

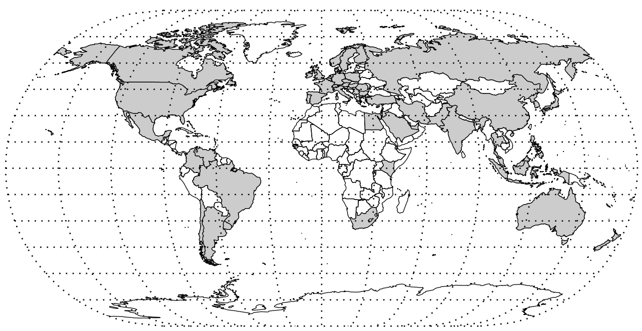
To summarize, we have presented a very general model of diffusion of ISO 9000 (and ISO 14000) certification that (1) accounts for cross-country and own-country imitation effects, (2) operationalizes different definitions of cross-country effects, (3) allows for observed and unobserved differences across countries, and (4) accounts for omitted variables with a spatial structure.

5. Data

Our data for the number of ISO 9000 and ISO 14000 certifications were obtained from ISO, which took over the original Mobil survey of global certification data that started in 1992. Altogether, 12 "cycles" of the global certification survey have been released during 1992–2003 (ISO 2003). Although annual since 1995, the earliest cycles were released at irregular intervals. To transform the early data to an annual grid, we used cubic spline interpolation between sample points. In the year 2000, the major revision ISO 9000:2000 was released. A significant number of firms that were previously certified to the earlier version of the standard did not seek recertification to the new version, although recertification is required every three years. Other firms consolidated multiple site-level certifications into a single firm-level certification, which was not possible under the earlier versions of the standard. Because neither disadoption nor consolidation is the focus of our study, we discarded the data on ISO 9000 certification after 2000, leaving nine annual observations per country (1992–2000) for ISO 9000. ISO 14000 was published in September 1996, and did not undergo any major revision during our observation horizon. We have eight annual observations for 1995–2002 (some firms received certification before the final standard was published).

[7] Anselin (1988) shows that the joint distribution of the spatial error vector $\tilde{\mathbf{e}}_t$ is normal with mean zero and variance-covariance matrix equal to $\sigma_\eta^2((\mathbf{I} - \mu\mathbf{W}')(\mathbf{I} - \mu\mathbf{W}))^{-1}$.

Figure 1 Map of the Spatial Sample



The initial sample includes all countries which have at least one ISO 9000 certification by the year 2002, in a total of 169 countries. It is impossible to meaningfully estimate diffusion patterns with severely limited data, so we restrict our analysis to the 59 countries with at least 200 cumulative certifications. We lack information about bilateral trade or country characteristics for Taiwan, Lithuania, and Latvia, so our final sample includes 56 countries. For consistency, the same sample was used for ISO 14000. Figure 1 gives a graphical representation of the spatial sample.

Of the 56 countries, 31 had less than 20 ISO 9000 certifications in 1993, so in most countries widespread adoption had not yet started. In contrast, for the last year in our analysis ($T = 2000$ for ISO 9000, $T = 2002$ for ISO 14000), the mean cumulative number of ISO 9000 and ISO 14000 certifications is, respectively, 7,170 and 851, with a standard deviation of 11,664 and 1,622. Figure 2 shows that the diffusion curves of selected but typical countries are either S-shaped or convex, consistent with the outcome of a diffusion process.

Economic and demographic information was obtained from the TableBase database (Dialog 2003), from the CIA *World Factbook* (CIA 2003), and from the Census Bureau. We mostly used values for 1997, except for population, which is from the year 2000, and bilateral trade, from 1996 (the latter is from the *World Trade Flows*, 1980–1997; see Feenstra 2000).[8] To make the covariates of consistent scale, they were standardized prior to using them in the diffusion model. Geographic distance was based on the latitude and longitude of the countries' capitals. The cultural data were taken from Hofstede (2001), where the Arab countries in our sample (Egypt, Jordan, Saudi Arabia, and United Arab Emirates) are treated as one region. For Cyprus, we used Greece's cultural scores; for Kenya, we applied the scores for Eastern Africa.

[8] The top exporters do not vary much from year to year, circumventing the need to make this measure time specific over the observation period.

6. Empirical Analysis

6.1. Estimation

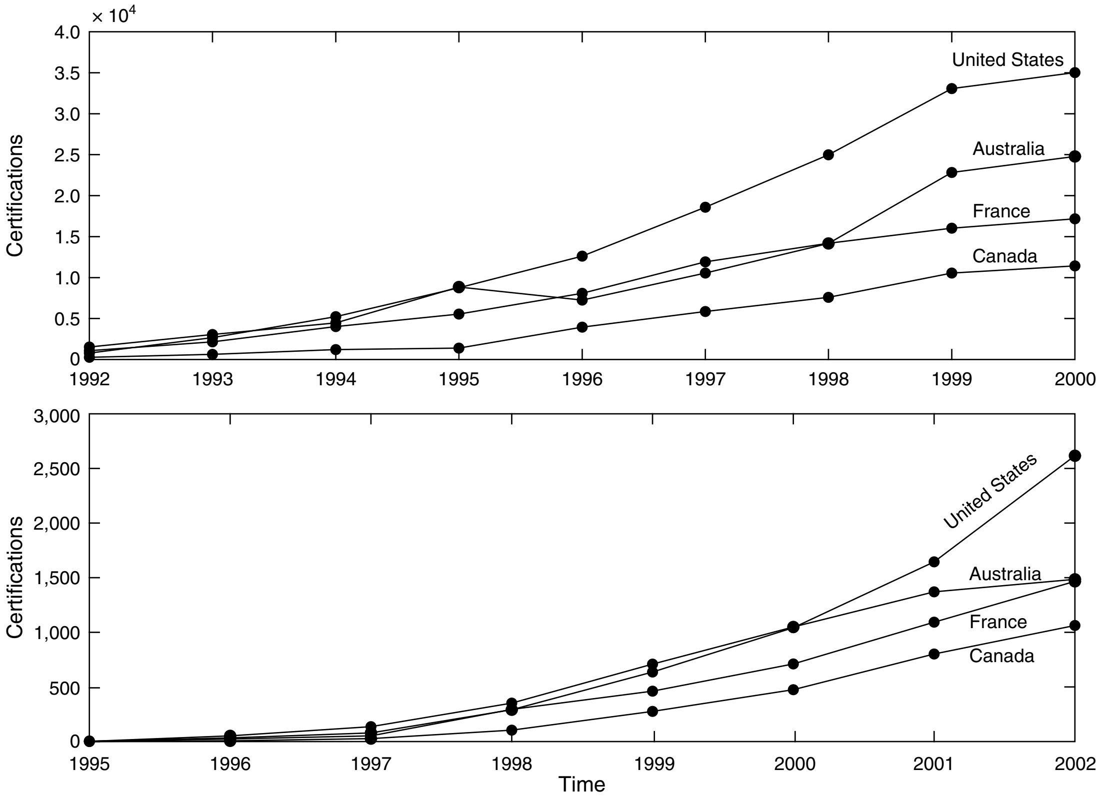
We use Bayesian methods to estimate the parameters' mean and standard deviation. A detailed description of the estimation algorithm is available in the online appendix (provided in the e-companion).[9] Bayesian methods allow us to estimate all proposed models, from nonrandom effects to hierarchical random coefficients within a consistent framework. Our time series are short: for ISO 9000 (ISO 14000), we have only nine (eight) observations per country. We focus on annual differences in certification rather than levels, so we "lose" one observation. Another observation is needed for initialization in Equation (3). Finally, we use the last available observation (year 2000 for ISO 9000; 2002 for ISO 14000) as holdout to evaluate prediction. This leaves us with six observations per country for model estimation for ISO 9000 and five for ISO 14000. Such short time series are not uncommon when studying diffusion processes that are measured infrequently, as is the case of ISO 9000 and ISO 14000. The use of Bayesian methods allows us to make the most of the country-specific data to estimate country diffusion rates. However, for those countries where the within-country data are uninformative of the diffusion process, the method will "shrink" the estimates toward the hierarchical mean, which is based on pooled data across all countries. The amount of shrinkage is determined by the informativeness of the within-country data relative to the pooled across-country data.[10]

We carried out preliminary tests with different values for neighbor set size n for each distance measure. The best results in terms of fit and prediction were obtained with small set of neighbors, between three and eight, with little sensitivity in that range. To compare the different contagion mechanisms with a manageable number of empirical models, we ran all models with $n = 5$. Recall that in addition to the 32 models defined earlier, we defined four variants of the baseline model without cross-country effects with and without accounting for unobserved heterogeneity

[9] An electronic companion to this paper is available as part of the online version that can be found at http://mansci.journal.informs.org/.

[10] Using Markov chain Monte Carlo (MCMC) methods, we sample from the marginal posterior distribution of each parameter in turn, conditional on the current values of other parameters and on the data (Tanner and Wong 1987, Gelfand and Smith 1990). All models were run for a total of 20,000 iterations. The first 15,000 observations were used for initialization and the last 5,000 iterations were used for inference. To reduce the autocorrelation in the MCMC sampler, every fifth draw was saved for analysis. The plots of the sampled values for each parameter show that they converge. We tested for differences in parameters' means across different intervals (Gelman et al. 1995) and found none significant. In most cases, convergence was achieved after 3,000 to 4,000 iterations.

Figure 2 Yearly ISO 9000 and ISO 14000 Certification Counts for Four Countries



and omitted variables. Our model selection strategy for the two data sets compares all 36 models for each standard.

Figure 3 shows the actual number of ISO 9000 certifications compared to the fitted ($T = 1997$) and the predicted ($T = 2000$) values from the model with geographic cross-country effects, random effects to account for heterogeneity, and no contemporaneous correlation in errors. The model is generally very effective in tracking the cross-country heterogeneity in ISO 9000 certification.

6.2. Model Selection

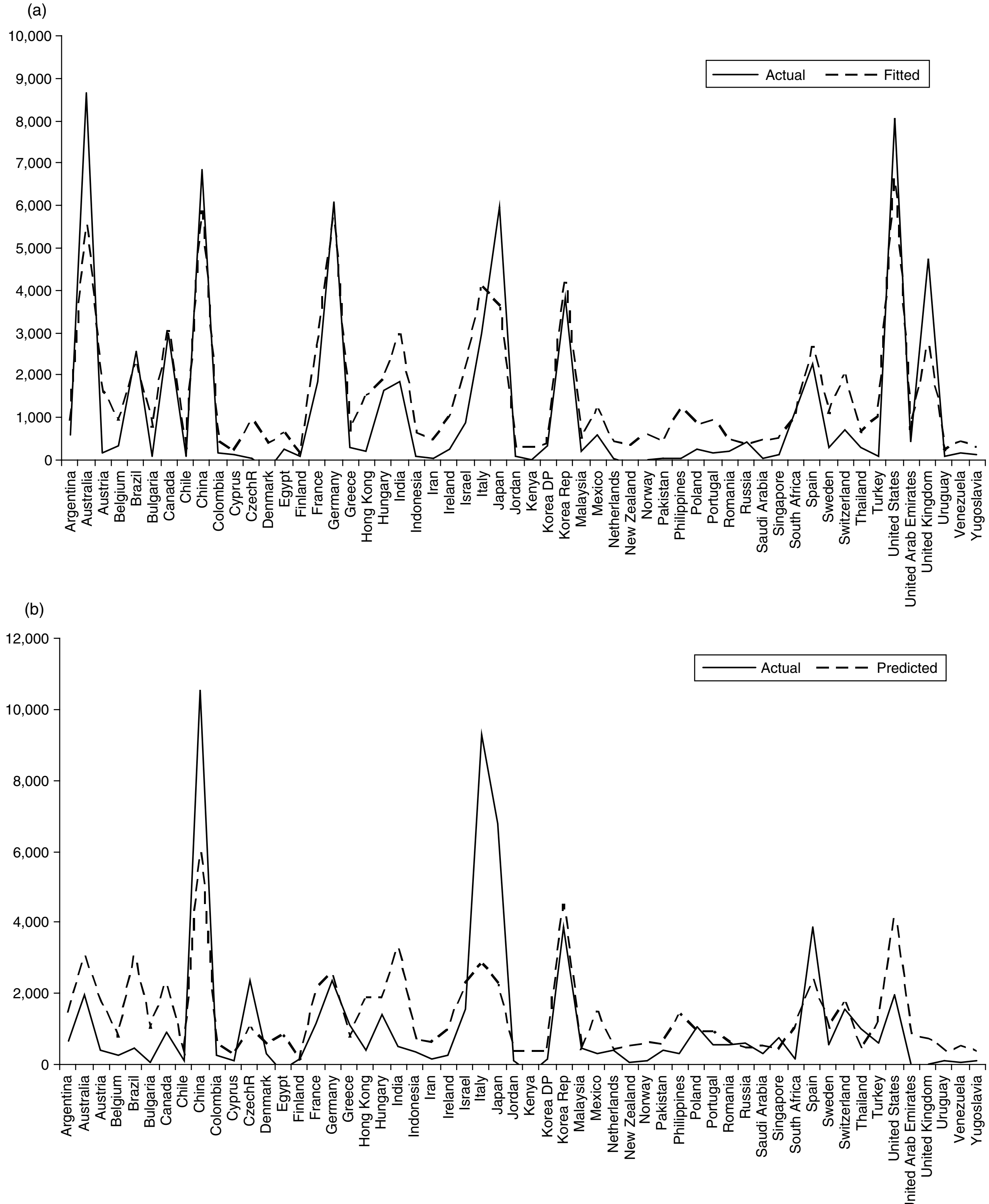
To focus on cross-country effects, we first make a rough selection among the many specifications by comparing them based on marginal likelihood and root of the mean squared error (RMSE). For each model, we calculate the marginal likelihood as the harmonic mean of the posterior likelihood values across iterations of the sampler (Newton and Raftery 1994, Gelfand and Dey 1994). The marginal likelihood warrants against overfitting the data, as overfitting increases the variability of the likelihood across iterations which in turn reduces the harmonic mean of the likelihoods. Consequently, models with more parameters, such as the "combined" specification, may present worse marginal likelihood values. The RMSE statistics are estimated from the differences between the predicted versus actual values for the holdout period ($T = 2000$ for ISO 9000, $T = 2002$ for ISO 14000) at every sweep of the sampler.[11]

Table 1 shows the log of marginal likelihoods for the 36 model specifications for ISO 9000 and ISO 14000. The table shows that, in most cases, the models with long-term (cumulative) cross-country influence provide a better fit than those with short-term influence. Table 2 shows the prediction performance for the same 36 models. The maximum prediction accuracy with long-term cross-country influence is slightly better or similar to that of the short-term model. Given the superior fit and (mostly) better prediction results, we retain for further analysis the specifications where adoption depends on cumulative certifications.

We see that the random-coefficients models that account for unobserved heterogeneity produce better fit and substantially better predictions than the nonrandom effects specifications. This is an important benefit of our Bayesian estimation approach. With our short time series, it is difficult to meaningfully account for country-specific diffusion parameters using classical methods. However, our results show that the information in the time series helps

[11] Consistent with Equation (2), these differences are scaled by $c_{k,t-1}$. This scaling prevents model selection from being dominated by one or two countries with the largest number of certifications.

Figure 3 **(a) Actual and Fitted New ISO 9000 Certifications for 1997; (b) Actual and Predicted New ISO 9000 Certifications for 2000**



make much better predictions. In view of their fit and prediction accuracy, we focus on the model specifications that account for unobserved country heterogeneity through random effects.

Tables 1 and 2 show limited support for the models with contemporaneously correlated errors to account for omitted variables, especially for the random coefficients models. After accounting for unobserved

Table 1 Log Marginal Likelihoods for All Model Specifications in the ISO 9000 and ISO 14000 Data Sets

	Nonrandom effects models		Random coefficients models	
	No omitted var.	Omitted var.	No omitted var.	Omitted var.
ISO 9000				
No cross-country effects	−1,695.3	−1,689.7	**−1,584.4**	−1,584.3
Cross-country effects				
Short-term: geography	−1,685.5	−1,682.6	−1, 536.2	−1,540.1
Short-term: bilateral trade	−1,695.4	−1,689.9	−1, 546.5	−1,550.2
Short-term: culture	−1,688.2	−1,679.0	−1, 561.2	−1,531.1
Short term: combined	−1,721.4	−1,682.8	−1, 553.9	−1,586.9
Long-term: geography	−1,683.2	−1,676.9	**−1,513.9**	−1,516.9
Long-term: bilateral trade	−1,693.5	−1,689.3	**−1,522.6**	−1,528.4
Long-term: culture	−1,680.5	−1,687.0	**−1,524.8**	−1,565.6
Long-term: combined	−1,734.8	−1,689.5	**−1,520.5**	−1,574.0
ISO 14000				
No cross-country effects	−1,183.1	−1,182.2	**−1,048.7**	−1,047.9
Cross-country effects				
Short-term: geography	−1,185.2	−1,184.8	−1, 024.0	−1,018.3
Short-term: bilateral trade	−1,184.8	−1,183.6	−1, 015.3	−1,015.2
Short-term: culture	−1,185.5	−1,183.6	−1, 020.8	−1,017.8
Short term: combined	−1,189.0	−1,188.3	−1, 008.3	−1,039.6
Long-term: geography	−1,181.2	−1,183.4	**−1,014.7**	−1,018.2
Long-term: bilateral trade	−1,182.5	−1,181.5	**−998.2**	−997.2
Long-term: culture	−1,184.9	−1,195.6	**−999.1**	−997.0
Long-term: combined	−1,197.1	−1,190.9	**−998.7**	−1,032.0

Note. The bold statistics correspond to the models selected for further analysis.

Table 2 Mean Squared Errors for Holdout Predictions Across All Model Specifications in the ISO 9000 and ISO 14000 Data Sets

	Nonrandom effects models		Random coefficients models	
	No omitted var.	Omitted var.	No omitted var.	Omitted var.
ISO 9000				
No cross-country effects	68.88	65.87	**60.01**	59.14
Cross-country effects				
Short-term: geography	72.59	72.39	56.51	55.80
Short-term: bilateral trade	68.39	65.84	56.66	56.09
Short-term: culture	64.84	74.41	60.47	66.16
Short term: combined	65.70	65.38	56.26	55.68
Long-term: geography	79.51	78.80	**56.57**	57.26
Long-term: bilateral trade	68.01	66.63	**54.75**	55.90
Long-term: culture	70.14	67.04	**66.05**	61.03
Long-term: combined	69.62	67.21	**55.96**	57.99
ISO 14000				
No cross-country effects	25.4	26.1	**21.7**	21.3
Cross-country effects				
Short-term: geography	24.4	25.1	21.3	20.4
Short-term: bilateral trade	25.3	26.3	21.8	21.4
Short-term: culture	24.6	25.7	21.8	22.2
Short term: combined	29.1	24.6	21.7	22.5
Long-term: geography	26.8	26.3	**21.5**	22.7
Long-term: bilateral trade	25.7	26.5	**22.1**	22.6
Long-term: culture	24.9	30.2	**19.4**	19.8
Long-term: combined	30.6	29.4	**23.0**	29.2

Note. The bold statistics correspond to the models selected for further analysis.

heterogeneity, there appears to be little evidence for contemporaneous correlation in the residuals across countries, so we retain the more parsimonious model without such effects for further analysis.

In sum, the subset of models on which we focus for subsequent analysis of cross-country effects have in common that they (1) are based on cumulative certification levels in other countries, (2) account for unobserved heterogeneity, and (3) have independent errors across countries. In Tables 1 and 2, the corresponding fit and prediction statistics are underlined for clarity. This subset consists of the best specifications in terms of fit and prediction, or when there is no systematic difference in performance, the specifications that are more parsimonious. The substantive conclusions of our paper do also apply outside this set.

7. Results

7.1. The Diffusion Parameters of ISO 9000 and ISO 14000 Certification

We now discuss the diffusion parameters of ISO 9000 and ISO 14000 and relate them to what is known about these parameters in other contexts. In the specifications (14)–(17), the country-specific effects M_k, p_k, λ_k, and γ_k are modeled as functions of underlying covariates. To prevent overfitting, we base the inclusion of covariates on improvement of the marginal likelihood. For the random coefficients models,[12] the only significant covariate was population (for M_k). This is not surprising, as the random coefficients model itself already accounts for country-specific effects.

Table 3 reports parameter estimates for selected random effects models for both data sets. The potential number of certifications M_k in country k is positively related to population size. The innovation coefficient is around 0.04 for ISO 9000 and around 0.05 for ISO 14000. These values are consistent with those found in meta-analyses on diffusion parameters for durable and high-technology consumer products. Pooling across more than 200 different applications of

[12] We focus on the random coefficients models because of their fit and prediction superiority. Tests with the nonrandom coefficients models revealed that GDP per capita and (in the case of ISO 14000) the environmental sustainability index (ESI) were insignificant. While the insignificance of the ESI seems at odds with Neumayer and Perkins (2004), we analyse a different dependent variable than they do (certification growth rather than level), and their results indicate that "attitude to the environment" is only weakly significant.

Table 3 Parameter Estimates for the ISO 9000 and ISO 14000 Data Sets with Standard Deviations in Parentheses

	(1)	(2)	(3)	(4)	(5)	(6)
ISO 9000						
Market potential: intercept/1,000	3.670 (3.630)	5.198* (2.426)	3.998 (2.731)	9.452* (1.680)	8.009* (1.625)	7.481* (1.629)
Market potential: population	4.765* (2.160)	1.888* (0.940)	2.492* (1.109)	3.152* (1.284)	2.052* (1.003)	1.877* (0.899)
Innovation coefficient	0.043 (0.028)	0.042 (0.027)	0.044 (0.028)	0.045 (0.027)	0.044 (0.027)	0.042 (0.027)
Imitation coefficient						
Own-country	0.478* (0.067)	0.278* (0.052)	0.306* (0.055)	0.291* (0.051)	0.246* (0.046)	0.218* (0.043)
Cross-country: geography		0.095* (0.030)			0.076* (0.029)	0.059* (0.027)
Cross-country: bilateral trade			0.061* (0.027)		0.047 (0.027)	0.040 (0.026)
Cross-country: culture				0.105* (0.034)		0.066* (0.029)
Error variance	722.1 (64.0)	456.5 (40.1)	477.3 (41.5)	489.3 (43.8)	436.5 (39.3)	427.66 (39.5)
ISO 14000						
Market potential: intercept/1,000	1.747* (0.399)	1.301* (0.244)	1.136* (0.238)	1.322* (0.244)	1.044* (0.214)	0.923* (0.212)
Market potential: population	0.549 (0.405)	0.235 (0.165)	0.260 (0.148)	0.372* (0.176)	0.221 (0.113)	0.198 (0.108)
Innovation coefficient	0.040 (0.027)	0.045 (0.028)	0.065* (0.030)	0.046 (0.028)	0.055 (0.028)	0.064* (0.027)
Imitation coefficient						
Own-country	0.799* (0.099)	0.370* (0.063)	0.379* (0.070)	0.342* (0.058)	0.282* (0.053)	0.260* (0.049)
Cross-country: geography		0.181* (0.033)			0.098* (0.031)	0.085* (0.031)
Cross-country: bilateral trade			0.118* (0.033)			0.090* (0.031)
Cross-country: culture				0.133* (0.035)	0.108* (0.032)	0.098* (0.032)
Error variance	100.75 (9.75)	75.91 (7.37)	67.85 (7.02)	69.22 (7.33)	65.43 (7.40)	62.31 (6.12)

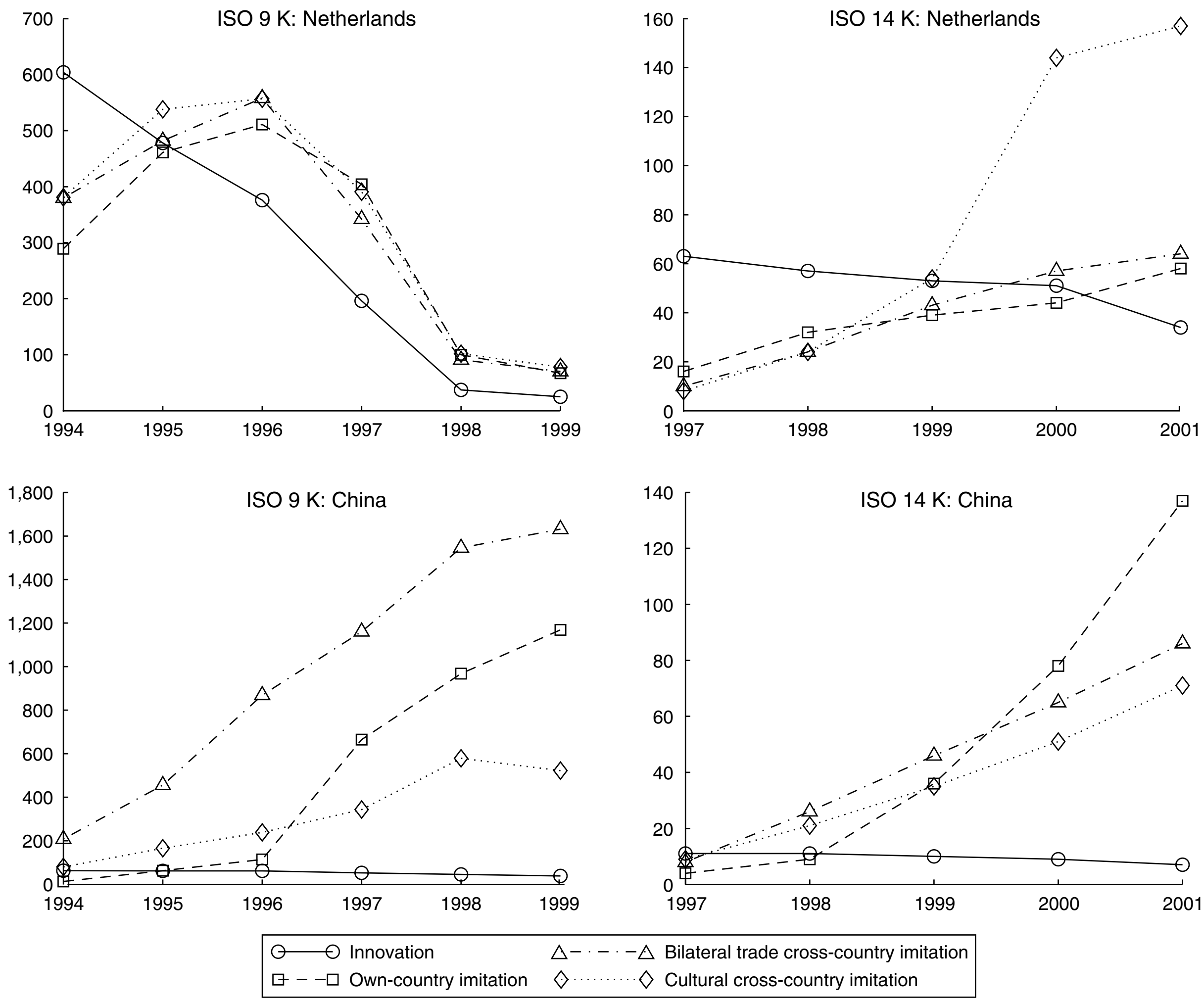
*Indicates that ratio of the parameter and its standard deviation exceeds 2. Model (1) has no cross-country effects. Model (2)–Model (4) contain cross-country effects based on geography, bilateral trade, and culture, respectively. Model (5) combines the best predicting two versions of cross-country effects from Model (2)–Model (4). Model (6) combines all definitions of cross-country effects.

consumer durables, Sultan et al. (1990) find an average value for p of 0.03. This means that the diffusion process for management standards (in essence an industrial durable "good") has a similar autonomous component as that for a typical durable consumer good.

When cross-country imitation is accounted for, the own-country imitation coefficients are between 0.22 and 0.31 for ISO 9000 and between 0.26 and 0.38 for ISO 14000. Sultan et al. (1990) find an average value of 0.3 for the imitation effect for consumer durables. Note from a comparison of model (1) with models (2)–(6) that the own-country imitation coefficient is inflated by 50% to 100% when cross-country imitation is not accounted for. This suggests that any work on multicountry diffusion that does not explicitly consider the cross-country influence may confound within- and cross-country imitation effects and hence overestimate the within-country imitation parameter.

In Table 3, the estimated cross-country effect coefficients vary from 0.040 to 0.181. No meta-analysis of cross-national diffusion coefficients exists for us to compare our estimates to. We note that the cross-country diffusion parameters are almost all significant and positive and that the findings of the models are robust to the other empirical specifications from §4 including those with spatially correlated errors.

Figure 4 ISO 9000 and ISO 14000 Certifications Resulting from Various Diffusion Sources



To illustrate the differences between countries and to show the flexibility of our model in capturing a rich set of diffusion phenomena, we show the diffusion patterns for two countries, the Netherlands and China, and for the two standards. To construct the graph, we use for each standard the model with all cross-country contagion mechanisms, but to avoid a cluttered graph we focus on the contrast between the effects of bilateral trade and cultural similarity.

Figure 4 shows that the autonomous component of adoption for both ISO 9000 and ISO 14000 is greater in the Netherlands than in China. The developed countries in Europe were among the first to adopt both standards and in turn influenced other countries. This is in some part a result of the availability of resources in those countries, which facilitates firms to take risk and be innovators.

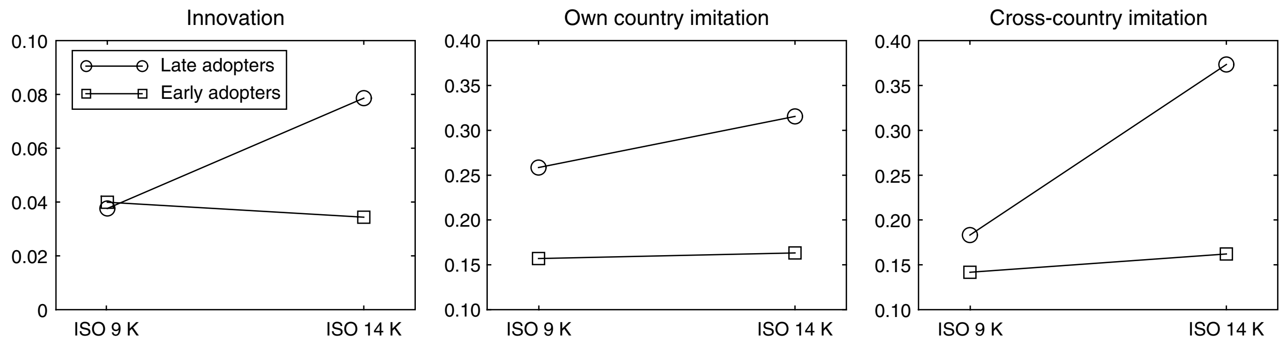
In China, adoption of ISO 9000 was initially largely fueled by trade-related pressures. This is to be expected, given that China has become one of the main suppliers of firms in developed countries and downstream pressures are likely to occur. ISO 14000 shows other driving forces beyond trade relations, as also suggested in the literature (e.g., the strength of relations with communities and other cultural factors). In both China and the Netherlands, the proportion of new ISO 14000 certifications that can be attributed to cultural similarity with other countries is greater than in the case of ISO 9000.

7.2. The Research Questions Revisited

7.2.1. The Nature of Diffusion of ISO 9000 and ISO 14000. Tables 1 and 2 show that the specifications without cross-country effects always fit and usually predict worse for ISO 9000 and ISO 14000. The empirical evidence therefore clearly points to the presence of cross-country effects in the spread of both standards.

For ISO 9000, the cross-country effect based on geographic distance produces superior fit and good prediction, while that based on bilateral trade links provides good fit and superior prediction. However,

Figure 5 Comparison of the Diffusion Coefficients Between ISO 9000 and ISO 14000 and Between Early- and Later-Adopting Countries



the cross-country effect defined by cultural similarity performs the worst in terms of fit and especially prediction. Thus, the data suggest that geography proximity and export relations played a very important part in the contagion process and in the transmission of evidence about ISO 9000's usefulness across borders, while the role of cultural similarity in the diffusion of this standard was smaller.

The strong impact of geographic distance suggests that firms in neighboring countries have a greater tendency to observe and share information about management practices. To the extent that this leads to competitive mimicry (Guler et al. 2002), the geographic effect may be seen as "horizontal" contagion (i.e., involving similar firms). The strength of the bilateral trade link is likely the result of firms requiring suppliers to have ISO 9000 certification, regardless of their location. This contagion is among buyer-seller diads and can therefore be termed "vertical." Our findings suggest that both types of contagion contribute to global diffusion of ISO 9000 certification.

In contrast, for ISO 14000, the cultural distance specification produces good fit and superior prediction. The bilateral trade specification fits well but produces worse fit. The geographic specification fits the worst. Comparing the two data sets, the role of cultural similarity in cross-country contagion therefore appears larger for ISO 14000. Although tentative, this finding is consistent with our prediction that ISO 14000 is more culturally driven than ISO 9000.

7.2.2. The Diffusion Rate of ISO 9000 vs. ISO 14000. Our random coefficients procedure yields posterior estimates of the diffusion parameters, i.e., of the market potential M, the innovation effect p, the own-country imitation effect λ, and the cross-country imitation effect γ, for each country and standard. In §3, we speculated how these parameters might be different for ISO 9000 versus ISO 14000 and for early- versus later-adopting countries. To check our speculations, we compute the posterior of the mean of these parameters in a 2 (ISO 9000 versus ISO 14000) by 2 (early versus late) design, defining early and late based on a median split in penetration of certification in the initial year for ISO 14000.[13] Figure 5 displays the comparisons between the four groups.[14]

The diffusion process of ISO 14000 certification presents directionally larger average coefficients of innovation, own-country imitation, and cross-country imitation than that of ISO 9000, so the later process diffused faster than the earlier one. This is consistent with literature reviewed earlier and with our expectation that some uncertainty about the usefulness of ISO 14000 or the certification process was resolved by experience with ISO 9000. It is also consistent with an effect of increased globalization between the introductions of ISO 9000 and ISO 14000 that led to a more unified world and hence increasing imitation rates (Mahajan and Muller 1994). The difference in adoption speed across the two standards is more pronounced for the late adopters group where significance approaches or is above 90%. The late adopters, usually poorer and developing countries, were very slow to adopt ISO 9000 but less far behind in adopting ISO 14000.

7.2.3. The Diffusion Rate in Early- vs. Later-Adopting Countries. First, we observe that in general late adopters have a considerably higher rate of innovation. This difference in innovation rates between groups is very pronounced in ISO 14000 while much less so in the case of ISO 9000 (see the

[13] The median split on first year ISO 14000 certification levels separates countries that have ISO 14000 certifications in the first year of its availability from countries that did not. Several alternative segmentations based on (1) different lower and upper percentiles of penetration, and (2) timing of first certification yielded substantively similar results. Defining early and late adoption based on ISO 9000 data is more ambiguous due to lack of data for 1986–1993.

[14] The pooling of data in this 2 by 2 design immunizes the comparison of parameters across cells from small sample biases present in nonlinear models (see Van den Bulte and Lilien 1997), even if for each combination of country and standard, the time series are of unequal length across design cells. By pooling the data, the number of observations quickly becomes large enough to wipe out small sample biases. This was verified by means of several Monte Carlo simulations.

first panel of Figure 5). Second, we find that later-adopting countries have significantly higher within-country imitation rates for both ISO 9000 and ISO 14000 (see also Comin and Hobijn 2004, Takada and Jain 1991). Finally, later-adopting countries also have higher cross-country imitation rates especially for the later ISO 14000 standard (see the third panel of Figure 5). These effects are consistent with the expectation formulated in §3 that early certification in one country can resolve uncertainty about ISO standards to firms in another country and thereby speed up adoption.

7.2.4. Measures of Influence and Susceptibility. As explained in the theoretical section and the modeling section, the structure of cross-country interaction depends on the exact measure of proximity on the inter-firm network. Empirically, we find that the diffusion of ISO 9000 and ISO 14000 certification takes place within a global network of firms and managers, organized by geography, trade, and/or culture each of which come with their own set of cross-country effects. We propose two measures of the importance of countries in stimulating certification across borders, influence, and susceptibility, which seek to represent how much a country contributes to foreign certification and how much foreign countries contribute to domestic certification, respectively.

Our influence and susceptibility measures are computed by summing the estimated cross-country network matrix $q_{kj}(k, j = 1, \ldots, K)$ alternatively across columns or rows, respectively. Specifically, the influence index I_{kt} is defined as the total number of certifications in country $j \neq k$ that can be attributed to pressure from country k in year t:

$$I_{kt} = \sum_{j=1,\ldots,K;\, j\neq k} \underbrace{q_{jk} \cdot \frac{C_{k,\,t-1}}{M_k}}_{\text{pressure of } k \text{ on } j} \cdot \underbrace{(M_j - C_{j,\,t-1})}_{\text{untapped firms in } j}. \tag{19}$$

The index I_{kt} combines two terms. The first term is simply the multiplication of the coefficient q_{jk} that captures the strength of influence of k on j, with the cumulative certification base $C_{k,\,t-1}/M_k$ in k. This term serves as a measure of the "pressure" exerted by country k on j. The second term is the "untapped" firms in country j. Similarly, the susceptibility of country k is

$$S_{kt} = \sum_{j=1,\ldots,K;\, j\neq k} \underbrace{q_{kj} \cdot \frac{C_{j,\,t-1}}{M_j}}_{\text{pressure of } j \text{ on } k} \cdot \underbrace{(M_k - C_{k,\,t-1})}_{\text{untapped firms in } k}. \tag{20}$$

This measure equals the number of certified firms in country k and year t that the model attributes to foreign pressures. Figure 6 presents the summed (across time) relative measures of influence, $\sum_t^T I_{kt} / \sum_t^T \hat{c}_{kt}$,[15] and susceptibility, $\sum_t^T S_{kt} / \sum_t^T \hat{c}_{kt}$, using the combined specification (6) in Table 3. Note that the relative susceptibility index $\sum_t^T S_{kt} / \sum_t^T \hat{c}_{kt}$ is equal to the cumulative share of certifications in k due to foreign pressures from $j \neq k$ (see Equation (1)).

For ISO 9000, countries like the United Kingdom, Japan, and the United States, appear to have moderate to low susceptibility to cross-national pressures coupled with a large influence on other countries, i.e., the model estimates that for firms in these countries, certification is not driven by firms in other countries, but rather by those at home. Within the confines of the model, these countries owe their influence to their central place in the network consisting of bilateral trade relations and neighboring countries. On the other side of the spectrum reside countries like China and Korea that have low to moderate influence but are quite susceptible. This distribution of countries is consistent with the existence of downstream pressures among trading nations found by Lücke (1993) and Comin and Hobijn (2004).

Comparing this with the bottom graph, we see that environmentally proactive countries such as Sweden, Denmark, and the Netherlands were more influential in the spread of ISO 14000 than of ISO 9000. Overall though, the relative influence and susceptibility for many countries remains broadly similar across ISO 9000 and ISO 14000.

Interestingly, many countries have a share of certifications attributed to foreign pressures larger than 0.5. For these countries, the majority of domestic certification originates from cross-country influence. For policy makers interested in encouraging rapid diffusion of management practices, our results suggest that focusing on gaining rapid acceptance in a few key influential countries helps accelerate adoption in many other, more susceptible, countries.

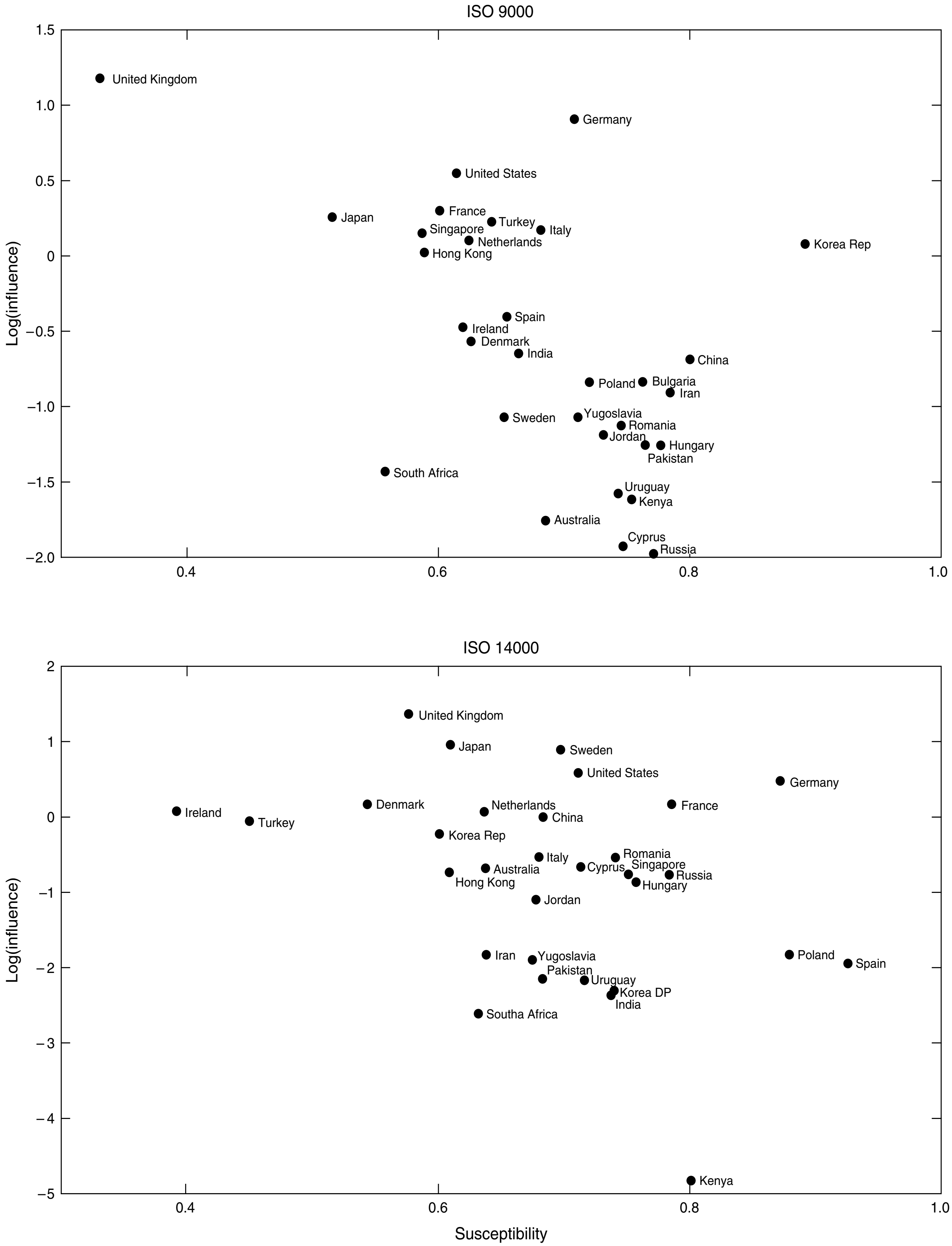
8. Conclusion

We presented a model of international diffusion of management standards and estimated it on country by year data for ISO 9000 and ISO 14000 certification. Our predictions about the nature and speed of adoption and about individual country influence are derived from a model of network diffusion wherein a firm's adoption decision is based on proximity to earlier adopters on an inter-firm network and a private evidentiary threshold.

We estimated an empirical model of certification that embeds alternative definitions of inter-firm proximity, and at the same time accounts for a wide array

[15] To compare across countries, we divide the absolute measures by the estimated total of certifications $\sum_t^T \hat{c}_{kt}$ in each country, to obtain a relative measure of influence and susceptibility.

Figure 6 Influence and Susceptibility Values for a Sample of 32 Countries



Note. Because many countries are clustered in the region of low influence, we use a log transform of influence, $\log(\sum_t^T I_{kt} / \sum_t^T \hat{c}_{kt})$, in Figure 6 to avoid cluttering. For the same reason, the graph only includes the 20% most and 20% least influential countries of both standards.

of country-specific phenomena and cross-country influences. We infer that cross-country effects are statistically (Table 3) and substantively (Figure 4) important in both ISO 9000 and ISO 14000 certification. Moreover, ISO 9000 certification follows export flows and geographic proximity, while ISO 14000 appears to also diffuse across culturally similar countries. We conclude therefore that the nature of diffusion seems to be a function of the nature or scope of the standard. Although speculative, our results suggest that standards with more narrowly business-related objectives, such as quality management, accounting principles, or software standards, will diffuse more along supply chains and hence bilateral trade relationships. In contrast, standards that focus on "societal" issues such as the environment, labor standards, corporate social responsibility, etc., may experience more culturally-driven diffusion.

We further found evidence that past certification, whether to the same standard in earlier-adopting countries or to an earlier standard, lowers the perceived risk associated with current adoptions, leading to an increase in diffusion rates. Our results suggest that the diffusion of future standards may increase even more, given the increasing installed base of ISO certification and given the increased density of inter-firm networks caused by globalization.

We finally focused on country level differences in influence on—and susceptibility to—the global diffusion of these management practices. From our findings, we conclude that large developed countries such as the United Kingdom, Japan, and the United States will play key roles in the global diffusion of management standards. However, depending on the nature of the standard, some groups of countries with specific interests may emerge as leaders in a specific area, e.g., countries such as Denmark or Sweden, with their traditionally higher concern for the environment, were some of the most influential in global diffusion of ISO 14000 but less so in the case of ISO 9000. Our results may be useful to ISO, auditors, accreditation bodies, government agencies, and others. In particular, they help determine where these organizations should focus their efforts in launching future management standards.

A limitation to our approach is that we observe certification at the country level instead of the firm level. Should firm level observations become available, a good avenue for future research is to allow for more flexible definitions of inter-firm networks. Also, our approach does not consider direct attempts by various organizations to encourage certification. It would be of practical interest to model the influence of sources of information other than the inter-firm network such as seminars, government incentives, marketing efforts by ISO, marketing efforts by the auditors, and the like.

9. Electronic Companion

An electronic companion to this paper is available as part of the online version that can be found at http://mansci.journal.informs.org/.

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Online Appendix

Markov Chain Monte Carlo (MCMC) Estimation Steps for the Random Coefficients Models

The previously presented model (for the cumulative imitation specification) is based on the following equations:

$$\begin{aligned} c_{kt} &= \left(p_k + \sum_{k'=1}^{K} q_{kk'} \frac{C_{k',\,t-1}}{M_{k'}}\right)(M_k - C_{k,\,t-1}) + e_{kt} \\ q_{kk'} &= \lambda_k \quad \text{if } k' = k \\ q_{kk'} &= \gamma_k \quad \text{if } k,\ k' \text{ are neighbors} \\ q_{kk'} &= 0 \quad \text{otherwise.} \\ e_{kt} &\sim N(0, \sigma_e^2) \cdot c_{k,\,t-1}, \end{aligned} \tag{EC1}$$

with the parameters having the following distributions:

$$M_k \backsim N(\mathbf{x}_{Mk}\beta_M, \sigma_M^2) \tag{EC2}$$

$$p_k \backsim N(\mathbf{x}_{pk}\beta_p, \sigma_p^2) \tag{EC3}$$

$$\lambda_k \backsim N(\mathbf{x}_{\lambda k}\beta_p, \sigma_\lambda^2) \tag{EC4}$$

$$\gamma_k \backsim N(\mathbf{x}_{\gamma k}\beta_\gamma, \sigma_\gamma^2). \tag{EC5}$$

In order for the model to be a meaningful diffusion model, all parameters should be subjected to nonnegativity constraints. In addition, the parameter M_k is subject to the constraint that $M_k \geq \max_t(C_{kt})$. We include these restrictions in our estimation algorithm described below.

The parameters are estimated by drawing from their full conditional distributions. This process is illustrated below for M_k (the potential number of certifications in country k). M_k has a full conditional likelihood that combines the distribution of $c_{kt} \mid M_k$ with the empirical distribution of M_k itself.

$$L(M_k \mid \text{rest}) \propto \prod_k \prod_t [\hat{c}_{kt} \mid M_k] \cdot [M_k] = \prod_k \prod_t N(\hat{c}_{kt}(M_k \mid \text{rest}), \sigma_{ek}^2) \cdot N(\mathbf{x}_{Mk}\beta_M, \sigma_M^2), \tag{EC6}$$

where

$$\hat{c}_{kt}(M_k \mid \text{rest}) = \left(p_k + \sum_{k'=1}^{K} q_{kk'} \frac{C_{k',\,t-1}}{M_{k'}}\right)(M_k - C_{k,\,t-1}). \tag{EC7}$$

Because these distributions are a nonconjugate pair for M_k and we need to implement the logical constraints on the parameters, we use the Metropolis-Hastings algorithm to draw from the posterior distribution of M_k. We obtain a new value for M_k, M_k^{new}, by drawing δ_{Mk} from the appropriate normal distribution, with mean zero and a variance obtained in a burn-in period that guarantees an acceptance rate of M_k^{new} between 30% and 40% (Gelman et al. 1995). M_k^{new} is defined by

$$M_k^{\text{new}} = M_k + \delta_{Mk}. \tag{EC8}$$

In each sweep of the sampler the new value M_k^{new} is accepted with probability θ

$$\theta = \min\left[\frac{L(M_k^{\text{new}} \mid \text{rest})}{L(M_k \mid \text{rest})}, 1\right]. \tag{EC9}$$

Because the estimation should guarantee that $M_k \geq \max_t(C_{kt})$, we set $M_k^{\text{new}} = M_k$ in iterations when $M_k^{\text{new}} < \max_t(C_{kt})$.

For the innovation parameter p_k and contagion parameters λ_k and γ_k, the estimation steps are similar to the ones above for M_k. For the initial values of these parameters, we choose values that are larger than zero and similar to values presented in literature presented in the review section (again, we tested for different initial values and found insignificant differences in the final results).

To obtain the draws for the parameters from the lower level of the hierarchy, e.g., β_M and σ_M^2, we combine the higher level draws for M_k with the hierarchical model $M_k \backsim N(\mathbf{x}_{Mk}\beta_M, \sigma_M^2)$. Denote the number of covariates in the matrix $\mathbf{x}_{Mk}$ by P_M. Further, define the priors $[\beta_M] \sim N(\mu_{0M}, \Sigma_{0M})$ with $\mu_{0M} = \mathbf{0}$ and $\Sigma_{0M} = 10{,}000 \cdot \mathbf{I}_{P_M}$ and $[\sigma_M^2] \sim IG(1, 1)$. Both prior distributions are diffuse for the parameter space of interest, having little impact on the final results. The posterior distributions are a result of a conjugation of the priors with the data distributions

$$\beta_M \sim N_{P_M}(\mathbf{V}_M(\Sigma_{0M}^{-1} \cdot \mu_{0M} + \Sigma_M^{-1} \cdot \mu_M), \mathbf{V}_M) \tag{EC10}$$

$$= N_{P_M}\left(\mathbf{V}_M\left(\Sigma_{0M}^{-1} \cdot \mu_{0M} + \frac{\mathbf{x}'_M\mathbf{M}}{\sigma_M^2}\right), \mathbf{V}_M\right), \quad \text{with} \tag{EC11}$$

$$\mathbf{V}_M = (\Sigma_{0M}^{-1} + \Sigma_M^{-1})^{-1} = \left(\Sigma_{0M}^{-1} + \frac{(\mathbf{x}'_M\mathbf{x}_M)}{\sigma_M^2}\right)^{-1}, \tag{EC12}$$

and

$$\sigma_M^2 \sim IG(1 + 0.5K, 1 + 0.5((M - \mathbf{x}_M\beta_M)'(M - \mathbf{x}_M\beta_M))). \tag{EC13}$$

For the error variance σ_e^2, the errors between estimated and actual number of certifications are calculated in each draw and standardized using the chosen scale, in this case, the last observed number of certifications

$$\tilde{e}_{kt} = \frac{c_{kt} - \hat{c}_{kt}}{\sqrt{c_{k,t-1}}}. \tag{EC14}$$

For the draws of the variance σ_e^2, we use the inverse gamma distribution. The diffuse prior is defined as $\sigma_{0e}^2 \sim IG(1, 1)$. The draws are taken from the following posterior distribution:

$$\sigma_e^2 \sim IG(1 + 0.5K(T - 1), 1 + 0.5\tilde{\mathbf{e}}'\tilde{\mathbf{e}}), \tag{EC15}$$

where $\tilde{\mathbf{e}} = \text{vec}(\tilde{\mathbf{e}}_{kt})$.

Reference

See references list in the main paper.