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# Do ‘liberal market economies’ really innovate more radically than ‘coordinated market economies’? Hall and Soskice reconsidered

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ABSTRACT

In *Varieties of Capitalism; The Institutional Foundations of Comparative Advantage*, Peter A. Hall and David Soskice (H&S) argue that technological specialization patterns are largely determined by the prevailing “variety of capitalism”. They hypothesize that “liberal market economies” (LMEs) specialize in radical innovation, while “coordinated market economies” (CMEs) focus more on incremental innovation. Mark Zachary Taylor [Taylor, M.Z., 2004. Empirical evidence against varieties of capitalism’s theory of technological innovation. International Organization 58, 601–631.] convincingly argued that Hall and Soskice’s empirical test is fundamentally flawed and proposed a more appropriate test of their conjecture. He rejected the varieties of capitalism explanation of innovation patterns. We extend and refine Taylor’s analysis, using a broader set of radicality indicators and making industry-level comparisons. Our results indicate that Hall and Soskice’s conjecture cannot be upheld as a general rule, but that it survives closer scrutiny for a substantial number of industries and an important dimension of radicality.


## 1. Introduction

In the extensive introduction to their influential edited volume, Peter A. Hall and David Soskice (H&S) argue that the technological specialization patterns of developed countries are largely determined by the “varieties of capitalism” prevailing in these countries (Hall and Soskice, 2001).[1] In “liberal market economies” (LMEs), the activities of economic actors are mainly coordinated through market institutions, in an environment characterized by competition and formal contracting. In “coordinated market economies” (CMEs), however, strategic interaction between firms and other actors play a much more important role in determining the rate and direction of economic activities. Typical examples of LMEs are the US and the UK. The group of CMEs contains Germany and Japan, among others.[2]

H&S hypothesize that LMEs would specialize in radical innovation, while CMEs would focus more on incremental innovation. We believe that H&S’s empirical test of this hypothesis is fundamentally flawed. In a recent article, Taylor (2004) criticized H&S’s testing procedure as well. His alternative testing procedure led him to reject the varieties of capitalism explanation of specialization patterns. The testing procedure we propose in this paper differs from Taylor’s in two main respects: it studies (de)specialization in radical innovations at a more disaggregated level (industries instead of aggregate economies) and it considers a more general set of radicality indicators.

To understand why we join Taylor (2004) in thinking that H&S’s empirical analysis yields unwarranted claims, we should first explain their testing procedure. They compared the innova-

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[1] By now, hundreds of contributions to social sciences were inspired by H&S. Examples of subfields influenced by H&S are political science (e.g., Kenworthy, 2006; Kitson, 2005), human resource management (e.g., Aguilera and Dencker, 2004), industrial relations (e.g., Hancke and Rhodes, 2005), governance studies (e.g., Griffiths and Zammuto, 2005) and innovation studies (e.g., Casper and Kettler, 2001; Asheim and Coenen, 2006).

[2] H&S also identify an “intermediate” group, of which France and Italy are important members (Hall and Soskice 2001, p. 21). Below, we will present H&S’s full categorization of countries.

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tion specialization patterns of two countries: the US (an LME) and Germany (a CME). Data from the European Patent Office on patents granted in 1983–1984 and 1993–1994 were used to investigate in which technology classes these countries patented relatively heavily. Their results indicate that the US patented relatively heavily in technology classes related to biotechnology, telecommunications and semiconductors. These are, according to H&S, technologies characterized by radical innovations. Germany, on the other hand, obtained relatively many patents in technology classes such as transport and mechanical engineering, which would feature more incremental innovations. These results are considered to confirm the H&S hypothesis.

The approach of H&S can be criticized on many grounds, but we will focus on three.[3] First, it is highly questionable to contend that a comparison of two countries yields evidence that supports a hypothesis about much larger groups of countries.[4] Second, we agree that a technology class like semiconductors is much more susceptible to radical innovation than a class like transport, but would not be surprised if the few radical innovations in transport would cluster in a specific country. The evidence that innovations (irrespective of their radical or incremental nature) within a technology class tend to cluster in specific geographical locations is abundant.[5] There is no reason to *a priori* discard the contention that this localization can also be observed for radical innovations only, too. Third, scholars of technological change provided ample evidence of the existence of technology life cycles.[6] Radical innovations occur relatively often during the early stages of the life cycle of a technology, while incremental innovations are much more common in later stages. Hence, H&S's choice to denote specific technologies as characterized by radical innovations and others as characterized by incremental innovation is not without problems, if only because H&S adopt identical classifications for their 1983–1984 and 1993–1994 analyses. Some of the technologies with a strong emphasis on radical innovations in the early period might well have entered a stage in the technology lifecycle dominated by incremental innovations later on.

We propose a test that does not suffer from the problems sketched above, using data originating from the US Patent Office and obtained from the NBER Patent-Citations Data File. After having used a concordance to map patent classes to industry classes, we will construct industry-specific frequency distributions for several measures of basicness (or "radicality") computed from patent citation data for the period 1975–1995. In doing so, we draw on previous work by Trajtenberg et al. (1997) who built on the basic idea that patented innovations that are often cited in subsequently issued patents are relatively more important.[7] Next, the frequency distributions will be compared with similar frequency distributions constructed from patents granted to several LMEs and CMEs, to see whether LMEs really specialize in radical innovations or not. The non-parametric statistical testing procedures will also allow us to find out whether such a finding (if any) holds for all industries, or for a limited subset of industries only. Our analysis adds to Taylor (2004), whose study refuted the H&S hypothesis, in two ways. First, we argue that the analysis should explicitly take differences across industries into account, so the appropriate level of analysis is the industry rather than the aggregate economy level.[8] Second, we consider a broader set of radicality indicators than Taylor, whose analysis focused on the number of citations received. Our alternative indicators consider the range of technologies affected by the patented innovation as well as the range of technologies from which knowledge was used to arrive at the patented innovation. As will be shown below, this leads to a nuanced picture: Taylor is right in burying the H&S hypothesis as a general law, but for a number of industries and dimensions of radicality the H&S hypothesis appears to be correct.

The organization of the paper is as follows. In Section 2, we briefly discuss the broad background of the H&S distinction between LMEs and CMEs and H&S's results on the prevailing types of innovation in these countries. Section 3 introduces the testing procedures advocated by us, as well as a detailed description of the variables that play a role in these tests. Section 4 is devoted to a discussion of the data. The actual tests of the H&S hypothesis are reported upon in Section 5. Section 6 concludes.

## 2. Innovation in liberal and coordinated market economies

The H&S hypothesis revolves around two conceptualizations that should be discussed more extensively. First, the most important differences between liberal market economies and coordinated market economies should be dealt with. Second, we should summarize how H&S look at the distinction between radical and incremental innovation. This section discusses these issues, describes the methodologies applied by H&S and finally interprets their main results.

The "Varieties of Capitalism" approach advocated by H&S stresses the notion that the way firms resolve many of the coordination problems they are confronted with varies across countries.[9] LMEs and CMEs can be seen as two archetypes representing the extremes of a continuum. In LMEs,

> "... *firms coordinate their activities primarily via hierarchies and competitive market arrangements.* (...) *Market relationships are characterized by the arm's-length exchange of goods or services in a context of competition and formal contracting. In response to the price signals generated by such markets, the actors adjust their willingness to supply and demand goods or services* (...)." (Hall and Soskice, 2001, p. 8)

In CMEs, on the other hand,

> "... *firms depend more heavily on non-market relationships to coordinate their endeavors with other actors and to construct their core competencies. These non-market modes of coordination generally entail more extensive relational or incomplete contracting, network monitoring based on the exchange of private information*

[3] A more extensive list of problems pertaining to H&S's empirical approach can be found in Akkermans (2005).

[4] Some of H&S's results run counter to earlier work based on patent statistics for a much broader set of countries that focused on other aspects than LME vs. CME differences, such as differences in country size (Archibugi and Pianta, 1992).

[5] See, for instance, Caniëls (2000, Chapter 8) and Breschi (2000). The presence of universities generating spillovers concerning frontier technologies (see, e.g., Audretsch and Feldman, 1996; Piergiovanni and Santarelli, 2001) is likely to play an important role in this clustering.

[6] Utterback and Abernathy (1975) is the seminal contribution in this respect. Klepper (1996) provided a formal model explaining observed regularities.

[7] Trajtenberg (1990) is generally seen as the genesis of this type of research, which focused solely on American issues for a long time. Maurseth and Verspagen (2002) is an example of a recent contribution addressing citation patterns across European regions. See Michel and Bettels (2001) for an account of differences in citation practices across international patent offices.

[8] Taylor (2004) added intercept dummies for six broad technology classes to its equations regressing the radicality of patents (measured by the number of citations received) on the variety of capitalism they originated from. This approach assumes that the sensitivity of the radicality of innovations to originating from either an LME or a CME is equal across technology classes.

[9] In an earlier book (Albert, 1993), Michel Albert also distinguished between types of capitalism, arguing that social coalitions and politically constructed institutions produce government policies and that institutional arrangements shape the effects of government policy.

*inside networks, and more reliance on collaborative, as opposed to competitive, relationships to build the competencies of the firm.* (...) *the equilibria on which firms coordinate in coordinated market economies are more often the result of strategic interaction among firms and other actors.*" (Hall and Soskice, 2001, p. 8)

To operationalize the distinction between LMEs and CMEs for analytical purposes, H&S proposed two indicators of institutional practices. These relate to corporate finance and labor markets. High levels of stock market capitalization (defined as the ratio of the market value of listed companies to GDP) and low levels of employment protection (measured by a composite index of the ease of 'hiring and firing') reflect reliance on markets. Informal cluster analysis leads H&S to a classification of 23 OECD countries. Six countries were denoted as LMEs and eleven countries as CMEs. The six members of the third group, which we will denote as MMEs ("mixed market economies"), are sometimes referred to as the countries representing the 'Mediterranean' variety of capitalism.[10]

H&S (pp. 20–21) show that LMEs and CMEs do not differ too much in terms of their economic performance. The levels of GDP per capita and the growth rates of GDP are in the same order of magnitude. Unemployment rates, though, are generally higher in LMEs. In general, the distribution of income is much more unequal in LMEs and average working hours are longer. Unfortunately, the H&S hypothesis concerning the nature of innovation in the two varieties was tested using data for two countries only, as we will explain below.

H&S (pp. 36–41) develop sensible arguments why LMEs should be relatively good at developing radical innovations. However, they neither give a clear definition of radical innovations, nor of incremental innovation. They indicate that radical innovation "*entails substantial shifts in product lines, the development of entirely new goods, or major changes to the production processes* (...)" (Hall and Soskice, 2001, pp. 38–39), whereas incremental innovation is "*marked by continuous but small-scale improvements to existing product lines and production processes*" (Hall and Soskice, 2001, p. 39). Although most economists of innovation will agree that these descriptions do at least reflect the most important aspects of widely accepted definitions of the two archetypes of innovation, only few will support the operationalization of these descriptions chosen by H&S.

H&S stated that radical innovation is particularly important for dynamic technology fields, such as biotechnology, semiconductors, software, and telecommunications equipment. They associated incremental innovation with technology fields like machine tools, consumer durables, engines and specialized transport equipment. To test their hypothesis, H&S compared the technological specialization patterns of a typical LME (the United States) and a typical CME (Germany). They found that the European Patent Office granted relatively many patents in dynamic technology fields to US inventors, and relatively many patents in technology fields associated to incremental innovations to German inventors. These findings were presented as evidence in favor of H&S's central hypothesis.

One of the widely accepted facts about innovations is that their impacts are characterized by skewness. Even in technologically dynamic sectors, many innovations do not affect the profitability and/or stock market valuation of firms (see Scherer et al., 2000). An indication that many innovations do not have an impact in a technological sense was provided by Trajtenberg (1990). He showed that almost half of all patents ever granted up to 1982 in the once technologically dynamic field of computed tomography (CT) scanners were never cited in subsequent patents. As will be discussed below, this is a strong sign that such patents were not radical at all, even though they belong to a field that would most probably have been associated to radical innovation by H&S.

The Neo-Schumpeterian/evolutionary theory on innovation also stresses that technologies cannot be associated with radical innovations alone. Dosi (1982), for example, argues that technologies, like science, are sometimes subject to paradigm shifts. These shifts are characterized by the emergence and diffusion of one or a few radical innovations. Afterwards, bunches of minor innovations take place along the lines of the new technological trajectory. Together, these might yield substantial gains in terms of productivity, but they are of an incremental nature. Similar arguments can be found in Utterback and Abernathy (1975). H&S's claim that specialization of LMEs in radical innovation is remarkably stable over time (they studied the 1983–1984 and 1993–1994 periods) is at odds with the literature, given that they studied technological specialization across fields rather than within fields. Although formal investigations into this issue are beyond the scope of this paper, we feel that H&S's empirical analysis tells much more about economic specialization patterns than about technological specialization. Finally, ever since Schumpeter (1942) introduction of the term "creative destruction", radical innovations have had a connotation of being very pervasive, i.e., affecting technological change and production processes in many different industries. This aspect of radicality cannot be appropriately addressed by the type of analysis H&S opted for.

In this section we introduced the reader to the main hypothesis in the influential piece by H&S. We do not question the arguments underlying this hypothesis. Nevertheless, we are not convinced by the empirical support for the hypothesis given by H&S. This opinion was shared by Taylor (2004), who also criticized H&S for their choice to test a general conjecture based on two countries (of which the US is often considered to be an outlier) and for their neglect of technology life cycles. As far as we are aware, the present article is the first to address radicality in a multidimensional way, also stressing pervasiveness across technologies and industries.

## 3. Tests based on patent citation indicators

This paper contributes to the relatively recent literature that attempts to capture the importance of innovations by means of patent citation data. In one of the pathbreaking articles in this tradition, the basic source of information is succinctly described as follows:

*"If a patent is granted, a public document is created containing extensive information about the inventor, her employer, and the technological antecedents of the invention, all of which can be accessed in computerized form. Among this information are "references" or "citations". It is the patent examiner who determines what citations a patents must include. The citations serve the legal function of delimiting the scope of the property right conveyed by the patent. The granting of the patent is a legal statement that the idea embodied in the patent represents a novel and useful contribution over and above the previous state of knowledge, as represented by the citations. Thus, in principle, a citation of Patent X by Patent Y means that X represents a piece of previously existing knowledge upon which Y builds."* (Jaffe et al., 1993, p. 580)

As was first confirmed by Trajtenberg (1990), patents that are often cited by later patents are more important than patents that

[10] The 'Mediterranean' variety of capitalism features strong reliance on non-market mechanisms in corporate finance and a focus on market mechanisms in labor relations. The classification of countries can be found in Table 2. In line with H&S, we excluded CME Iceland from the statistical analysis, as a consequence of which it does not appear in the table.

are virtually never cited. Of course, this importance depends on the question whether inventors were really aware of the knowledge claimed in earlier patents. An affirmative answer to this question is not warranted, since it is not the patentee who includes citations, but an expert employee of the patent office. In a recent paper, however, Jaffe et al. (2000) use results of surveys among inventors to conclude that citations do give indications (although noisy ones) of spillovers from the cited invention to the citing invention.

### 3.1. Indicators of radicality

In this paper, we will use data contained in the NBER Patent-Citations Data File to distinguish between radical and incremental innovations, like Taylor (2004) did. The general idea is that patents that are "important" according to a number of citation-based indicators are more likely to represent radical innovations than patents that report average or below-average importance. Three measures of importance will be studied, "number of citations received", "measure of generality" and "measure of originality". The first measure was introduced by Trajtenberg (1990), the latter two by Trajtenberg et al. (1997). Since the database also contains records for the variable "country of first inventor", we can study which countries specialize in radical patents and which do not, for each of the dimensions of radicality.

We will denote the indicator "number of citations received" by NCITING, in line with the notation adopted by Trajtenberg et al. (1997). This indicator simply supposes that a patent that is cited more often than another one has had more impact on subsequent technological developments and can therefore be seen as more radical.[11]

As was argued in the previous section, many notions of radical innovation stress its property of pervasiveness, i.e., the feature that many industries and/or technological fields are affected by the innovation after the innovation itself and the knowledge associated with it have started to diffuse (see Lerner, 1994). This aspect of importance is captured by the indicator GENERAL, which was defined by Trajtenberg et al. (1997, p. 27) as follows:

$$\mathrm{GENERAL}_i = 1 - \sum_{k=1}^{N_i} \left( \frac{\mathrm{NCITING}_{ik}}{\mathrm{NCITING}_i} \right)^2 \qquad (1)$$

The second term on the right hand side is basically a Herfindahl index, in which $N_i$ stands for the number of different patent classes (indicated by $k$) from which patent $i$ received citations. The indicator always takes on values between 0 and 1, and high values represent strong pervasiveness.[12] Equation (1) cannot be used for patents that did not receive a single citation. In such cases we assigned a zero value to the indicator GENERAL.

Finally, we consider a measure that does not relate to the number or diversity of patents citing the patent under study, but the diversity of patents it is citing itself. If patents from several technological classes are cited in a patent, it is quite likely that many different types of knowledge had to be "combined" in order to come up with the patented innovation (see, e.g., Shane, 2001). Such fusion technologies can be seen as radical rather than incremental, because incremental innovations generally require improvements with respect to one or a few technological fields. In line with Trajtenberg et al. (1997, p. 29), we use the indicator ORIGINAL, which is also expressed in terms of a Herfindahl index:

$$\mathrm{ORIGINAL}_i = 1 - \sum_{k=1}^{N_i} \left( \frac{\mathrm{NCITED}_{ik}}{\mathrm{NCITED}_i} \right)^2, \qquad (2)$$

where $\mathrm{NCITED}_{ik}$ represents the number of patents in technology class $k$ cited by the patent for which the radicality is assessed. In line with our treatment regarding the GENERAL indicator of patents receiving no citations, we assign a zero value to the ORIGINAL indicator if a patent does not contain any reference to earlier patents.

### 3.2. Construction of radicality quantiles

We will define radical innovations using rankings of patents based on the three indicators discussed above. Patents that have a high score as compared to other patents will be considered as radical ones. At least two important caveats apply, however.

First, propensities to patent innovations vary strongly across industries, which consequently has implications for received citations (especially from subsequent patents granted to firms in the same industry). Using a European dataset, Verspagen and de Loo (1999) found average received citations to patents ratios ranging from 0.39 in the shipbuilding industry to 1.16 in the computer manufacturing industry. Hall et al. (2002) presented qualitatively similar results for American patents. Substantial parts of these differences seem to be due to varying industry-specific abilities of patents to act as (i) a way to prevent competitors from outright imitation, (ii) a way to force other firms into negotiations (often about cross-licensing) or (iii) a way to have potential competitors changing their technological strategies, by "fencing" or "blocking" (see Cohen et al., 2000).

Second, not all citations are received at once. Verspagen and de Loo (1999) reported that the (skewed) distribution of citations to patents issued by the European Patent Office applied for between 1979 and 1997 had a mean lag of 4.67 years. Based on citations to USPTO patents issued during a much longer period, Hall et al. (2002) even found mean lags of up to 16 years. The consequence of the often long lags is that relatively new patents will often have received fewer citations (and/or citations in fewer technological fields) than older patents. Another issue that precludes reasonable comparisons of citation-based indicators across years relates to observed increasing propensities to cite. As Hall et al. (2002) argued, increased computerization of the patent system led to less time-consuming queries by patent examiners, as a consequence of which the citations to patent ratios rose considerably in the 1980s.

To deal with these differences, we base our rankings on industry-specific cohorts of patents applied for in a given year. That is, we first construct quantiles for patents associated with industry $i$ applied for in year $t$. Now, we can define the patents in the 10th decile as radical innovations.[13] We represent the number of these patents granted to inventors in country $k$ by $n_{it}^{*k}$. Next, useful aggregations can be obtained by summing over appropriate indexes. The number of important innovations produced by country $k$ in year $t$,

[11] In an early study, Albert et al. (1991) already offered evidence that NCITING and experts' valuation of patented innovations correlate positively.

[12] As is indicated in the appendix of Hall et al. (2002), this measure of generality is biased downwards if it is based on small numbers of citations. The data we use in this study have been corrected for this bias. This also holds for the originality indicator proposed below.

[13] Of course, it is rather arbitrary to define the bottom 90 percent of innovations as incremental and the top 10 percent as radical. Below, we will also report some analyses based on a 95/5 percent division. We will also use analytical techniques that take the whole set of quantiles into account, without an explicit borderline between incremental and radical innovations. In future work, it might be interesting to use analytical techniques that study distributional characteristics to discern radical innovations from incremental innovations. Techniques explored by Silverberg and Verspagen (2007) offer a good point of departure (see Castaldi and Los, 2008, for some industry-level explorations).

**Table 1**
Hypothetical contingency table.

| Quantiles | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Country A | 190 | 170 | 150 | 130 | 110 | 90 | 70 | 50 | 30 | 10 | 1000 |
| Country B | 5 | 15 | 25 | 35 | 45 | 55 | 65 | 75 | 85 | 95 | 500 |
| Total ($N_i$) | 195 | 185 | 175 | 165 | 155 | 145 | 135 | 125 | 115 | 105 | 1500 |
| Score ($a_i$) | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |

for example, can be defined as $n_t^{*k} \equiv \sum_{i=1}^{m} n_{it}^{*k}$ (with $m$ standing for the number of industries), and the number of important innovations produced by industry $i$ in country $k$ over the entire period can be written as $n_i^{*k} \equiv \sum_{t=1}^{T} n_{it}^{*k}$ (with $T$ representing the number of years). For some analytical techniques described below, frequencies of incremental innovations are also required. The notation will be equivalent, but asterisks will be reserved for radical innovations. The number of patents related to incremental innovations granted to inventors in country $k$ will thus be indicated by $n_{it}^{k}$.

### 3.3. Analytical techniques

We will basically use three techniques to analyze the question whether LMEs do indeed specialize in radical innovations, as was contended by H&S. The first two techniques mainly serve descriptive goals, the third one enables us to produce a statistically sound verdict. First, we will present "Revealed Comparative Technological Advantages" (RCTAs), which are defined in the same vein as Revealed Comparative Advantages used in empirical analyses of trade patterns. For industry $i$, country $k$'s RCTA is defined as

$$\mathrm{RCTA}_i^k = \frac{n_i^{*k}/(n_i^{*k} + n_i^k)}{\sum_{k=1}^{C} n_i^{*k} / \sum_{k=1}^{C} (n_i^{*k} + n_i^k)} \tag{3}$$

RCTAs can also be computed for specific time periods or for aggregate economies (and even groups of economies such as the class of CMEs) by choosing appropriate summations. RCTAs defined as in equation (3) always yield nonnegative values. Values smaller than 1 indicate "negative specialization" in the generation of important patents, values greater than 1 point to specialization. A problem with this conventional way of presenting degrees of specialization is that negative specializations are compressed into the $[0,1\rangle$ interval, while positive specialization are spread over $\langle 1,\infty\rangle$. To report degrees of specialization in a symmetric fashion, we will always present the natural logarithms of the RCTAs. This type of analysis is very comparable to what H&S used as their informal test. The fundamental difference between their reliance on patents by industry to define radical innovations and our reliance on citation indicators remains, however. The central H&S hypothesis suggests higher values of the logs of the RCTAs for LMEs than for CMEs.

Our second technique to depict positive or negative specialization does not rely on a single boundary between incremental and radical innovations. We will present histograms in which the quantiles of radicality are depicted on the horizontal axis. The height of the bars indicate the relative frequencies of patents belonging to these quantiles as granted to inventors in the country or group of countries of interest. If the country would show no specialization in innovations of a specific importance decile, all bars would be equally high (i.e., 0.10). In this case, the 10% least important patents issued by USPTO to any inventor in the world would account for exactly 10% of the total number of patents awarded to this country. If the H&S hypothesis is true, LMEs would yield patterns with a more positively or less negatively sloping set of bar heights, depending on the specialization of countries that got patents granted but are not included in the analysis.

The RCTAs and diagrams with relative frequencies can sketch insightful pictures, but do not provide us with opportunities to test whether observed differences between LMEs and CMEs are statistically significant. In that respect, we would not gain anything in comparison to H&S. To test for differences in the innovation specialization of two countries or groups of countries, we could use a standard $\chi^2$ test based on contingency tables. Such a test compares the actually observed frequencies for all cells of the table (i.e., frequencies of patents included in the defined quantiles for the respective countries) with the expected frequencies under the null hypothesis of no differences in specialization. As is well known from the literature on categorical data analysis (see, e.g., Agresti, 2002) this test is only appropriate if none of the two dimensions of the table can be ordered in any reasonable way. In our case, however, the quantiles represent categories that can be measured on an ordinal scale: the tenth decile is closer to the ninth decile than to the third. The statistical test we use to avoid this problem was originally proposed by Bhapkar (1968). It is also based on observed and expected frequencies in contingency tables. An example of such a table is given in Table 1.

It is assumed that country A got granted twice as many patents as country B. If we denote the unknown probability that a random observation from the $j$th sample ($j$ = country A, country B) belongs to the $i$th category ($i$ = 1, . . ., 10) by $\pi_{ij}$, we might formulate our null hypothesis as $H_0$: $\sum_i a_i \pi_{ij}$ is independent of $j$. In this expression is $a_i$ the "score" assigned to category $i$.[14] $H_0$ thus implies that the mean scores are identical for the two countries or groups of countries.

The Bhapkar (1968) test involves the computation of a test statistic that should be compared with a critical value from a $\chi^2$ distribution with 1 degree of freedom (if two countries are compared; in the general case the number of degrees of freedom is equal to the number of samples minus one). Let $p_{ij} = n_{ij}/N_j$, that is, the observed frequencies divided by the row totals. Now, the sample analogs of the population means are $A_j = \sum_i a_i p_{ij}$. If we write $w_j = N_j/B_j$, with $B_j = \sum_i (a_i - A_j)^2 p_{ij}$, Bhapkar (1968, p. 331) shows that the generalized least square technique now yields a large sample test statistic $X = \sum_j w_j A_j^2 - C^2/w$, with $C = \sum_j w_j A_j$ and $w = \sum_j w_j$. If the null hypothesis of a common mean cannot be rejected, the corresponding estimate for this mean equals $C/w$.[15]

[14] The choice of scores is somewhat arbitrary. In the bottom row of Table 1, equidistant scores have been indicated. In the analysis below, we will experiment with an alternative score setup, that stresses the importance of observations in higher deciles to a substantial extent.

[15] The hypothetical samples from country A and country B would yield an $X$-statistic of 656.7, which is well above the 5% critical value of 3.84 taken from the $\chi^2$ distribution with 1 d.f. Thus, the assumption that the patents of country A and country B have an equal mean radicality should be rejected.

**Table 2**
Revealed Comparative Technological Advantages (in logarithms)[a].

| | #Patents[b] | 10%[c] | | | 5%[c] | | |
|---|---|---|---|---|---|---|---|
| | | NCIT | GEN | ORI | NCIT | GEN | ORI |
| LMEs | 117.5 | −0.22 | −0.12 | −0.11 | −0.27 | −0.16 | −0.18 |
| Australia | 9.0 | −0.45 | −0.29 | −0.30 | −0.47 | −0.37 | −0.32 |
| Canada | 39.5 | −0.14 | −0.09 | −0.11 | −0.18 | −0.11 | −0.16 |
| Ireland | 0.9 | −0.18 | +0.13 | +0.05 | −0.40 | +0.15 | +0.36 |
| New Zealand | 1.1 | −0.81 | −0.35 | −0.53 | −1.02 | −0.56 | −0.60 |
| UK | 66.9 | −0.23 | −0.12 | −0.07 | −0.28 | −0.16 | −0.17 |
| US | 1189.7 | +0.16 | +0.13 | +0.18 | +0.19 | +0.16 | +0.19 |
| CMEs | 615.9 | −0.26 | −0.22 | −0.34 | −0.34 | −0.28 | −0.39 |
| Austria | 7.9 | −0.68 | −0.40 | −0.39 | −0.83 | −0.47 | −0.53 |
| Belgium | 7.9 | −0.31 | −0.28 | −0.27 | −0.37 | −0.32 | −0.43 |
| Denmark | 4.7 | −0.41 | −0.30 | −0.31 | −0.37 | −0.37 | −0.46 |
| Finland | 5.5 | −0.39 | −0.33 | −0.34 | −0.42 | −0.44 | −0.38 |
| Germany | 167.5 | −0.46 | −0.29 | −0.28 | −0.56 | −0.36 | −0.35 |
| Japan | 347.3 | −0.14 | −0.16 | −0.39 | −0.21 | −0.21 | −0.41 |
| Netherlands | 19.8 | −0.44 | −0.42 | −0.31 | −0.53 | −0.49 | −0.37 |
| Norway | 2.7 | −0.56 | −0.30 | −0.19 | −0.55 | −0.60 | −0.36 |
| Sweden | 20.5 | −0.31 | −0.19 | −0.23 | −0.37 | −0.28 | −0.37 |
| Switzerland | 32.1 | −0.40 | −0.26 | −0.16 | −0.47 | −0.30 | −0.29 |
| MMEs | 92.3 | −0.54 | −0.38 | −0.29 | −0.66 | −0.47 | −0.37 |
| France | 64.3 | −0.50 | −0.32 | −0.21 | −0.60 | −0.40 | −0.27 |
| Greece | 0.2 | −0.77 | −0.49 | −0.24 | −0.98 | −0.19 | −1.15 |
| Italy | 24.9 | −0.62 | −0.52 | −0.48 | −0.75 | −0.65 | −0.62 |
| Portugal | 0.1 | −0.30 | −0.81 | −0.82 | +0.01 | −0.81 | $-\infty$ |
| Spain | 2.7 | −0.93 | −0.75 | −0.82 | −1.28 | −0.96 | −0.91 |
| Turkey | 0.1 | −1.70 | −1.70 | −0.62 | −1.01 | $-\infty$ | $-\infty$ |

[a] Positive values indicate specialization towards radical innovation, negative values reflect specialization towards incremental innovation (see Section 3.3).
[b] #Patents refers to the total number of patents (in thousands) granted to inventors in the (groups of) countries listed, in the period 1970–1995. In constructing the ORIGINAL indicator, only patents granted in 1975 and later can be used, as a consequence of which fewer patents were used to compute the values in the columns titled ORI.
[c] *x*% indicates that for each industry in each year, the *x*% most important patents were considered to represent radical innovations.

## 4. Data issues

As mentioned above, our main source of data is the NBER Patent-Citations Data File, which contains data on patent citations in the period 1975–1999 to all utility patents granted by the US Patent Office in the period 1963–1999. For the present analysis, we used the large subset of these patents applied for in the somewhat shorter period 1970–1995, to avoid possible problems concerning citation lags (see Section 3.2). The dataset contains nearly 2.1 millions of patents, of which nearly 0.9 millions were granted to inventors outside the US. These patents also include patents granted to individuals and governments, but more than 75% were awarded to non-governmental organizations (corporations and universities).[16]

The radicality indicators as taken from the same source are based on citations included in patents granted from 1975 to 1999. Hall et al. (2002) report that more than 16.5 millions of citations were involved in the underlying computations. Self-citations (i.e., citations to previous patents granted to the same organization) are included. The GENERAL and ORIGINAL indicators of radicality were constructed on the basis of citations from and to patents classified into 426 3-digit original patent classes. As we will see below, this classification is much more fine-grained than the 42-industry classification we use to study specialization patterns. This implies that it is very well possible that very general innovations did have technological consequences in one or only a few industries as defined below. We do not consider this as a problem, because patents with a high GENERAL indicator will have had a more widespread impact within such an industry than a patent with a low value for GENERAL. As such, the former patent can still be considered as more radical than the latter.

We assign patents to industries by means of OTAF classification codes contained in US patents. These codes are not contained in the NBER Patent-Citations Datafile, but we could easily match the industry codes in USPTO's PATSIC-CONAME database to the citation data. The OTAF classification assigns patents to one or more industries that are most likely to use the patented process or to manufacture the patented invention. To this end, a concordance was set up that maps 124,000 USPC classes onto 41 fields, plus one "other industries" category. Thus, at the most detailed level, 42 industries are discerned.[17] This is also the classification we use for the purpose of this paper. The full classification can be found in Appendix A.

An issue we had to deal with is that 30% of the patents examined by USPTO were assigned to multiple SIC codes. Actually, some patents got as many as seven codes. In studies like these, two approaches can be adopted. If the "whole counts" approach is chosen, the patent count for all $z$ SICs concerned is increased by one. This approach emphasizes the nonrival nature of knowledge, in the sense that the usefulness of a patent for a given industry is not necessarily reduced if other industries could also benefit from it. A drawback is that if one would like to aggregate patent counts over industries, one ends up with more patents than have been granted to inventors in that country. This disadvantage is avoided by the second approach, "fractional counting". This approach amounts to adding $1/z$ to patent counts of SICs assigned to the patent. This implies that the patent is "shared". We opted for the fractional

[16] See Hall et al. (2002, p. 413) for details.

[17] See Hirabayashi (2003) for an overview of issues related to the principles underlying the PATSIC database. Griliches (1990, p. 1667) was quite critical about early versions of the OTAF classification, but improvements have been sizeable.

counting method, because we would encounter problems in assigning patents to radicality quantiles if a patent would fall in the *x*th quantile for one industry and in the *y*th quantile for another relevant one. Results for aggregate economies would be flawed, because either the recorded number of patents would be higher than the actual number, or the deciles would not be represented equally in the population of all patents granted by USPTO.[18]

## 5. Empirical results

### 5.1. Revealed Comparative Technological Advantages

As a first indication for the empirical validity of the H&S hypothesis, we consider the logarithms of the Revealed Comparative Technological Advantages given by equation (3). We present two sets of results for each of the three radicality indicators. In Table 2, the columns in the left panel give specialization patterns for the case in which radical innovations are defined as belonging to the 10th deciles. The three columns in the right panel are computed for a stricter definition of radical innovation. Only those patented innovations that are among the top 5% of patents filed in a year for an industry in terms of importance are considered to be radical.

In general, the results are quite robust for the choice of upper quantiles defining radicality. Countries that are specialized in radical innovation in the left panel show a similar specialization in the right panel. Quite often, the specialization patterns are somewhat more pronounced if radical innovations are defined in a stricter sense. The results are also robust for the indicator of radicality chosen. Most countries appear to have experienced a negative specialization in radical innovation for NCITING, GENERAL and ORIGINAL. The only two countries for which the direction of specialization is dependent on the indicator are Ireland and Portugal. For the latter country, this result might be a statistical artefact, due to the very small number of patents granted to inventors residing in this country.

Besides the United States, Ireland is also the only country for which some indication of a specialization in radical innovation is found. For the set of LMEs, we find specialization in incremental innovations. It should be stressed, however, that we excluded the US from the LME category, unlike H&S. We did this for two reasons. First, the decision to apply for a patent is likely to differ between the home market and foreign markets (see Jung and Imm, 2002). It could well be that inventors decide first to patent at the domestic patent office to get acknowledged as being a 'technically capable inventor'. Applications for foreign patents are more often done after an evaluation of the potential commercial value of such a patent. Hence, domestic patents are often thought to be of an inferior quality, on average. Second, we feel that the validity of H&S's hypothesis should not hinge on one country (see also Taylor, 2004). The United States is often considered to be the world's technological leader. This might of course be due to their early LME-character, but it appears sensible to us to consider the US as a special case.[19]

Before looking at the three varieties of capitalist economies as discerned by H&S, it is useful to assess the effects of the US on the results. This country shows a specialization in radical innovation, which runs counter to the Jung and Imm argument discussed above. Given the large fraction of all patents granted by USPTO to inventors in the US (see the first column of Table 3), it is to be expected that most other countries will appear to be specialized in incremental innovation. This appears to hold for the group of LMEs as well. The negative values are closer to zero, however, than the RCTAs found for the group of CMEs. This can be seen as provisional evidence in favor of H&S. The mixed type of capitalist economies appears to be most strongly specialized in incremental innovation.

Inspection of the RCTAs for individual countries leads us to conclude that the specialization patterns vary quite a bit across countries belonging to a given type of economy. In line with Taylor (2004), we find that New Zealand and, to a lesser extent, Australia are outliers among the LMEs. These countries turn out to have a specialization pattern that is closer to that of a typical CME. The opposite holds for CME Japan. It might be that this is due to an argument put forward by Archibugi and Pianta (1992), who contended that large economies tend to be less specialized in specific technology fields than small countries, because the latter do not have the resources to diversify their activities to the same extent. We feel, though, that this argument is much weaker in the present context. A small country with a strong specialization in communication technology, for example, would not waste resources by pursuing radical and incremental innovations simultaneously.[20] The heterogeneity within varieties of capitalism is a first indication against the H&S hypothesis, which suggests homogeneous LMEs vs. homogeneous CMES.

Before turning to results for methods that view the radical vs. incremental innovation distinction not as a binary issue but as a matter of gradual differences, we would like to stress that the RCTAs presented in Table 3 are computed for aggregate economies. Similar indicators can also be calculated at the industry level. For reasons of brevity, we will not document all results here, but restrict the exposition to a few selected industries (that can be seen as covering substantial parts of the manufacturing sector), the top 10% definition and the NCITING indicator only. The results are documented in Table 3.

Although we will postpone formal statistical analysis concerning differences among populations based on samples until Section 5.3, we can infer from Table 3 that LMEs other than the US do not systematically show RCTAs that indicate a stronger specialization in radical innovation. In four of the eight selected industries, CMEs tend to be more directed towards generating radical innovations.

### 5.2. Histograms for radicality distributions

To describe more general technological specialization patterns, we present three histograms. The relative frequencies of patents belonging to deciles of the entire population of all patents granted by USPTO defined using the NCITING indicator are depicted in Fig. 1.

The four (groups of) economies exhibit clear specialization patterns, in the sense that the heights of the bars are either monotonically increasing or decreasing. The specialization in more radical innovations by the US already apparent from Table 2 is strongly confirmed by the graph. The US are not only 'overrepresented' in the top 10% and top 5% patents, but also in less outspoken important innovations. The opposite holds for economies of the Mediterranean variety of capitalism. Fig. 1 indicates that the LMEs (excluding the US) and the CMEs considered as groups have rather similar specialization patterns. LMEs did obtain relatively many very unimportant patents, but also many very important patents. In the intermediate deciles, CMEs are relatively strongly represented.

[18] The latter problem would occur if we would decide to assign the patent to the highest decile found across the industries to which it is assigned by the PATSIC data.

[19] One could also invoke their unequalled government-sponsored defence-related technological activities as an argument to consider the US as a non-representative LME.

[20] An effect of size is clearly present for Portugal. This country did not produce a single patent that belonged to the 5% most important USPTO patents in terms of generality. Consequently, its specialization in such innovations appears to be minus infinity.

**Table 3**
Revealed Comparative Technological Advantages (in logarithms), selected industries. Radicality indicator: NCITING[a].

| Industry[b] | 5 Plastics | 10 Drugs | 15 Nonferrous metals | 20 Metal working machinery | 25 Miscellaneous machinery | 30 Miscellaneous electrical machinery | 35 Ships | 40 Aircraft |
|---|---|---|---|---|---|---|---|---|
| LMEs | −0.093 | −0.219 | −0.132 | −0.193 | −0.172 | −0.008 | −0.229 | −0.390 |
| CMEs | −0.267 | −0.482 | −0.420 | −0.082 | 0.052 | −0.469 | −0.143 | 0.172 |

[a] Positive values indicate specialization towards radical innovation, negative values reflect specialization towards incremental innovation (see Section 3.3). LMEs do not include the US.
[b] Results for the full set of industries can be obtained from the authors.

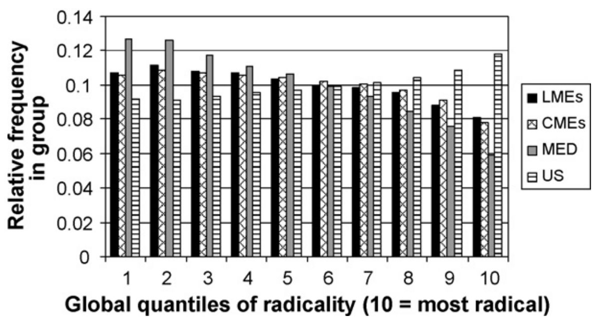


**Fig. 1.** Technological specialization patterns (Radicality indicator: NCITING).

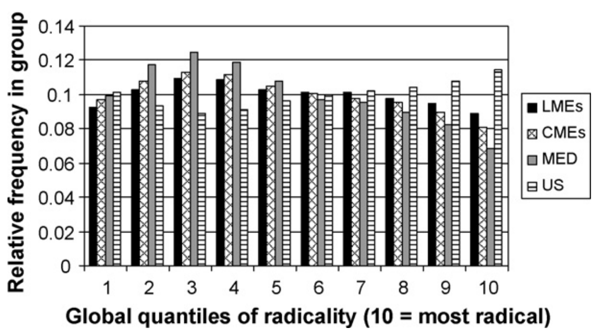


**Fig. 2.** Technological specialization patterns (Radicality indicator: GENERAL).

Although visual inspection indicates some differences in specialization patterns between LMEs and CMEs, we do not find strong evidence in favor of the H&S hypothesis.

Figs. 2 and 3 present similar distributions as Fig. 1, but for the GENERAL and ORIGINAL indicators, respectively.

The distributions indicate that there are noticeable differences between importance measured according to the three proposed indicators. With regard to ORIGINAL, LMEs seem to be much more specialized in radical innovation than CMEs. Concerning the GENERAL indicator, the distributions for the LMEs and CMEs group is much more alike Fig. 1 for NCITING. The distributions for MMEs and the US are not sensitive in a qualitative sense to the indicator type chosen.

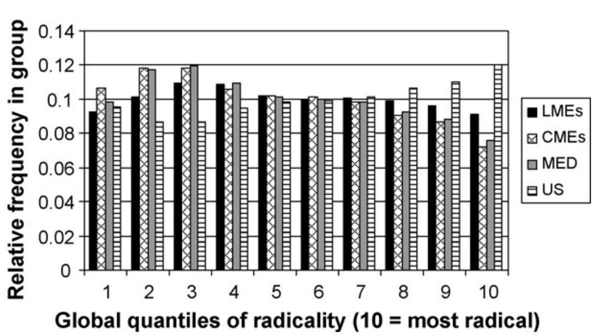


**Fig. 3.** Technological specialization patterns (Radicality indicator: ORIGINAL).

### 5.3. *Statistical tests on equality of distributions*

So far, we used descriptive statistics to study the validity of the H&S hypothesis. In this subsection, we turn to the results for Bhapkar's (1968) test outlined in Section 3. Table 4 presents results for pairwise comparisons of radicality distributions for the aggregates of the four groups of countries for which the distributions are depicted in Figs. 1–3. As we mentioned in our discussion of the test, results might be sensitive to the scores assigned to each decile (see Agresti, 2002). Therefore, we present results for two sets of scores. The left panel is obtained by using a "linear" (or "equidistant") set of scores. That is, we assigned a score $a_i = i$ to each of the deciles. For the rightmost panel, we adopted a scoring system that weighs patents in the very important deciles more heavily. We assigned scores $a_i = i^2$ to decile $i$. Cells in the table contain the letters referring to the (group of) countries that turned out to be the most radical of the countries corresponding to the rows and columns, respectively. Significance levels are indicated by the number of asterisks. Thus, C*** in the upper left cell indicates that CMEs were more specialized in radical innovation than LMEs at a significance level of 1%, if linear scores are used and the radicality indicator is NCITING.

Overall, the results are rather robust for alternative sets of scores. Furthermore, the differences are highly significant. The US turns out to be most strongly specialized in radical innovation, irrespective of the radicality indicator considered. MMEs are consistently found to be least specialized in radical innovation, with one major exception:

**Table 4**
Pairwise comparisons of radicality distributions (aggregate manufacturing sector)[a].

| | Linear scores | | | Quadratic scores | | |
|---|---|---|---|---|---|---|
| | CMEs | MMEs | US | CMEs | MMEs | US |
| Citations received | | | | | | |
| LMEs | CME** | LME*** | US*** | CME* | LME*** | US*** |
| CMEs | | CME*** | US*** | | CME*** | US*** |
| MMEs | | | US*** | | | US*** |
| Generality | | | | | | |
| LMEs | LME*** | LME*** | US*** | LME*** | LME*** | US*** |
| CMEs | | CME*** | US*** | | CME*** | US*** |
| MMEs | | | US*** | | | US*** |
| Originality | | | | | | |
| LMEs | LME*** | LME*** | US*** | LME*** | LME*** | US*** |
| CMEs | | MME*** | US*** | | MME*** | US*** |
| MMEs | | | US*** | | | US*** |

[a] Cells in the table refer to the (group of) countries that appear to be the most radical innovators in pairwise comparisons of the countries in corresponding rows and columns, respectively.
* Significant at 10%.
** Significant at 5%.
*** Significant at 1%.

**Table 5**
Differences in radicality between LMEs and CMEs (by Industry)[a].

| | | NCIT | GEN | ORI | | | NCIT | GEN | ORI |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Food | L*** | | L** | 22 | Special industry machinery | C*** | | L*** |
| 2 | Textiles | | L** | L*** | 23 | General industrial machinery | C*** | C** | L*** |
| 3 | Inorganic chemistry | | | L*** | 24 | Refrigeration machinery | | | |
| 4 | Organic chemistry | L*** | L*** | L*** | 25 | Miscellaneous non-electrical machinery | C*** | | |
| 5 | Plastics | | | L*** | 26 | Electrical transmission machinery | | | L*** |
| 6 | Agricultural chemicals | L*** | L*** | L*** | 27 | Electrical industrial apparatus | C*** | | L*** |
| 7 | Soaps | L*** | | | 28 | Household appliances | | L*** | L*** |
| 8 | Paints | | | L*** | 29 | Electrical lighting | C*** | | |
| 9 | Miscellaneous chemicals | | C** | | 30 | Miscellaneous electrical machinery | L*** | L*** | L** |
| 10 | Drugs | L*** | L*** | L*** | 31 | Radios and TVs | | L*** | |
| 11 | Oil and gas | | C*** | | 32 | Electronic components | C** | L*** | L*** |
| 12 | Rubber | | | L*** | 33 | Motor vehicles | C*** | C*** | |
| 13 | Stone and glass | | C* | L* | 34 | Missiles | | | L* |
| 14 | Primary ferrous products | | | L** | 35 | Ships and boats | | | |
| 15 | Non-ferrous metals | L** | | L*** | 36 | Railroad equipment | | | |
| 16 | Fabricated metal products | C** | C*** | | 37 | Motorcycles, bicycles and parts | C*** | C*** | C** |
| 17 | Engines | C*** | | L*** | 38 | Miscellaneous transport equipments | C*** | C*** | C* |
| 18 | Farm machinery | | C*** | C** | 39 | Ordinance | L*** | L*** | L*** |
| 19 | Construction machinery | | C*** | | 40 | Aircraft | C*** | C** | L*** |
| 20 | Metal working machinery | C*** | | L*** | 41 | Instruments | C* | L*** | L*** |
| 21 | Office machinery | L*** | L*** | L*** | 42 | Miscellaneous | | | L*** |

[a] L indicates significantly stronger specialization towards radical innovation in LMEs than in CMEs. C indicates significantly stronger specialization towards radical innovation in CMEs than in LMEs. Blank cells indicate no significant difference in radicality between LMEs and CMEs. LMEs do not include the US. The Bhapkar test was performed using linear scores.

* Significant at 10%.

** Significant at 5%.

*** Significant at 1%.

if the ORIGINAL indicator is chosen, MMEs are significantly more radical innovators than CMEs.

Of course, the results for comparisons between LMEs and CMEs are the most interesting from the perspective of this paper. In general, these results for the aggregate manufacturing sector seem to confirm the H&S hypothesis. For the GENERAL and ORIGINAL indicators, LMEs are clearly more specialized in producing radical innovations. A different picture is found for NCITING, however. In our discussion of Fig. 1, we already indicated that LMEs showed high relative frequencies (as compared to CMEs) for virtually non-cites and very highly cited patents. This phenomenon is reflected in the test results. If very important patents do not weight very heavily (like in the set of linear scores) CMEs appear as more specialized in radical innovations than LMEs, although significance is weaker than for other pairwise comparisons in Table 4. Using scores in which very highly cited patents get more weight (like in the set of quadratic scores), we find that the significance is reduced even further.

We now turn to Bhapkar tests for comparisons of specialization patterns at the industry level. Our discussion of RCTAs already indicated that results for aggregate economies (or groups of them) could well hide strongly heterogeneous patterns at a lower level of aggregation. Table 5 presents results for comparisons of specialization patterns of LMEs and CMEs for all 42 industries that we can distinguish. To save space, we report results for the linear set of scores. For an overwhelming majority of comparisons, application of quadratic scoring yielded qualitatively identical results.

The results for ORIGINAL are very clear. In many industries, the group of LMEs is more specialized in radical innovation than the group of CMEs. Apparently, inventors in LMEs draw on a much broader base of technologies in producing new innovations. If radicality of innovations is defined in this way, strong support is found for the H&S hypothesis. This result does not carry over to the NCITING and GENERAL indicators, however. For these indicators, the results could best be described as a “mixed bag”. Generalizing the results somewhat, we find that LMEs are relatively more specialized in radical innovation in industries that produce chemicals and related products as well as in electronics industries. CMEs, however, appear to have an edge over LMEs in radical innovation concerning metals, machinery and transport equipment industries. Relative differences in the degree to which industries innovate and/or patent their innovations are thus responsible for the result that LMEs specialize more strongly in radical innovation if the aggregate manufacturing sector is studied.

To conclude our discussion of the empirical analysis, we feel that it offers much evidence against the H&S hypothesis. However, we do not refute the hypothesis as strongly as Taylor (2004) did. We found that countries belonging to a common variety of capitalism are very heterogeneous in their technological specialization patterns, which is in line with Taylor’s findings. We also found that LMEs and CMEs tend to reflect very heterogeneous specialization patterns at the level of industries. For some classes of industries, the H&S hypothesis is confirmed, for other classes the results run counter to the hypothesis. The main piece of strong evidence in favor of the H&S hypothesis was found for the indicator that regards innovations that merge knowledge from relatively many technological fields as radical. Hence, our industry-level analysis using indicators for multiple indicators of radicality lead us to the conclusion that H&S can certainly not be seen as a general law, but that Taylor’s outright rejection of the hypothesis is too strong.

## 6. Conclusions

This paper addressed the question whether Hall and Soskice’s (2001) hypothesis that ‘liberal market economies’ specialize in radical innovation while ‘coordinated market economies’ specialize in incremental innovation is true or not. We first indicated why we feel that H&S’s empirical analysis is flawed in several ways. Many of these flaws were also identified in an earlier critique by Taylor (2004). Next, we used US data on patent citations for an analysis that we not only consider to be more rigorous than H&S’s, but also as more extended than Taylor's.[21] We studied the hypothesis not only for the aggregate manufacturing sector, but checked its validity at the industry level as well. Furthermore, we did not only look at the number of citations received as an indicator of radicality, but also considered other dimensions: the extent to which a range of technologies was impacted by an innovation ("generality") and the extent to which the innovation itself drew together knowledge from several technologies ("originality").

We found that the H&S hypothesis should be rejected as a law that would apply to all industries and all dimensions of radicality. Not only do LMEs and CMEs constitute varieties of economies that represent quite diverse patterns of specialization, results also turned out to be quite heterogeneous across industries. With regard to the received citations indicator and the generality indicator, LMEs roughly specialized in radical innovations in industries related to chemicals and electronics, while CMEs did so in machinery and transport equipment industries. If we focus on the originality indicator, the H&S hypothesis is by and large confirmed. Hence, the truth appears to be somewhere in between the extreme results found by H&S on the one hand and by Taylor on the other.

The present analysis could well be broadened and deepened in future work. It should, for instance, be kept in mind that we only considered outputs of innovation processes, like Hall and Soskice did. Specialization in radical innovation does not necessarily mean that these countries are relatively good at producing such innovations. Theory might predict that we would find such a relation, but it might well be that governments play in important role in choices by private organizations to aim at radical innovations. In such cases, countries specialized in radical innovations could have relatively unproductive R&D processes, in terms of the number of radical innovations per unit of input.

Another interesting issue relates to the identification of radical innovations. In the computations of our Relative Comparative Technological Advantages, we used manufacturing-wide cutoff-points to assign innovations to either the class of incremental innovations or the class of radical innovations. This is a rather crude method. Recent advances in extreme value statistics might prove valuable in devising methods to come up with distribution-dependent cutoff points that also make sense from the viewpoint of the economics of innovation (see Silverberg and Verspagen, 2007; Castaldi and Los, 2008).

Finally, it might be worthwhile to study why specialization patterns vary strongly across countries. The specialization of CMEs towards radical innovation in machinery and transport equipment manufacturing might hint at a role for the cumulative nature of innovation processes.[22] In these industries, CMEs like Germany, Japan and Sweden have been leading in a technological sense for decades and might still draw on their base of knowledge in generating the most important innovations. This interpretation is highly speculative, however, and needs careful scrutiny using longitudinal analysis.

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## Appendix A

The table below contains the industry classification used, the OTAF and SIC codes, all taken from USPTO's PATSIC-CONAME datafile on CD-ROM.

| Nr. | Product description | OTAF code | SIC code |
|---|---|---|---|
| 1 | Food and kindred products | 20 | 20 |
| 2 | Textile mill products | 22 | 22 |
| 3 | Industrial inorganic chemistry | 281 | 281 |
| 4 | Industrial organic chemistry | 286 | 286 |
| 5 | Plastics materials and synthetic resins | 282 | 282 |
| 6 | Agricultural chemicals | 287 | 287 |
| 7 | Soaps, detergents, cleaners, perfumes, cosmetics and toiletries | 284 | 284 |
| 8 | Paints, varnishes, lacquers, enamels, and allied products | 285 | 285 |
| 9 | Miscellaneous chemical products | 289 | 289 |
| 10 | Drugs and medicines | 283 | 283 |
| 11 | Petroleum and natural gas extraction and refining | 1329 | 13, 29 |
| 12 | Rubber and miscellaneous plastics products | 30 | 30 |
| 13 | Stone, clay, glass and concrete products | 32 | 32 |
| 14 | Primary ferrous products | 331+ | 331, 332, 3399, 3462 |
| 15 | Primary and secondary non-ferrous metals | 333+ | 333–336, 339 (except 3399), 3463 |
| 16 | Fabricated metal products | 34- | 34 (except 3462, 3463, 348) |
| 17 | Engines and turbines | 351 | 351 |
| 18 | Farm and garden machinery and equipment | 352 | 352 |
| 19 | Construction, mining and material handling machinery and equipment | 353 | 353 |
| 20 | Metal working machinery and equipment | 354 | 354 |
| 21 | Office computing and accounting machines | 357 | 357 |
| 22 | Special industry machinery, except metal working | 355 | 355 |
| 23 | General industrial machinery and equipment | 356 | 356 |
| 24 | Refrigeration and service industry machinery | 358 | 358 |
| 25 | Miscellaneous machinery, except electrical | 359 | 359 |
| 26 | Electrical transmission and distribution equipment | 361+ | 361, 3825 |
| 27 | Electrical industrial apparatus | 362 | 362 |
| 28 | Household appliances | 363 | 363 |
| 29 | Electrical lighting and wiring equipment | 364 | 364 |
| 30 | Miscellaneous electrical machinery, equipment and supplies | 369 | 369 |
| 31 | Radio and television receiving equipment except communication types | 365 | 365 |
| 32 | Electronic components and accessories and communications equipment | 366+ | 366, 367 |
| 33 | Motor vehicles and other motor vehicle equipment | 371 | 371 |
| 34 | Guided missiles and space vehicles and parts | 376 | 376 |
| 35 | Ship and boat building and repairing | 373 | 373 |
| 36 | Railroad equipment | 374 | 374 |
| 37 | Motorcycles, bicycles and parts | 375 | 375 |

[21] The analysis of Taylor (2004), however, is broader in scope in another aspect: it does not only consider patented innovations, but also academic publications.

[22] Dosi (1982) convincingly argued that technologies often develop along lines determined by specific capabilities of firms that took an early lead. This is a self-reinforcing process. Agglomeration effects can even strengthen these processes at the higher levels of geographic aggregation, i.e. regions and countries.

| Nr. | Product description | OTAF code | SIC code |
|---|---|---|---|
| 38 | Miscellaneous transportation equipment | 379- | 379 (except 3795) |
| 39 | Ordinance except missiles | 348+ | 348, 3795 |
| 40 | Aircraft and parts | 372 | 372 |
| 41 | Professional and scientific instruments | 38- | 38 (except 3825) |
| 42 | All other SICs | 99 | 99 |

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