The diffusion of barcode scanning in European retailing

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This version: June 2005
First draft: March 2005

Abstract

This paper presents a set of panel data to study the diffusion of barcode scanning in European retailing over the period 1981-1996. Using a standard diffusion model, we observe that countries differ most in the saturation intensity of barcode scanning and less in timing or speed of diffusion. Evaluating a number of explanatory variables proposed in the literature, we find that scale and income effects spur retail IT diffusion: countries with growing retail sectors or economies adopt barcode scanning more intensely. There is also evidence for a classic substitution effect: barcode scanning reduces demanded labor time, and wage increases spur its adoption. We further argue that changes in the intensity of retail competition can be proxied by the development of hypermarkets. However, results concerning the effect of competition on IT diffusion are largely inconclusive. We do not find a significant impact of employment protection legislation.

JEL classification: L5, L81, O33.

Keywords: IT diffusion; retail competition; employment protection legislation.

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Thanks to Oz Shy, Irina Suleymanova and participants at the WZB seminar, the *InterVal* yearly meeting and the BDPEMS workshop for comments and helpful discussions. Anna Kälberer and Kemal Azun provided able research assistance. Financial support from the German Federal Ministry of Education and Research, project *InterVal – Internet and value chains* (01AK702A), is gratefully acknowledged. The authors are responsible for all remaining errors.

1 Introduction

Since the resolution of Solow's highly cited paradox regarding the productivity effects of information technology (IT), attention has shifted towards cross-country differences in IT productivity. Studies attribute large post-1995 productivity gains in the US to increased IT usage mainly in the distribution sector. Some even identify a 'retail revolution' (Ark et al., 2005; Brown, 1997). Most European countries, however, have not experienced such a manifest development; neither in IT diffusion nor retail productivity (McKinsey Global Institute, 2002; Ark et al., 2003).

With this paper, we want to contribute to our understanding of the forces underlying IT diffusion in service industries. We take a cross-country perspective: given that IT investments are productive, why is their intensity so different across industrialized countries? We focus on IT diffusion in retailing, a sector that has not been studied extensively, although credited a major role in recent productivity developments. For ten European countries, we combine data from various sources to analyze diffusion of a distinct retail technology: barcode scanning.

This enables us to address a number of interesting issues: First, we document substantial cross-country differences in retail adoption of barcode scanning. Second, we address policy by shedding some light on the influence of competition, product and labor market regulation on IT diffusion. We also control for other factors such as scale and income effects, as well as labor costs. Finally, our results can help in predicting the next 'revolution at the checkout counter' (Brown, 1997), which will involve the replacement of scanning by radio frequency identification (RFID).

As we investigate the effects of labor market and product market restrictions on technology adoption, our work is complementary to a number of studies which examine the interrelations between innovation, regulation and productivity (OECD, 2001; Scarpetta et al., 2000, 2002, for instance, and the references therein). This literature has typically stressed the negative effects of labor and product market regulations on productivity and innovative activities.

1.1 Barcode scanning across Europe

We begin with a first glance at the data on barcode scanning in Europe. Data on the number of retail outlets with barcode scanners were collected until 1997 by the national member organizations of the European Article Numbering Association (EAN). They are made available on a country-year basis in the EAN's yearly reports.[1] In contrast to the United States, where the first retail outlet was equipped with a barcode scanner already in 1974 (Nelson, 2001), diffusion of barcode scanning in Europe did not take off before the 1980s.

The three panels of figure 1 indicate how many retail outlets use barcode scanning (in %, scatter points), separately for each of the 10 countries we study.[2] Lines represent fitted values from a country-specific estimation of a logistic growth function (see below for more detail). All series accord with a sigmoid-shaped curve common to diffusion processes. However, some series still appear to be in the region of increasing growth rates at the end of the observation period (1996). Countries seem to differ substantially in the extent of diffusion. Our objective is to shed some light on the factors underlying these differences by means of a panel estimation.

1.2 Analytical framework

In empirical studies of aggregate data on diffusion, a logistic function has proven a parsimonious starting point.[3] It captures the typical sigmoid shape through three interpretable parameters:

$$\begin{aligned} S_t &= \frac{S^*}{1 + \exp(-\beta(t - \tau))}, \\ \text{where} \quad S^* &= \gamma N_t. \end{aligned} \tag{1}$$

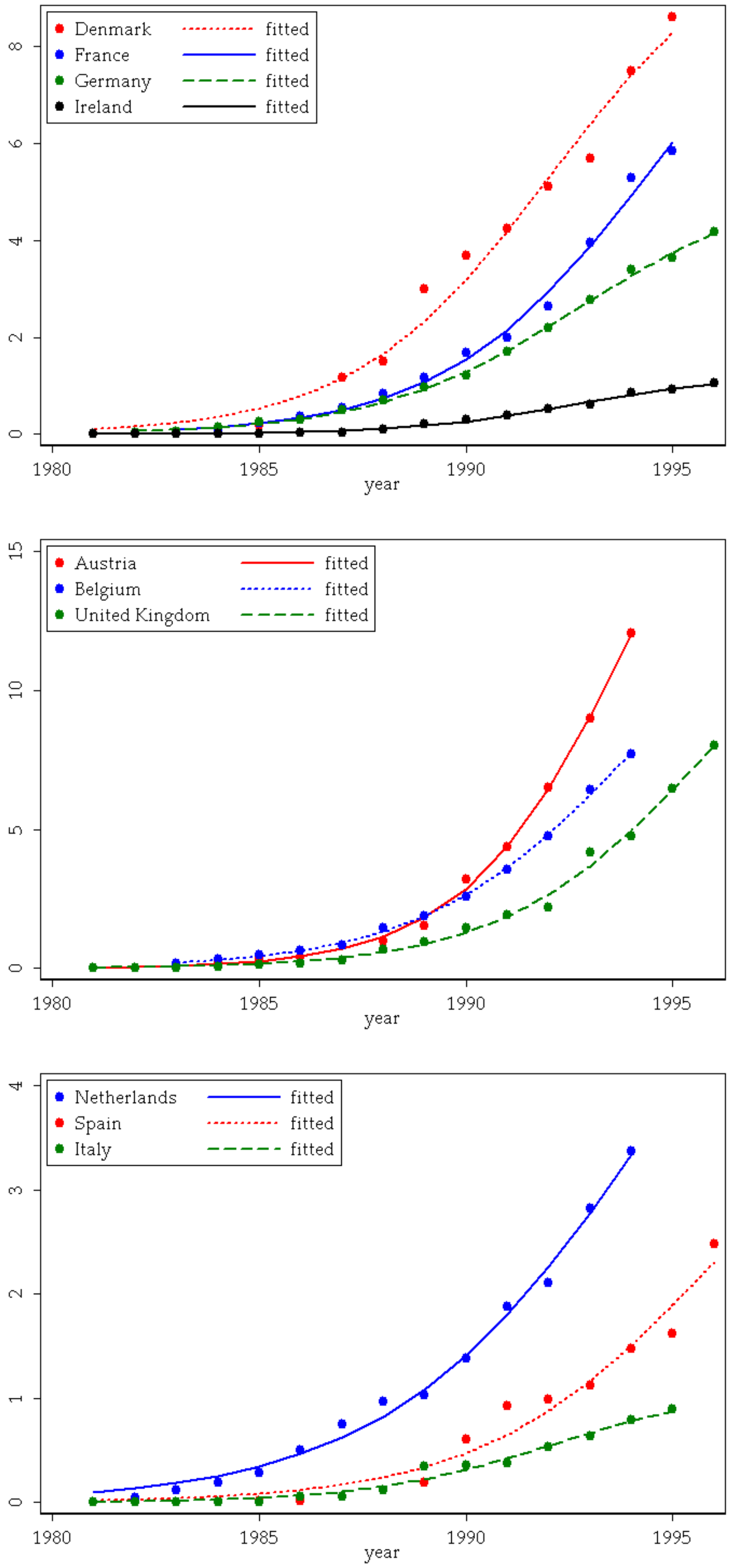
S_t indicates the number of adopters (outlets with a barcode scanner) at time t. S^* is the potential number of adopters, the 'saturation level' to which S_t converges: a fraction γ of

[1] The data and its sources are described in more detail in section 2.1 and the appendix.

[2] Similar pictures arise if the number of barcode scanning stores is related to population. The absolute values in figure 1 have to be taken with a grain of salt, however, since countries may differ in measurement of the total number of retail outlets. We return to this point below.

[3] See Geroski (2000) for a survey. With micro data, discrete choice and hazard rate models are commonly used.

Figure 1: Number of barcode scanning stores (in %, by country)



the total number of outlets N_t. Various theoretical models of new technology adoption lead to an aggregate diffusion path which can be described by such a sigmoid curve.[4]

Since the logistic function is symmetric, S_t equals half of its saturation level at the curve's inflection point: the date t at which the growth rate of the number of adopters is no longer increasing. τ indicates this inflection point and is hence a measure for the timing of adoption – it shifts the S-curve forwards or backwards. Too see this, consider t^k, the moment in time where a share k of the saturation level is reached:

$$\frac{S^*}{1+\exp(-\beta(t^k-\tau))} = kS^*$$
$$\Leftrightarrow \quad t^k = \tau - \beta^{-1}\log(k^{-1}-1).$$

At k =0.5, $t^k = \tau$. Differentiating equation 1 with respect to time shows that coefficient β is a measure for the speed of adoption. It gives the growth rate of S_t, relative to its distance to the saturation level: $\frac{\mathrm{d}S_t}{\mathrm{d}t}\frac{1}{S_t} = \beta\frac{S^*-S_t}{S^*}$. The growth rate of S_t attains it's maximum, $\frac{\beta}{2}$, at the inflection point $t = \tau$.

2 Explaining country differences

We obtain the fitted values shown in figure 1 from country-specific nonlinear least squares (NLS) estimations of equation 1. N_t – the number outlets – is given in hundreds such that γ indicates the saturation level as the percentage of barcode scanning stores. Table 1 provides more detailed results on these estimations. In line with the literature cited in our introduction, cross-country differences seem to be most pronounced with respect to the saturation level of IT adoption as measured by $\hat{\gamma}_i$. For example, while Austria is estimated to have 24% of outlets with barcode scanning in the long run, Italy only 1.1%.

Although a larger number of retail outlets may explain the small Italian figure, these figures overall seem rather low from today's perspective, where also small retailers work with (mainly hand-held/mobile) barcode scanners. We presume that the EAN data and hence our estimates rather apply to the 'first generation' of fixed scanner installations.

[4]Previous studies – following the seminal work by Griliches (1957) – have often used another version of equation 1, where $S_t = \frac{S^*}{1+\exp(-\alpha-\beta t)}$. However, we find that the above version, which acknowledges that $\alpha = \beta\tau$, is more parsimonious and easier to interpret.

Moreover, due to possible country differences in counting the number of retail outlets (see the appendix for more detail), these figures should not be taken too literally. In our panel estimations described in section 3, we account for such potential differences.

The estimated saturation level for Ireland also deserves a note. In contrast to the Italian case, we are rather surprised by the low value, since Ireland's retail structure is more comparable to the UK's (cf. table 6 in the appendix). As Ireland has developed strongly throughout the 1990s, we presume that our data cover only the very beginning of the corresponding diffusion process. In particular, our series may lack its inflection point. As a result, the estimated $\hat{\gamma}_i$ may be unreliable in the case of Ireland. We get back to this point in section 3.

Table 1: Estimates from country-wise regressions

Country	$\hat{\gamma}_i$	$\hat{\beta}_i$	$\hat{\tau}_i$	Observations	R^2
Austria	24.0*	.50*	1994.0	14	.999
Belgium	15.9*	.39	1994.1	12	.999
Denmark	10.7	.42	1992.1*	15	.992
France	10.7	.41	1994.4	13	.997
Germany	5.3*	.41	1992.8*	15	.999
Ireland	1.3*	.48	1992.7*	16	.998
Italy	1.1*	.45	1992.1	15	.990
Netherlands	7.4	.31*	1994.6	14	.997
Spain	4.6	.36	1996.0	16	.980
United Kingdom	15.4	.41	1995.8	16	.996
Cross-country average	9.6	.41	1993.9	10	

Parameter estimates from country-wise NLS estimation of equation 1. Starred coefficients differ significantly from cross-country average (95% confidence level, F-test based on asymptotic standard errors).

As a final remark on table 1, we note that cross-country differences with respect to timing and speed of diffusion seem less pronounced. Only in two cases do estimates for β_i differ significantly from the cross-country average (which implies a growth rate of 20% at the inflection point). Estimates for τ_i differ significantly in three cases. We therefore focus on explaining differences in γ_i with a joint regression analysis of the panel. In the following section, we present of our set of independent variables. We then relate these to theoretical explanations for differences in the diffusion of barcode scanning, which include technology-specific factors (section 2.2), labor market restrictions (section 2.3), and competition and product market regulation (section 2.4). Related literature is discussed along the way. We also present some precursory evidence here and there. In section 3, we finally present our econometric specifications and the corresponding results.

2.1 Data

Publicly available information on the retail sector is scarce, even on a country-year basis. We compile data from various sources and restrict attention to the 10 countries listed in table 1. Country-year data on the adoption of barcode scanning are published for the years 1981 to 1996 in the yearly reports of the EAN.[5] Table 2 gives a description of the main independent variables used in section 3. For more detailed cross-country summary statistics, see table 6 in the appendix.

Table 2: Summary of independent variables

Label	Description	Source	Cross-country mean 1981 / 1996
OUT	No. of retail outlets (per mn. inhabitants)	Euromonitor, World Bank	9361.8 / 7952.4
HYP	No. of hypermarkets (per mn. inhabitants)	Euromonitor, World Bank	6.8 / 13.3
EPL	OECD indicator of strictness of employment protection legislation	OECD	2.5 / 2.2
VOL	Retail sales volume (index 1995=100)	OECD, Euromonitor	85.7 / 101.3
GDP	Per capita real GDP (index 1995=100)	World Bank	74.8 / 5.8
WAGE	Retail hourly real wage (index 1995=100)	GGDC	74.2 / 101.1

Source of *GDP* and population figures is the World Bank (2003). Data on the number of hypermarkets and the total number of retail outlets are from various issues of "Retail trade international", a publication by market research firm Euromonitor. The most recent is Euromonitor (2002). As a measure for the severity of labor market restrictions, we use version 1 of the revised OECD indicator of the strictness of employment protection legislation (OECD, 2004). The indicator of retail sales volume (*VOL*) is also from the OECD.[6] The *WAGE* index is constructed using data from the 60-Industry Database of the Groningen Growth and Development Centre (GGDC). Pre-1990 values for unified

[5]The earliest report available is the 1983 report, which also gives figures for 1981 and 1982 for most countries (or indicates that there were no barcode scanning stores before 1983 in a particular country).

[6]For Italy and Spain, this indicator does not cover the whole sample period. For these two countries, we therefore constructed a comparable indicator based on Euromonitor and GGDC data (see appendix).

Germany for the variables *VOL* and *WAGE* were constructed by applying pre-1990 trends for Western Germany to 1990 values for unified Germany. We also had to replace some missing values with univariate procedures. A detailed list of all data manipulations is given in appendix A.

2.2 Technology-specific effects

When deciding about the adoption of a new technology, a firm typically compares costs and benefits of adoption at a given point in time (Hall and Khan, 2003). For example, heterogeneity across potential adopters regarding these costs or benefits may be one reason why diffusion of new technology is rarely instantaneous. In our case, the installation of a barcode scanner represents a major capital investment, which basically enables a retailer to check out more retail items in less labor time.[7] In line with Levin et al. (1987, 1992), we assess a number of factors which can make barcode scanning more or less valuable in different countries.[8]

First, the financial returns to this capital investment depend on future market conditions. Since return-on-investment is faster in growing markets, retailers there will adopt more intensely than retailers in stagnating or contracting markets. In addition, barcode scanning may introduce or increase economies of scale in retailing. In both cases, we expect adoption intensity to increase with market volume. We use an OECD indicator of retail sales volume (*VOL*) to evaluate these effects. Second, barcode scanning is likely to reduce customer waiting time at the checkout. Customers in high-income countries have a higher opportunity cost of waiting. Using per capita *GDP* as income measure, we expect diffusion of barcode scanning to increase with *GDP*. Notice that in this interpretation, barcode scanning is a product-enhancing innovation: it increases the quality of retailing for the costumer.

However, barcode scanning can also be interpreted as a process-enhancing innovation which reduces the costs of retailing. Most prominently, barcode scanning may be a labor-

[7]Clearly, barcode scanning enables a retailer to engage in other potentially productivity-enhancing practices, e.g. sophisticated logistics systems ('efficient consumer response', 'category management'). However, these systems did not develop before the mid-1990s and still represent "untapped potential" (Haberman, 2001).

[8]Levin et al. (1987, 1992) study the adoption of barcode scanning in the U.S. retail sector. They analyze firm-specific data relating to the early years of the technology (1974-1985).

saving technology which reduces total labor demand. For a precursory validation, we regress the number of hours worked in retailing (*HOURS*) on the number of barcode scanning stores, all in per-capita or indexed terms. We allow for country-specific constants and time trends in *HOURS*. The results (table 3) suggest that barcode scanning indeed has a negative effect on labor demand, although the effect becomes insignificant when we include sales volume (*VOL*) as control variable.

Table 3: Regression results on labor-saving effect of barcode scanning

	Dependent variable: *HOURS*		
Variable (x)	Coefficient	Coefficient	mean of x (std. dev. of x)
SCAN	-5.933*	-2.884	101.8
	(2.844)	(2.688)	(132.0)
VOL		169.511*	93.2
		(34.636)	(8.8)
Country fixed effects:	yes	yes	
Country time trend:	yes	yes	
Time span (max.)	1981-1996	1981-1996	
Observations	146	146	
R^2	0.977	0.981	
Root MSE	1672.9	1537.7	

OLS estimates (country fixed effects and time trends omitted). Standard errors in parentheses (star indicates significance at the 95% level). *HOURS* is the number of hours worked in the retail industry, per mn. inhabitants; constructed from series on persons engaged and average hours worked in the GGDC 60-industry database (`www.ggdc.net`). Cross-country summary statistics: mean 55969.5, std. dev. 10780.3. *SCAN* is the number of scanning outlets per mn. inhabitants.

In addition to this classic capital-labor substitution effect, barcode scanning may allow retailers to substitute unskilled for costly skilled labor. Clerks at scanner checkouts need neither know prices nor be able to type quickly. In both cases of substitution, we therefore expect countries with rising retail wages to invest more in a labor-saving technology such as barcode scanning. In estimations, we use an index of real average hourly wages in the retail sector (*WAGE*).

2.3 Employment protection legislation

A related question is whether labor market restraints hinder IT diffusion. For example, strict employment protection legislation (EPL) may prohibit retailers from substituting barcode scanners for labor as extensively as the technology might allow. Accordingly, a conventional wisdom has been that less flexible labor markets (with stricter EPL) impede IT adoption (IMF, 2001, for example); with corresponding policy recommendations. Yet, the literature on the relationship between labor market regulation such as EPL and innovation provides mixed results (Bassanini and Ernst, 2002, for a review).

In support of the conventional view, Gust and Marquez (2004) analyze a panel of cross-country data and find that IT investments are lower in countries with higher EPL. In contrast to the conventional view, Koeniger (2005) finds a positive effect of EPL on innovative activity – at least in the short- and medium-term – for a panel of OECD countries. He also shows theoretically, that EPL in the form of collective dismissal costs may increase innovative activities. Accordingly, Agell and Lommerud (1993) and Agell (1999) argue that labor market regulations, in particular EPL, need not reduce investment incentives and productive efficiency, as they provide insurance against adverse economic shocks or structural shifts in labor demand. Haucap and Wey (2004) show that labor market rigidities can increase firms investment incentives when they tend to enforce egalitarian wage structures.

2.4 Product market regulation and competition

In the industrial organization literature, retail markets have typically been regarded as more or less perfectly competitive. This perception has led scholars to abstract from the retail level and concentrate on the manufacturers' side. Yet, fragmented retail structures are most often the direct result of entry restrictions. In general, these restrictions tend to favor small retailing in downtown areas against large scale retail formats as exemplified by *Wal-Mart*. Most prominently, planning and construction restrictions have been used in all European countries to ban large retailing formation; e.g., by not granting construction permissions or by limiting store size (see Wey, 2005, for a recent account of retail restrictions in the UK, Italy and Germany). These restrictions have been eased first in the UK by the Thatcher government and later on also in other European countries.

With these developments, hypermarkets became an integral element of European retail markets. According to a widely used definition, hypermarkets have a minimum size of 2,500 square meters and sell food and non-food items. Hypermarkets often locate in peripheral areas which are easily accessible by car. In most European countries, the hypermarket retail format emerged in the 1970s and 1980s, parallel to an increase in motorization.[9]

We claim that the number of hypermarkets (*HYP*, in per capita terms) is an inverse indicator of entry restrictions. An increasing number of hypermarkets is a result from less restrictive entry regulations, and hence a proxy for increasing competitive intensity due to regulatory change. Apart from that, hypermarkets may reflect competitive intensity on other grounds. They can be regarded as low-cost competitors, which exploit the cost benefits of out-of-town locations, sophisticated logistics, and economies of scale (Basker, 2004). One may also view retail competition as competition of retail channels or formats (Michael, 1994). In that sense, the emergence and growth of a new format like the hypermarket intensifies retail competition as such.

Table 4 presents some evidence in support of our claim. Since retail competition essentially works through entry and exit of firms, the appearance of competitive hypermarkets should have led to increased exit rates. We therefore regress the number of outlets (*OUT* net of hypermarkets) on the number of hypermarkets (*HYP*). Unfortunately, two countries in our sample – Germany and Denmark – apply a slightly broader hypermarket definition which includes superstores (supermarkets with a floor space between 1,500 and 2,500 square meters). We therefore allow for a different effect for these two countries, the difference measured by the coefficient for *D*HYP*.

The first two coefficient columns of table 4 imply that an increase of the number of hypermarkets leads to a decrease in the number of other outlets. However, the estimate for Germany's and Denmark's hypermarket definition is positive as long as we do not allow for a country-specific time trend in *OUT-HYP*. With time trends, the average effect is

[9]French retail group *Carrefour* claims to have invented the concept. It opened its first hypermarket in 1963 near Paris, "with a floor space of 2,500 square meters, 12 checkouts and 400 parking spaces" (see `www.carrefour.com/english/groupecarrefour/annees60.jsp`).

negative for both hypermarket definitions, but not precisely estimated. In order to assess whether hypermarkets indeed imply more competitive threat than other modern retail formats, we used the joint number of hyper- and supermarkets (*SUPHYP*, see appendix A) as an alternative regressor.[10] The estimated average effect of *SUPHYP* on the number of other outlets is much smaller than the hypermarket effect. We conclude that the number of hypermarkets is a valid proxy for the intensity of retail competition and a better indicator than the number of supermarkets.

Table 4: Regression results on hypermarket competition

	Dependent variable:			
	OUT-HYP	*OUT-HYP*	*OUT-SUPHYP*	
Variable (x)	Coefficient	Coefficient	Coefficient	mean of x std. dev. of x
HYP	-196.921*	-31.204		11.0
	(25.898)	(48.340)		9.5
$D * HYP$	298.300*	-68.124		19.2
	(60.212)	(121.573)		4.5
$SUPHYP$			-0.783	207.4
			(1.021)	202.6
Country fixed effects:	yes	yes	yes	
Country time trend:	no	yes	yes	
Time span (max.)	1980-2001	1980-2001	1980-2001	
Observations	215	215	203	
R^2	0.959	0.991	0.991	
Root MSE	1100.7	538.5	552.4	

OLS estimates (country fixed effects and time trends omitted). Standard errors in parentheses (star indicates significance at the 95% level). D is a dummy variable equal to one for Germany and Denmark, who use a different hypermarket definition than the other countries. $SUPHYP$ is the number of super- and hypermarkets per mn. inhabitants (Source: Euromonitor; 12 obs. missing).

Concerning related literature, we are not aware of theoretical or empirical work that studies the relationship between retail deregulation, hypermarket retailing and IT diffusion in particular. But the relationship between competition and technology diffusion has been studied on a more general level (Stoneman, 2002, for a survey). Götz (1999) studies the diffusion of new technology in a monopolistically competitive industry. He finds that increased competition often promotes diffusion. In contrast, Boucekkine et al. (2004) study a differentiated-products Cournot duopoly and find an inversely U-shaped relationship between competition and diffusion. In their model, an increase in competition (a de-

[10]In this case, we do not have to distinguish between definitions, since it does not matter how stores at the margin between super- and hypermarkets are classified.

crease in product differentiation) stimulates diffusion only when products are substitute enough. If products are highly differentiated, more competition hinders diffusion.

The closely related literature on the relationship between market structure and innovation incentives is also inconclusive. While the Schumpeterian (1942) idea has been that there is a positive relationship between innovation incentives and concentration and large firms, respectively, others have emphasized the negative effects of monopoly power on innovation. Borrowing from the parallel literature on market structure and product quality, one may also claim that the influence of market structure on innovation is neutral, or in general ambiguous (Swan, 1970; Spence, 1975). See, e.g., Tirole (1988) and Kamien and Schwartz (1982) for early surveys.

Empirical results mirror the theoretical ambiguity. For example, Levin et al. (1987, 1992) do find for the US that retailers in less concentrated markets adopt earlier and that intra-firm diffusion of barcode scanning is faster in less concentrated markets, but these effects partially bare significance. More importantly, as we argued above, concentration measures are not necessarily good proxies for competitive intensity in retail markets. Some studies of other industries find that competition hampers technology diffusion (Geroski, 2000; Karshenas and Stoneman, 1995, for reviews).

3 Econometric specification

Results from country-wise estimations of equation 1 indicate that cross-country differences in the diffusion of barcode scanning are most pronounced with respect to the saturation level as measured by γ. In order to assess how the proposed independent variables influence these differences, we therefore parameterize γ as follows:[11]

$$\gamma = \gamma_i^f + X_{it}\gamma^x, \tag{2}$$

where X_{it} contains the variables *HYP*, *EPL*, *VOL*, *GDP*, *WAGE* and *D*HYP*. As before *D* is a dummy variable equal to one for Germany and Denmark to account for the different

[11] See Liikanen et al. (2004) for a similar approach. Other empirical studies that estimate a logistic function, for example the one by Gruber and Verboven (2001), focus on parameterizing the speed or timing coefficients in equation 1.

hypermarket definition. Subscript $i = 1, ..., 10$ indicates countries and $t = 1981, ..., 1996$ indicates periods. The coefficients γ_i^f account for time-invariant country-specific effects, as well as for time-invariant cross-country differences in measurement of the independent variables.

After inserting equation 2 and an additive i.i.d. error term, we estimate equation 1 using NLS. The speed and timing coefficients of equation 1 are allowed to vary across countries, hence we specify $\beta = \beta_i$ and $\tau = \tau_i$.[12] As before, the number of outlets (N_t) is given in hundreds. It is important to note a potential endogeneity issue arising from the inclusion HYP in X_{it}. In addition, since γ measures the percentage change in the number of barcode scanning stores, an estimated effect of HYP on γ might arise solely from its negative effect on N_t, which we found in precursory regressions (table 4). We assess both possibilities below.

In addition to this specification (I), we consider two alternatives: in specification II, we exclude EPL from X_{it}; in specification III, we add the squared number of hypermarkets (HYP^2) to X_{it}. Unreported regressions based on the full sample exhibited convergence problems and led to large and unstable estimates for Ireland's fixed effects. This seems to confirm the suspicion that the data for Ireland do not cover a sufficiently large portion of its diffusion of barcode scanning. In what follows, we therefore present estimation results excluding Ireland. The independent variables' coefficients are virtually unaffected, compared to estimates including Ireland, but convergence is smoother and all fixed effects are now stable. Table 5 presents the results.

3.1 Results

Comparing specifications I and II reveals that the effect of EPL is not significantly different from zero, but its exclusion from the regression leaves the other variables' parameters largely unaffected. Using the coefficients from specification I, we find that a 10-point increase in the sales volume index (VOL) is estimated to increase the saturation percentage of barcode scanning stores by almost 1 point on average. A similar increase in the GDP

[12]We use the estimates from the country-wise regressions as initial values for the country fixed effects. For the independent variables' coefficients, we set initial values equal to ± 0.01, the sign being the expected sign as discussed in the previous sections.

Table 5: NLS estimation results

Dependent variable: Number of barcode scanning stores			
Specification	(I)	(II)	(III)
HYP	-1.852*	-1.828*	0.076
	(0.426)	(0.437)	(1.519)
HYP^2			-0.260
			(0.202)
$D * HYP$	6.668*	6.489*	-20.988*
	(2.505)	(2.408)	(5.481)
$D * HYP^2$			0.790*
			(0.252)
EPL	-1.333		-2.735
	(2.287)		(2.575)
VOL	0.087+	0.079	0.081
	(0.048)	(0.048)	(0.055)
GDP	0.394*	0.411*	0.468*
	(0.069)	(0.061)	(0.089)
$WAGE$	0.119*	0.109*	0.086*
	(0.032)	(0.028)	(0.036)
Observations	130	130	130
Adj. R^2	0.994	0.994	0.995
Root MSE	494.6	492.9	484.6

Asymptotic standard errors in parentheses.
Significance levels: * 95%, + 90%

index increases the saturation percentage by about 4 points on average. Both results confirm initial expectations. Although the income effect measured by *GDP* seems more important than the scale effect measured by *VOL*, both effects are hard to distinguish empirically since the two variables are highly correlated by definition. In any case, the estimated effects already can explain why the U.S. are ahead of most European countries when it comes to IT diffusion in the retail sector and the resulting productivity gains.

A 10-point increase in the retail wage index (*WAGE*) is estimated to increase the saturation percentage of barcode scanning stores by over 1 point on average. As expected, investment in labor-saving retail IT can be interpreted as a reaction to changes in labor costs. An increase in the number of hypermarkets by one per million inhabitants is estimated to decrease the saturation percentage of barcode scanning stores by about 2 points. This result challenges the view that competition spurs retail IT usage. Yet, the estimate for the broader hypermarket definition is positive and larger in absolute terms, suggesting increased competition leads higher long-run IT usage. However, since this estimate measures both a pooled hypermarket effect for Germany and Denmark and the effect of a different hypermarket definition, we cannot be sure which effect is more important in determining our estimate.

Another reason for the hypermarket results obtained in specifications I and II may be that the competition effect on IT diffusion is in fact highly non-linear, as proposed by Boucekkine et al. (2004). We therefore included the squared number of hypermarkets in a third specification. The corresponding results suggest that the competition effect on the diffusion of hypermarkets is not significant, at least for the countries employing the standard hypermarket definition. Only the estimates for the German-Danish definition are significant, and in line with the results by Boucekkine et al. (2004): for low levels of competition (less than $\approx \frac{21}{2*0.8} \approx$13 hypermarkets per mn. inhabitants), the competition effect on diffusion is negative; it turns positive only for high levels of competition (*HYP* larger than 13). Yet again, since these results base on observation from two neighboring countries, we cannot exclude that country-specific or regional effects are their main drivers.

3.2 Robustness

All findings remain qualitatively unchanged in a number of robustness checks. A potential source of endogeneity bias is the presumption that every new hypermarket built from the mid-1980s increases the number of scanning outlets by one. Although not necessarily, since hypermarkets operated long before the introduction of barcode scanning and hence the technology may not be as crucial for them as it might appear from today's perspective. In any case, the negative estimates in table 5 already suggest that this endogeneity bias cannot be very influential. Nevertheless, we re-run the three specifications with modified variables: deducting the number of hypermarkets from both the number of barcode scanning stores and the number of outlets, such that the estimated coefficient for *HYP* measures only the effect of hypermarkets on the adoption of barcode scanning of all other stores. Table 7 in appendix B reports the respective results – most estimates are slightly larger both in absolute value and significance, but nothing changes qualitatively.

A related point is the possibility that our estimates for the hypermarket effect iterate the indirect negative effect on the total number outlets found before, instead of a direct competition effect with respect to the adoption of barcode scanning. Under the assumption that hypermarket competition only drives out non-scanning stores,[13] the estimated coefficients already show that a direct effect must be present. Recall from table 4 that the effect of *HYP* on *OUT* was estimated to be negative for the standard hypermarket definition and positive for the broader definition (specification without country time trends). If only these indirect effects were at play in our final estimation equation, we should expect a positive γ-estimate for the standard definition, and a negative one for the broader definition. However, the estimates have the opposite signs in specifications I and II, hence a direct effect of the number of hypermarkets on the diffusion of barcode scanning must be present.

Finally, our conclusions regarding the effect of *EPL* may be premature. Given substantial manipulations necessary to obtain a complete time series (see appendix), and other measurement problems associated to the OECD *EPL* index (Blanchard and Wolfers, 2000), there are reasons to doubt the validity of the indicator used. In order to cross-check results, we replaced the *EPL* indicator by variables constructed using data from the *Social Reforms Database* of the Fondazione Rodolfo DeBenedetti (FRDB).[14] Amongst other information, this database provides a list of EPL reforms for all countries in our sample, and classifies them as marginal/structural and flexibility-increasing/-decreasing. From this information, we constructed 4 time series on the progressive number of EPL reforms for each country. However, when replaced for our initial *EPL* indicator in specification I, these variables also yield mainly insignificant and contradictory results.

4 Conclusion

Barcode scanning, a critical information technology in the retail sector, has diffused with different pace across European countries. Results from an econometric analysis of data from various sources confirm the intuitive expectation that barcode scanning has diffused

[13] A small retailer on the verge of bankruptcy will most probably not invest in new technology. Nevertheless, we only need to assume that an installed barcode scanner can be sold and re-used at another location.

[14] See `http://www.frdb.org/documentazione/scheda.php?id=55&doc_pk=9027` for more detail.

more intensely in countries where retail sectors and the economy as a whole was growing. This result can explain why the U.S. are ahead of most European countries when it comes to IT diffusion in the retail sector and the resulting productivity gains. With respect to an upcoming 'retail revolution' including RFID technology, it leads us to expect earlier and faster RFID diffusion in large and growing countries.

Most other factors that are usually prompted as drivers or restraints to diffusion also seem to play significant roles. In line with classic theory, our results suggest that wage increases lead retailers to substitute barcode scanners for labor. We do not find a significant impact of employment protection legislation. Our results concerning the impact of competitive intensity are somewhat puzzling on the one hand, but in line with a tradition of inconclusive literature on the other. In contrast to conventional wisdom, intensive competition – justifiably proxied by the number of hypermarkets – seems to hamper diffusion in most countries. There is also evidence for a non-linear relationship between competition and retail IT diffusion, but the respective estimates either bare significance or rely on a limited number of observations. Obviously, this issue requires further research.

Other directions for further research include measures of foreign direct investments in order to assess the role of large supranational retail firms in IT diffusion. Given data on the emergence of one-stop-shopping (e.g., motorization and demographics), it may also be possible to address the potential endogeneity of hypermarket development more rigorously with an instrumental variable estimation. Finally, the present results are based on a fairly small number of countries and explanatory variables. It should be interesting to include in the analysis the U.S., for which we were to date unable to get comparable aggregate data on the diffusion of barcode scanning.

A Data issues

Scanning outlets. Data source are the statistical appendices of the European Article Numbering Association's (EAN) yearly reports for 1983 through 1997 (available at `www.ean-int.org`). They give the number of barcode scanning outlets per country for the years 1981 through 1996, although this period is not completely covered for all countries. In the cases of Austria, Denmark, Ireland and Spain, it was clear from the text in the country sections of the reports that the number of scanning outlets was zero before 1984, although it is reported as missing in the respective appendix table. Missing observations in the series for Italy (1982) and Ireland (1989) were replaced by linear interpolation using adjacent observations. Data for the last years of observation, 1995 and/or 1996, seemed inconsistent with data for preceding years in the cases of Austria, Italy and the Netherlands. They indicated either a decrease of the the number of scanning outlets (Netherlands, 1995; Italy, 1996) or an overly strong increase (Austria, 1995 and 1996).[15] In a telephone interview, we were told by German EAN representatives that collection of these data became increasingly difficult during the mid-1990s, as barcode scanners became more popular and small firms were unwilling to answer questionnaires. Apparently for this reason, the EAN stopped collecting these data after 1997. We interpreted the inconsistent post-1995 data for Austria, Italy and the Netherlands as a first sign of these difficulties and therefore deleted them from our sample.

Retail outlets. Data on the number of retail outlets were taken from various issues of "Retail trade international", a publication by market researcher *Euromonitor International*. Every issue provides country-specific data on the retail sector, mostly collected from official and industry sources (such as trade magazines) for five consecutive years. The latest available issue is Euromonitor (2002), which covers the years 1997-2001. However, earlier issues covering the 1980s only provide figures for few single years. We therefore had to replace the missing values by interpolation for the following observations: Austria, 1981, 1982, 1984-1987; Belgium, 1981, 1983, 1985, 1986, 1988, 1989; Denmark, 1982-1984, 1986; France, 1982, 1983, 1985-1987; Germany, 1981-1983, 1987, 1989, 1991; Ireland, 1981-1987,

[15] According to the the original figures, the number of scanning outlets in Austria rose from 4,670 to 13,827 (hence by 300%) between 1994 and 1995. In relation to the total number of retail outlets in Austria, which *Euromonitor International* estimates at 38,546 for 1995, this would imply an increase in penetration from 12 to 36% in one year. We suspect that the post-1994 figures refer to the total number of scanner installations rather than the number of scanning outlets.

1989-1991; Italy, 1982-194; Netherlands, 1981, 1983, 1985, 1986; Spain, 1981-1984, 1988; United Kingdom, 1981, 1983, 1985, 1989, 1991. For every country covered, not all time series published in the various Euromonitor issues were consistent in overlapping years of coverage. Most probably, this is due to varying (non-)inclusion of gas stations and mobile retail outlets. We therefore used the most recent available series (Euromonitor, 2002) for absolute values and projected this series back to 1981 using the trends from preceding series.[16] Whenever two issues gave inconsistent figures for the same year, we took the figure from the more recent publication. This approach entails the implicit assumption that the outlet share of whatever type of retail outlets included (not included) in the Euromonitor (2002) figures but not included (included) in the earlier figures has remained constant over time. Then, our constructed time series reflect changes in the number of retail outlets accurately, and differences across countries regarding the inclusion of a certain type of outlet in the time series are accounted for in estimation by the country fixed effects.

Super- and hypermarkets. Data on the number of hypermarkets were also taken from the *Euromonitor* publications cited above. The following missing values for single years have been replaced by interpolation: Belgium, 1982, 1983; Denmark, 1984; Ireland, 1991; Italy, 1985; United Kingdom, 1983. Missing values for Italy, 1987 and 1988, and the United Kingdom, 1981, were replaced by data from the European Commission (1997, p. 21-17, table 9), which are consistent with the Euromonitor data for subsequent years. In the cases of Austria, Belgium, Denmark, the Netherlands and the United Kingdom, the time series published in the various Euromonitor issues were not always consistent in overlapping years of coverage. This may be due to changes in original industry sources. In these cases, the series from Euromonitor (2002) was projected back, in a similar way than described for the outlets series, using trends from preceding series. In the cases of Denmark and Germany, the figures base on a different hypermarket definition, which considers as hypermarkets food retailers who also sell non-food items (as in the standard definition) and have more than 1,500 square meters of retail space (as opposed to 2,500 square meters in the standard definition). The *Euromonitor* publications also include data on the number of supermarkets, but with a large number of missing values. The follow-

[16]In the cases of Austria and France, the series covering the late 1980s did not overlap with the subsequent series. We therefore extrapolated the earlier series, using information for 1985-1988, to obtain a value for 1989 which we could compare with the 1989 value of the following series.

ing missing values for single years have been replaced by interpolation: Austria, 1984; Belgium, 1981-1982, 1987-1988, 1990-1991; Denmark, 1984, 1990-1991; Ireland, 1980-1987, 1989, 1991-1992; Netherlands, 1988; Spain, 1989-1990. Data for the Netherlands, 1980-1986, and the United Kingdom, 1980-1984, are missing. In all cases except Denmark and Germany, the time series published in the various Euromonitor issues were not always consistent in overlapping years of coverage. In these cases, the series from Euromonitor (2002) was projected back, in a similar way than described for the outlets series, using trends from preceding series.

Employment protection legislation. The revised OECD indicator for employment protection legislation (EPL) is published by the OECD (2004) for three moments in time: the 'late 1980s' (1989), the 'late 1990s' (1998), and 2003. From these data we constructed a time series by assuming that EPL has not changed significantly throughout the 1980s. This is in line with the general view that the European wave of labor market deregulation began only in the 1990s (OECD, 2004). The fact that the FRDB database lists only three marginal EPL reforms prior to 1989 – two for France, 1986, and one for Italy, 1987 – reconfirms this assertion. For the years 1990-1997, we replaced missing values by linear interpolation. This assumes that, as a composite of various legislative reforms, the measured change in EPL legislation is somewhat smooth.

Sales volume. The OECD indicator of the volume of retail sales is not available for Spain, 1981-1990 and for Italy, 1981-1985. We constructed a comparable indicator using *Euromonitor* data on retail sales and data from the GGDC 60-industry database on retail value added deflators. For Italy and Spain, we used this indicator instead of the OECD indicator for the whole sample period.

Wages and hours worked. The GGDC database contains information on the number of persons employed, annual hours worked and labor compensation per employee and a value deflator for the retail sector. Unfortunately, the number of retail employees – which excludes self-employed persons or family members – is not available for all countries. The total number of hours worked as well as our index of the deflated average hourly wage are therefore based on the number of persons engaged.

Table 6: Detailed summary of variables

Variable	*OUT*	*HYP*	*EPL*	*VOL*	*GDP*	*WAGE*
Country						
Austria	4769.6	29.5	2.2	92.9	93.2	86.0
	(358.8)	(16.3)	(0.2)	(37.7)	(37.6)	(45.5)
Belgium	4629.1	7.4	2.8	92.9	93.2	85.9
	(816.7)	(1.8)	(0.9)	(42.9)	(36.6)	(38.0)
Denmark	6841.3	15.7	1.8	95.2	94.0	88.4
	(896.8)	(8.3)	(0.7)	(23.2)	(34.7)	(49.0)
Spain	20730.4	4.0	3.4	99.7	91.9	91.3
	(8573.0)	(6.6)	(0.8)	(27.3)	(46.0)	(46.3)
France	7159.5	15.0	2.8	97.4	94.8	92.2
	(2380.6)	(12.3)	(0.3)	(17.1)	(33.8)	(32.5)
Germany	4603.8	22.4	2.9	93.0	93.1	90.3
	(1946.7)	(11.9)	(0.9)	(27.2)	(31.5)	(37.2)
Ireland	9194.4	5.1	0.9	98.8	89.6	90.6
	(814.4)	(13.1)	(0.1)	(74.5)	(100.2)	(68.3)
Italy	16139.8	3.8	3.6	98.4	92.6	93.5
	(6221.5)	(9.1)	(1.9)	(25.8)	(34.2)	(21.2)
Netherlands	5469.3	2.4	2.5	102.9	93.6	95.0
	(652.0)	(1.5)	(0.6)	(25.0)	(40.2)	(24.0)
United Kingdom	6795.4	3.4	0.5	90.1	92.2	89.5
	(2708.7)	(4.6)	(0.2)	(64.4)	(44.8)	(43.4)

See table 2 for a full description of the variables. Country-specific means in the first line, figures in brackets give the difference between the maximum and the minimum value (range) of the respective series.

B Results for robustness checks

Table 7: NLS estimation results with modified outlet figures

	Dependent variable: $\tilde{S}_t$=S_t-HYP		
Specification	(I)	(II)	(III)
HYP	-1.934*	-1.938*	0.467
	(0.425)	(0.440)	(1.575)
HYP^2			-0.320
			(0.207)
$D * HYP$	5.220*	5.118*	-21.651*
	(1.428)	(1.379)	(5.228)
$D * HYP^2$			0.849*
			(0.253)
EPL	-1.512		-2.615
	(2.256)		(2.647)
VOL	0.095*	0.092+	0.090
	(0.047)	(0.049)	(0.058)
GDP	0.410*	0.429*	0.496*
	(0.068)	(0.061)	(0.089)
$WAGE$	0.115*	0.101*	0.076*
	(0.031)	(0.028)	(0.036)
Observations	130	130	130
Adj. R^2	0.994	0.994	0.994
Root MSE	498.2	496.6	491.9

NLS estimation of equation 1, with OUT_t replaced by $\tilde{OUT}_t$=OUT_t-HYP. Country fixed effects omitted. Asymptotic standard errors in parentheses. Significance levels: * 95%, + 90%

References

Agell, Jonas (1999), On the benefits from rigid labour markets: norms, market failures, and social insurance, *Economic Journal*, 109 (127), pp. F143–64.

Agell, Jonas and Kjell Erik Lommerud (1993), Egalitarianism and growth, *Scandinavian Journal of Economics*, 95 (4), pp. 559–79.

Ark, Bart van, Robert Inklaar and Robert H. McGuckin (2003), ICT and productivity in Europe and the United States: Where do the differences come from?, *CESifo Economic Studies*, 49 (3), pp. 295–318.

Ark, Bart van, Robert H. McGuckin and Matthew Spiegelman (2005), The retail revolution – can Europe match U.S. productivity performance?, Report 1358, The Conference Board.

Basker, Emek (2004), Selling a cheaper mousetrap: Entry and competition in the retail sector, Working Papers 0401, Department of Economics, University of Missouri.

Bassanini, Andrea and Ekkehard Ernst (2002), Labour market institutions, product market regulation, and innovation: Cross-country evidence, Working Paper 316, OECD Economics Department.

Blanchard, Olivier and Justin Wolfers (2000), The role of shocks and institutions in the rise of european unemployment: The aggregate evidence, *Economic Journal*, 110 (462), pp. C1–33.

Boucekkine, Raouf, Omar Licandro and Antonio Minniti (2004), Adoption and diffusion of cost reducing innovations : Cournot competition in duopoly, Technical report.

Brown, Stephen A. (1997), *Revolution at the checkout counter* (Harvard Univ. Press, Cambridge, Mass.).

Euromonitor (2002), *Retail Trade International* (Euromonitor International Plc., London).

European Commission (1997), *Panorama of EU Industry* (European Commission).

Geroski, Paul A. (2000), Models of technology diffusion, *Research Policy*, 29, pp. 603–625.

Götz, Georg (1999), Monopolistic competition and the diffusion of new technology, *RAND Journal of Economics*, 30 (4), pp. 679–693.

Griliches, Zvi (1957), Hybrid corn: an exploration in the economics of technological change, *Econometrica*, 25 (4), pp. 501–522.

Gruber, Harald and Frank Verboven (2001), The diffusion of mobile telecommunications in the European Union, *European Economic Review*, 45, pp. 577–588.

Gust, Christopher J. and Jamie Marquez (2004), International comparisons of productivity growth: The role of information technology and regulatory practices, *Labour Economics*, 11, pp. 33–58.

Haberman, Alan L. (2001), Appendix: 17 billion reasons to say thanks, in: Alan L. Haberman (ed.), *Twenty-five years behind bars*, pp. 113–151 (Harvard University Press), Proceedings of the Twenty-fifth anniversary of the U.P.C. at the Smithsonian Institution, September 30, 1999.

Hall, Bronwyn H. and Beethika Khan (2003), Adoption of new technology, in: Derek C. Jones (ed.), *New Economy Handbook* (Academic Press).

Haucap, Justus and Christian Wey (2004), Unionisation structures and innovation incentives, *Economic Journal*, 114 (127), pp. C149–C165.

IMF (2001), *The Information Technology Revolution*, chapter III, pp. 105–144 (International Monetary Fund).

Kamien, Morton I. and Nancy L. Schwartz (1982), *Market structure and innovation* (Cambridge University Press, Cambridge).

Karshenas, Massoud and Paul L. Stoneman (1995), Technological diffusion, in: Paul L. Stoneman (ed.), *Handbook of the economics of innovation and technological change*, pp. 265–297 (Blackwell).

Koeniger, Winfried (2005), Dismissal costs and innovation, *Economics Letters*, 88 (1), pp. 79–84.

Levin, Sharon G., Stanford L. Levin and John B. Meisel (1987), A dynamic analysis of the adoption of a new technology: the case of optical scanners, *The Review of Economics and Statistics*, 69, pp. 12–17.

Levin, Sharon G, Stanford L Levin and John B Meisel (1992), Market structure, uncertainty, and intrafirm diffusion: The case of optical scanners in grocery stores, *The Review of Economics and Statistics*, 74 (2), pp. 345–50.

Liikanen, Jukka, Paul Stoneman and Otto Toivanen (2004), Intergenerational effects in the diffusion of new technology: the case of mobile phones, *International Journal of Industrial Organization*, 22 (8-9), pp. 1137–1154.

McKinsey Global Institute (2002), *How IT Enables Productivity Growth*, MGI Reports (McKinsey & Company).

Michael, Steven C. (1994), Competition in organizational form: Mail order versus retail stores, 1910-1940, *Journal of Economic Behavior & Organization*, 23 (3), pp. 269–286.

Nelson, John E. (2001), Scanning's silver celebration, in: Alan L. Haberman (ed.), *Twenty-five years behind bars*, pp. 25–33 (Harvard University Press), Proceedings of the Twenty-fifth anniversary of the U.P.C. at the Smithsonian Institution, September 30, 1999.

OECD (2001), The cross-market effects of product and labour market policies, in: *Economic Outlook*, volume 70 (Organisation for Economic Co-operation and Development).

OECD (2004), *Employment outlook* (Organisation for Economic Co-operation and Development).

Scarpetta, Stefano, Andrea Bassanini, Dirk Pilat and Paul Schreyer (2000), Economic growth in the OECD area: recent trends at the aggregate and sectoral level, Technical report, OECD Economics Department.

Scarpetta, Stefano, Philip Hemmings, Thierry Tressel and Jaejoon Woo (2002), The role of policy and institutions for productivity and firm dynamics: evidence from micro and industry data, Technical report, OECD Economics Department.

Schumpeter, Joseph A. (1942), *Capitalism, socialism and democracy* (Routledge, London and New York), 5th edition, reprinted 1968.

Spence, A. Michael (1975), Monopoly, quality, and regulation, *Bell Journal of Economics*, 6 (2), pp. 417–429.

Stoneman, Paul (2002), *The economics of technological diffusion* (Blackwell, Oxford).

Swan, Peter L (1970), Market structure and technological progress: The influence of monopoly on product innovation, *The Quarterly Journal of Economics*, 84 (4), pp. 627–38.

Tirole, Jean (1988), *The theory of industrial organization* (MIT Press).

Wey, Christian (2005), Liberalization of European retailing, in: Ricardo Faini, Jonathan Haskel, Giorgio B. Navaretti, Carlo Scarpa and Christian Wey (eds.), *Contrasting Europes decline: do product market reforms help?* (mimeo).

World Bank (2003), *World development indicators CD-ROM* (World Bank).