Productivity and Prices in Europe: Micro-evidence for the period 1975 to 1990.

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Abstract

In the absense of free trade, domestic productivity will be a major determinant of prices. I consider an empirical framework where an industry's R&D determines its productivity. Using repeated cross-sections of absolute prices of individual goods across European countries, I find that products of an industry tend to be cheaper in countries with higher stocks of R&D in that industry. I proceed to consider a model with two sectors: a non-R&D-performing service sector and a manufacturing sector whose R&D expenditures lead to productivity gains. Here, higher productivity for the R&D-intensive sector is associated with lower prices of manufactures and a higher price ratio of services to manufactures for the country. Indeed, the data shows that high productivity countries have lower prices for manufactures and, implicitly, higher services to manufactures price ratios. This implies that the overall price level will be lower in the more productive country as long as the size of the productive sector is sufficiently large.

Keywords: Prices, productivity, real exchange rates.

JEL Classification: E31, F3

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1. Introduction

What determines price differences across countries? In the absence of free trade, prices of individual goods and services across countries will be related to cross-country productivity differences. I investigate this implication using a unique microeconomic dataset of absolute prices for goods and services across half dozen European countries: Germany, France, Italy, Britain, the Netherlands, and Denmark, in 1975, 1980, 1985, and 1990.

I consider the relation between product-specific real exchange rates and cross-country productivity differences implied by R&D stocks, at the industry level and, also, at the aggregate economy level.

First, I consider an empirical framework where an industry's R&D determines its productivity. Controlling for differences in GDP per capita, wage rates, and the degree of openness, I show that the products of an industry tend to be cheaper in countries with higher stocks of R&D in that industry. That is, industry productivity differences are negatively related with product-specific real exchange rates.

At the aggregate economy level, I find that a higher R&D stock for a country is associated with lower prices for manufactures. The impact of aggregate productivity on prices of manufacturing goods is very similar to, albeit typically somewhat bigger than, the price impact of industry productivity. Furthermore, comparing the impact of aggregate R&D-induced productivity on prices in manufacturing to the impact on prices in the service sector, the relative price of services to manufactures appears to be increasing with productivity.

Models of R&D-induced growth as in Segerstrom, Anant and Dinopoulos (1990) or Aghion and Howitt (1992) predict that the intensity of innovation-related activity over time as measured by the stock of R&D, largely determines productivity levels. I construct and estimate a model that explores the relationship between prices and aggregate productivity induced by R&D expenditures. Productivity is determined by the accumulation of R&D stock in the manufacturing sector.[1] I interpret the stock of R&D to be a measure of the accumulated stock of knowledge in the domestic economy. It will then serve as an adequate proxy of the productivity level of the domestic economy if the real world is well characterized

[1] OECD data suggest that about eighty percent of R&D is performed in the manufacturing sector. This sector has historically been responsible for over ninety percent of R&D performed in the United States.

by models of R&D-induced productivity growth. Given some transportation costs or trade barriers, countries with higher productivity levels will in turn have lower prices of manufactures. In what follows, I consider the extreme case where such costs are so high that no trade takes place. Thus, the domestic technology determines the domestic price level. The model also includes a service sector that does not perform R&D. This leads to the additional testable implication of a positive relation between productivity in the R&D-intensive sector and the services to manufactures price ratio.

I test this model's implications by looking at the relation between product-specific real exchange rates and cross-country aggregate productivity differences implied by differences in aggregate R&D stocks. I classify individual products into services and manufactures to enable comparison of the effects of aggregate productivity on the prices of products in the two sectors.

Canzoneri, Cumby, and Diba (1996) use aggregate time-series data across thirteen OECD countries and find that labor productivity in manufacturing relative to services appears to be cointegrated with the price of services relative to manufactures, supporting a premise of the Balassa (1964) and Samuelson (1964) hypothesis. They also find that purchasing power parity does not hold for the manufacturing sector, contradicting a second component of the Balassa-Samuelson hypothesis.[2]

More recently, Gali, Gertler, and Lopez-Salido (2001) consider a real marginal cost measure that accounts for the influence of productivity and wages on European inflation. They show that this theoretical ratio of wages to labor productivity moves together with the inflation rate for the Euro area during the period 1970 to 1998.[3] Here, I study the price impact of productivity and wage rates separately. My results support Gali etal (2001) by providing micro-evidence for a negative relation between productivity and prices and a positive relation between wage rates and prices in six European countries for the period 1975 to 1990.

This paper deviates in several dimensions from the existing empirical literature on the

[2]Similarly, Strauss (1996) uses aggregate time-series data across seven OECD countries and finds that cross-country differences in productivity of manufactures relative to services have a cointegrating relationship with the real exchange rate, presumably due to the relation between relative productivity and the services-to-manufactures price ratio.

[3]They go on to decompose this marginal cost measure into a wage markup and an inefficiency wedge inversely related to productivity. Looking at the behavior of these two variables, they conclude that labor market frictions is a key determinant of inflation in Europe.

relation between productivity and prices. First, this paper uses a microeconomic dataset consisting of absolute prices for individual goods and services, rather than using aggregate time series price indices. The dataset is unique in that it enables exact international price comparisons at a point in time for a broad set of goods and services, including most CPI items. Among other advantages, this allows for a more careful categorization of individual items into manufactures and services to help distinguish the impact of productivity on each sector.

Second, this paper highlights the relevance of R&D as a determinant of productivity and prices. The strong positive relation between R&D and productivity has been documented by Griliches (1980) and more recently by Zachariadis (2001) and Keller (2002.) However, there is no previous attempt to relate models of R&D-induced productivity to international price differences. In doing so, this paper proposes the use of R&D stocks as an alternative proxy for productivity that is free of certain problems associated with direct measures of total factor productivity or labor productivity.[4] The use of R&D stocks to instrument for productivity serves as a robustness check for previous work that has used direct measures of productivity.

The third way in which this paper deviates from the existing literature, is in its treatment of the manufacturing and service sectors. The previous literature has widely treated manufactures as "traded" and services as "non-traded". In fact, all commodities are better characterized by a certain degree of non-tradeability. There is a non-traded domestic component in the production of any good or service.[5] Thus, non-tradedness is not necessarily the defining characteristic of services relative to manufactures. In the current paper, I emphasize the tendency of manufactures to be intensive in R&D relative to services, focusing on this

[4]To calculate productivity levels one usually makes the assumption that at some initial date the countries in the sample have identical productivity levels, and then accumulates these levels to the present by using measures of productivity growth. Measures of productivity growth in turn face the problem of being driven by demand-induced cyclicality which renders them problematic proxies of technological change. Finally, the use of labor productivity ignores variations in capital and intermediate inputs.

[5]In this spirit, Crucini, Telmer, and Zachariadis (2001) use a ratio of exports and imports over output ("trade share"), and a measure of local input content ("input share") to capture the degree of tradedness for commodities produced in any industry. Electricity, Gas, and Water (ISIC 4150), commonly treated as a "non-traded" service industry, has a trade share of 72 percent and an input share of 26 percent, whereas Printing and Publishing (ISIC 3420) and Products of Petroleum and Coal (ISIC 3540), both of which are commonly treated as "traded", had respective trade shares of 15 and 40 percent and input shares of 24 and 14 percent respectively.

(rather than on frictionless trade) as the defining characteristic of the manufacturing sector. As a result, the framework presented here, in contrast to previous work, is consistent with a lower price level in the high productivity countries.

The data supports the prediction that countries with higher R&D stocks will tend to have lower prices of manufacturing goods.[6] The law of one price therefore fails for manufactures. This is consistent with other empirical evidence on the failure of the law of one price (LOP), including Isard (1977), Giovannini (1988), Knetter (1993), Haskel and Wolf (2001), and Crucini, Telmer, and Zachariadis (2001.) I also find that countries with higher R&D stocks have higher price ratios of services relative to manufactures. This finding is consistent with a basic premise of the Balassa-Samuelson hypothesis and with Canzoneri, Cumby, and Diba (1996).[7] A novel implication here is that depending on the relative size of the manufacturing sector, high productivity countries can have lower overall price levels. This contrasts markedly with the Balassa-Samuelson hypothesis.[8]

Finally, we see that wage rates have a positive impact on the prices of manufactures and services and that this impact is almost always stronger for services suggesting a wage markup in excess of productivity gains for that sector. Similarly, we note a positive impact of GDP per capita on international price differences that is always stronger for the service sector.

In the next section, I briefly describe the data, and in the third section I examine the relationship between industry-level productivity differences and real exchange rates for individual goods and services. In the fourth section, I present a framework where R&D in the manufacturing sector raises aggregate productivity which in turn affects real exchange rates. I go on to describe the statistical analysis and results for this empirical model. The final section briefly concludes.

[6]The inverse relation between R&D stocks and prices that exists in the data also provides evidence about the link between R&D and productivity in support of models of R&D-based productivity growth.

[7]Thus, an essential component of the Balassa-Samuelson hypothesis is shown to be empirically relevant, using two distinct measures of productivity and price data which differ in several dimensions.

[8]The Balassa (1964) and Samuelson (1964) hypothesis states that countries with higher relative productivity for traded goods (manufactures) will have a higher price level than other countries. This is because in the Balassa-Samuelson framework higher productivity in the traded goods sector leads to higher wages and higher prices in the non-traded (services) sector. Assuming LOP holds for traded goods, the overall price level is then higher in countries with higher prices for nontraded goods.

2. Data

I use Eurostat Survey prices of household goods and services across six European countries, Germany, France, Italy, the U.K., the Netherlands, and Denmark, in 1975, 1980, 1985 and 1990. A detailed description of the price data is given in Crucini, Telmer, and Zachariadis (2001). In this dataset, manufactures are goods like "Video recorder" or "Selected Brand of Motor car: less than 1.2 l, 998 cc" and services are items like "cup of coffee at cafe" or "Ladies' hairdresser: shampoo and set." Exactly the same item (for example the same brand of the same car) is sampled across European capitals at a point in time.

I use repeated cross-sections rather than a dynamic panel approach, since there is not always a direct match between goods sampled in different years. The repeated cross-section approach utilizes the maximum number of goods for every cross-section.[9] Considering bilateral price differences between the six countries provides 245 observations for services and 1305 observations for manufactures in 1975 (for 49 services and 261 manufacturing goods respectively), 230 and 1195 observations in 1980 (for 46 services and 239 manufactures,) 425 and 1840 observations in 1985 (for 85 services and 368 manufactures), and 270 and 1185 observations in 1990 (for 54 services and 237 manufactures.) For the industry-level application I exclude Denmark because of data unavailability. This gives 1324 observations for 331 goods and services in 1975, 1080 observations for 270 products in 1980, 2128 observations for 532 products in 1985, and 1456 observations for 364 products in 1990.

In figures 1a-d and 2a-d, I present each country's log deviations from German manufacturing goods prices and services prices respectively. In each case, panels a, b, c, and d present data for 1975, 1980, 1985, and 1990 respectively. The log deviations from German prices are presented in ascending order. Points below the zero line indicate goods for which a price is lower in Germany. As shown in figures 3a-d Germany is the country with the highest stock of R&D among the six countries in the sample throughout this period, with the exception of 1975. For 1975, 1980, 1985, and 1990, 46, 53, 60, and 56 percent of manufacturing goods were respectively cheaper in Germany, and 59, 64, 48, and 59 percent of services were more

[9] A panel approach would greatly limit the number of goods for any given year since not all goods that exist in a cross-section can be matched across cross-sections. Moreover, matching these goods over time would introduce a source of measurement error due to intertemporal mismatching, which we avoid when considering exactly the same good across locations at a point in time.

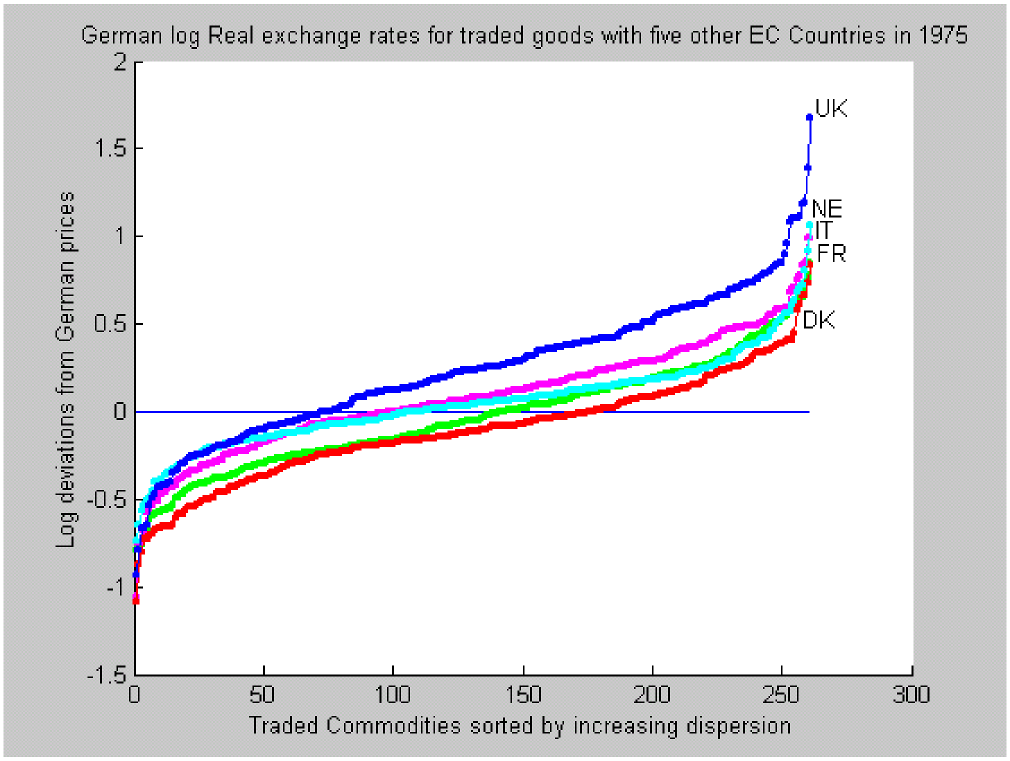


Figure 1a

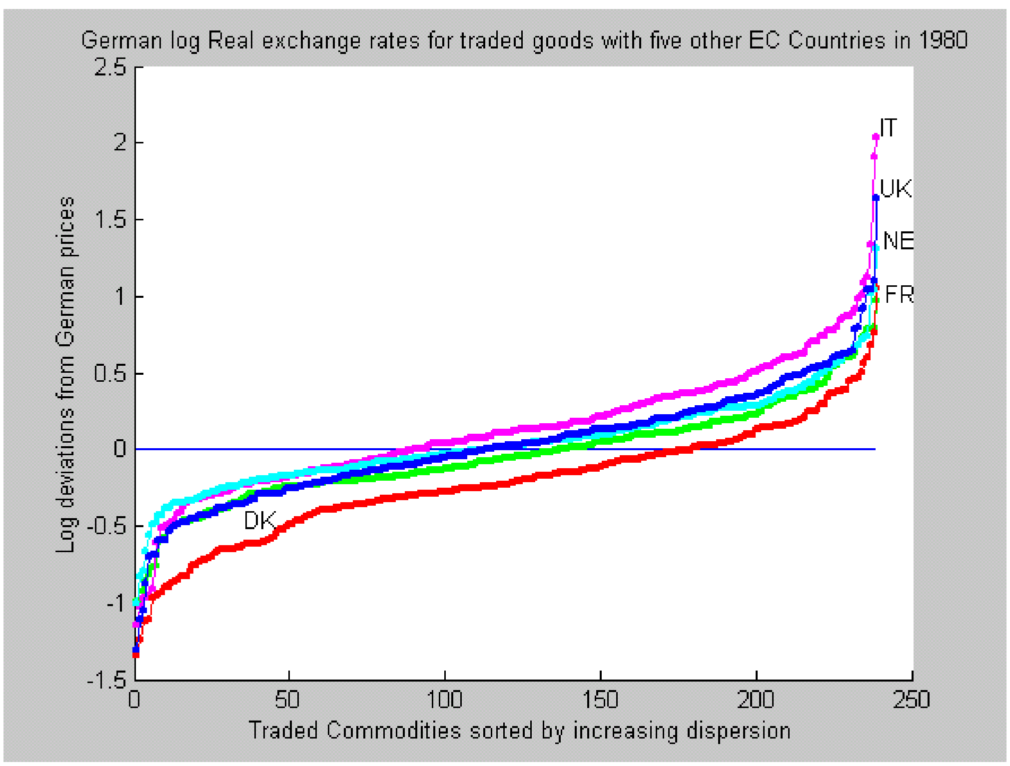


Figure 1b

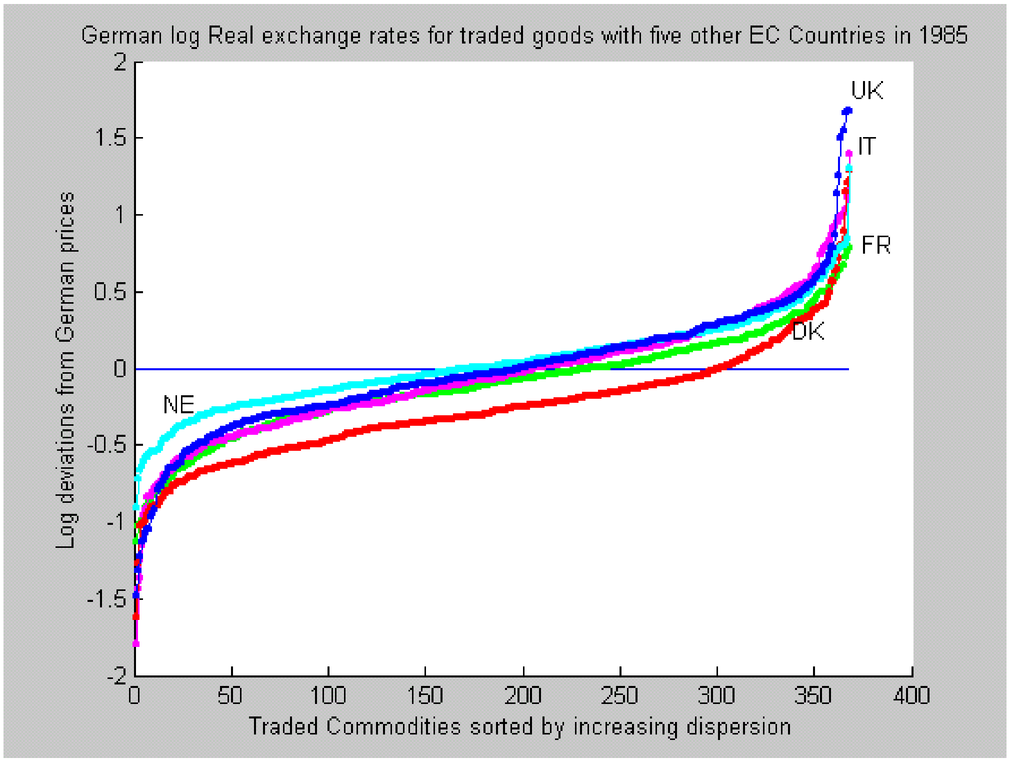


Figure 1c

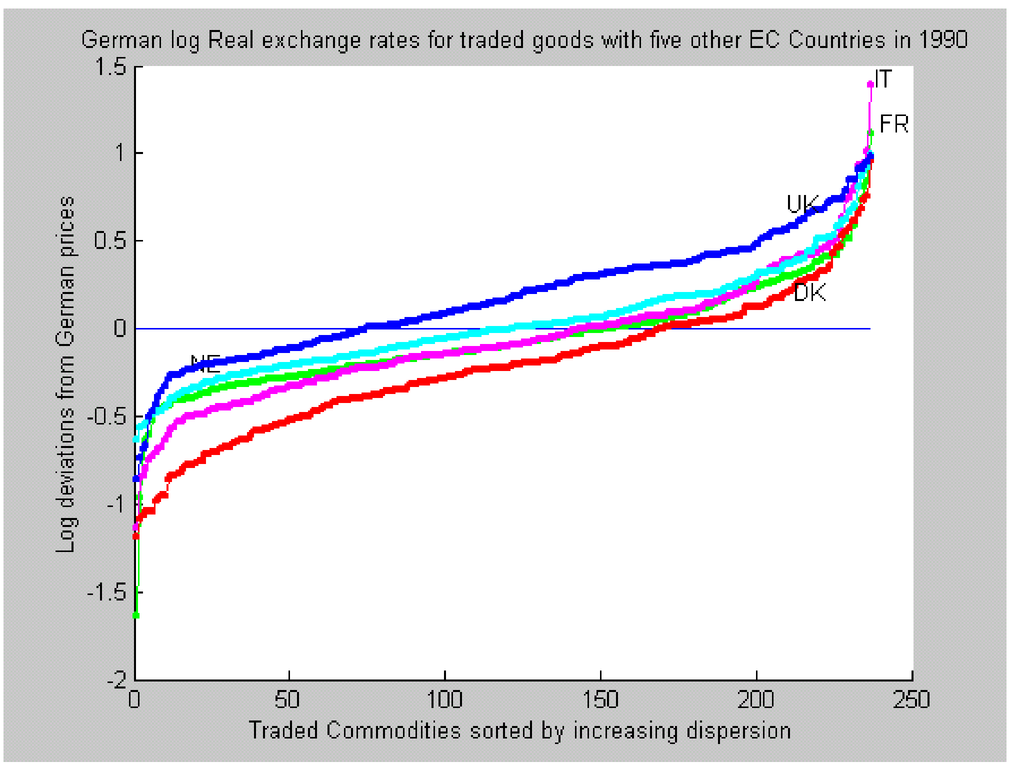


Figure 1d

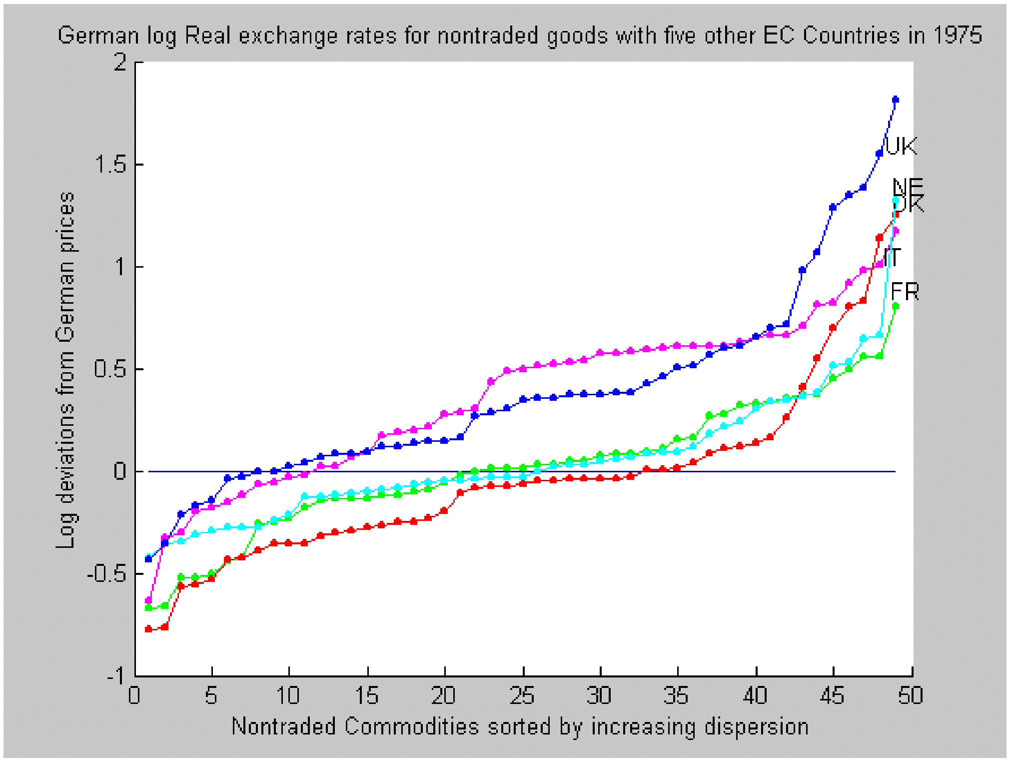


Figure2a

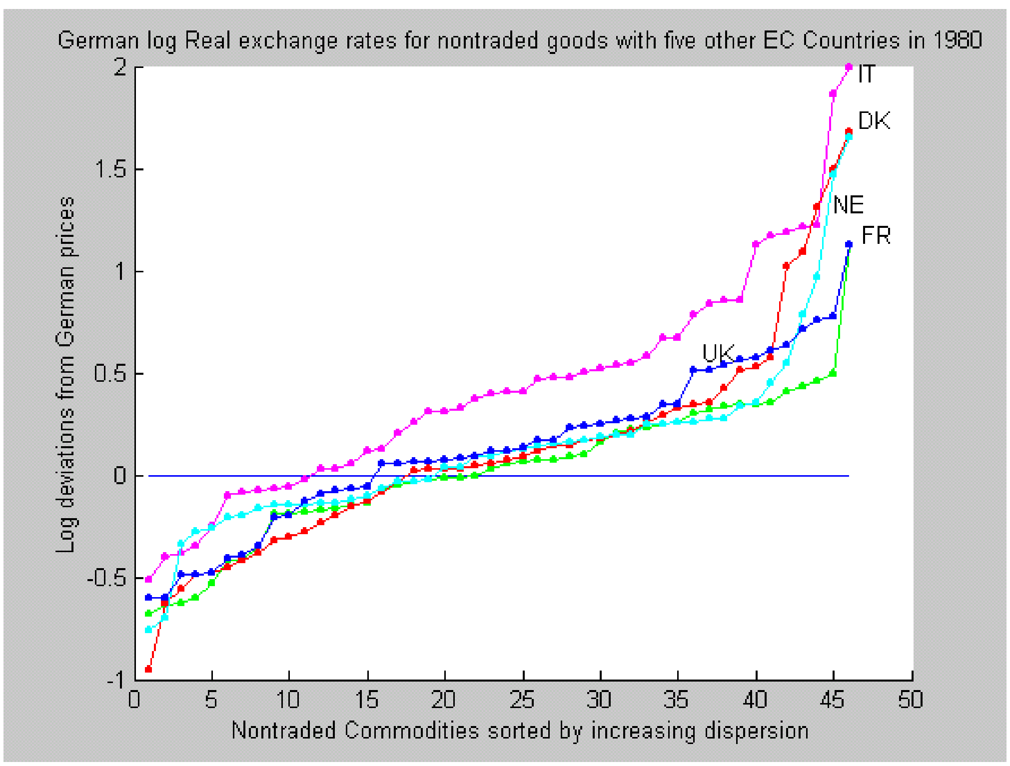
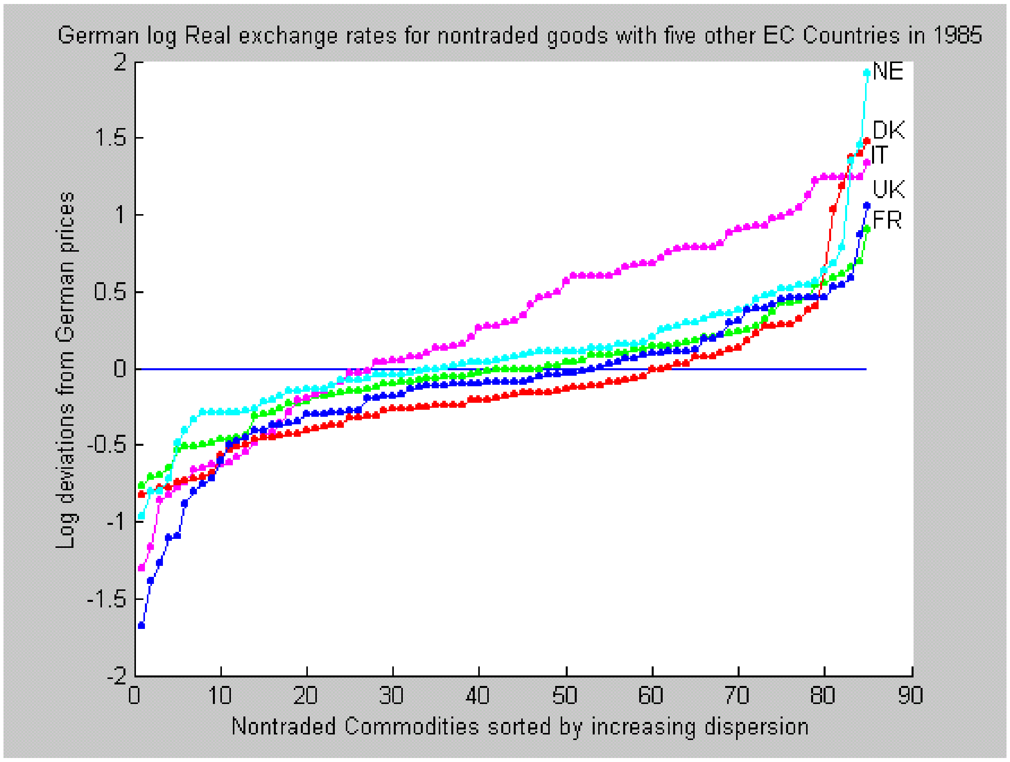


Figure 2b



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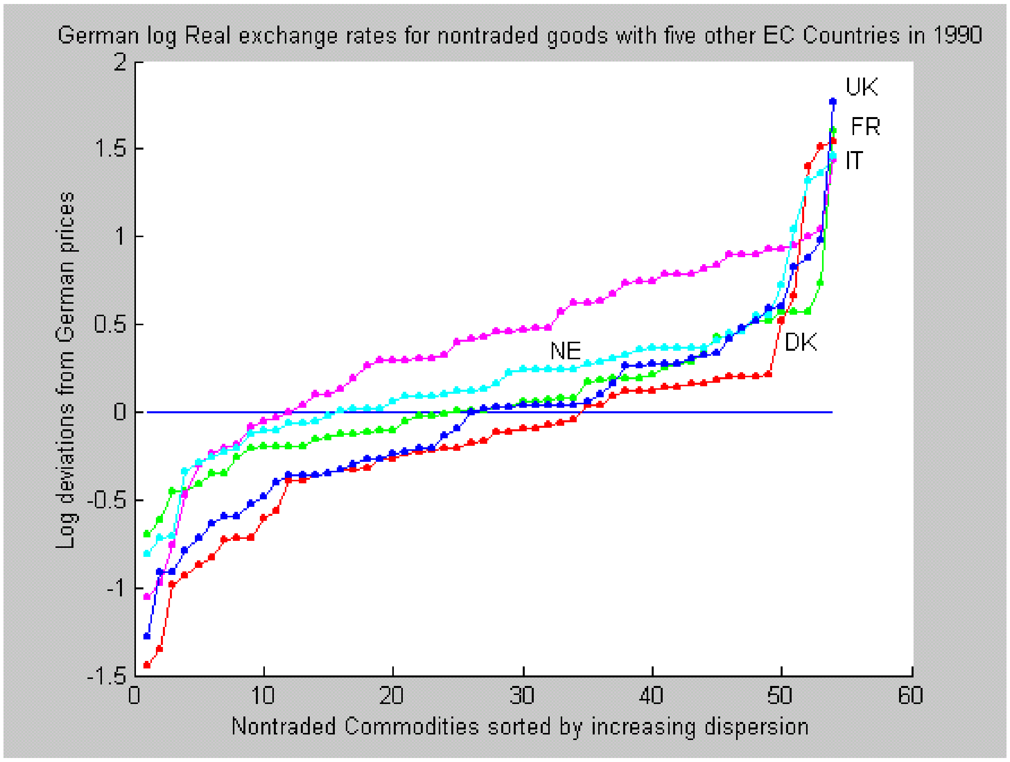

Figure 2d

expensive there.[10] The single year for which a majority of manufacturing goods in Germany had prices higher than in the other countries is 1975, for which the U.K. had the highest stock of R&D. In that same year, 76 percent of manufacturing goods prices in the U.K. were lower than in the other five countries providing informal evidence about the impact of R&D stocks on productivity and prices.

I construct the R&D capital stock for each of the six European countries in the sample using ten percent as the rate of depreciation for this stock. This depreciation rate is based on the findings of Nadiri and Prucha (1993) and is also used by Bernstein (1996). The equation is $H(R_j) = R_j + (1 - 0.1) \times H(R_{j-1})$, with R_j standing for R&D expenditures in constant prices and $H(R_j)$ standing for the implied stock of knowledge in country j. The benchmark value for this stock is obtained by assuming a steady state for the benchmark year. This implies $H(R_0) = \frac{R_0}{0.12}$, where the denominator is the sum of the assumed rate of depreciation and the growth rate. I use the 1997 ANBERD data from the OECD. This provides R&D expenditures at current prices in national currencies from 1973 onwards. I use the 1994 OECD STAN data to construct deflators from value-added output for each industry and country, and use these to obtain R&D expenditures in constant 1985 prices. Finally, I use US dollar exchange rates to convert R&D expenditures in constant 1985 prices to a common currency. In figures 3a-d, I present R&D stocks in millions of $US for the total economy, and for the manufacturing and service sectors for the six European countries in the sample. The U.K. has the highest stock in 1975, but is eventually surpassed by Germany which has the highest stock of R&D in 1980, 1985, and 1990. For each of the six countries in the sample, it is apparent that most of R&D is performed in the manufacturing sector.

I also construct industry-specific R&D stocks for a group of two-digit industries for the purposes of the disaggregated analysis of the next section. These industries are reported in Table 1. Wages and employment data, used to construct wage rates as the ratio of total wages and salaries to total employment, for the same group of industries were obtained from the 1994 OECD Sectoral Database.

Finally, Gross Domestic Product per Capita data in constant $US, the degree of openness, and population size for each country in the sample are obtained from the Penn World Tables.

[10]Comparing the same-year price deviations for manufactures with those for services, log price deviations for services appear to be displaced upwards relative to those of manufacturing goods.

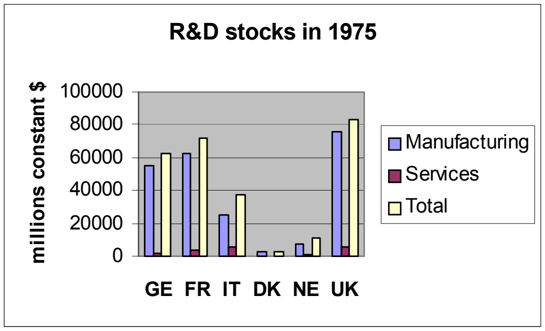

Figure 3a

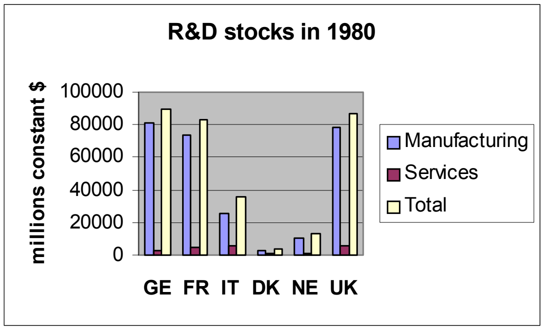

Figure 3b

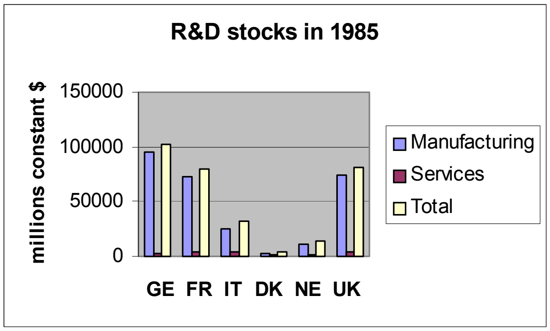

Figure 3c

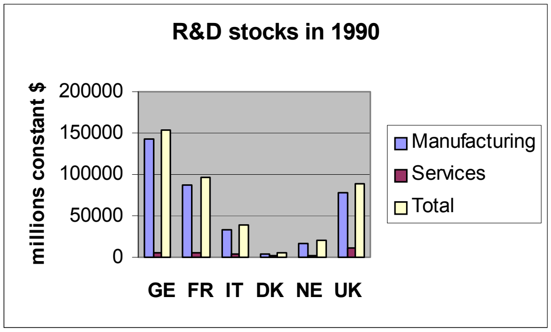

Figure 3d

Industry Description	SIC code
Food, Beverages, and Tobacco	31
Textiles, Apparel, and Footwear	32
Paper, Products, and Printing and Publishing	34
Chemicals, Products, and Drugs and medicines.	351-352
Products of Petroleum and Coal	353-354
Rubber and Plastic	355-356
Pottery, China, Earthware, Glass, and Glass Products	36
Iron, steel, and Non-ferrous metal basic industries	37
Fabricated metal products, except machinery	381
Manufacture of machinery except electrical	382
Office, computing and accounting machinery	3825
Electrical machinery, apparatus, appliances.	383
Radio, tele., communications equipment.	3832
Motor Vehicles	3843
Prof., scientific, measuring and control	385
Services[11]	6-9

Table 1: Availability of industry-level R&D data

3. The relation between productivity and real exchange rates

Are international productivity differences an important determinant of international price differences? Controlling for differences in GDP per capita, wage rates, the degree of openness, and population size, I show that the answer to this question is yes. A product of a certain industry is cheaper in the country with the higher stock of R&D in that industry.

I study the relation between international differences of individual products prices on the one-side and international industry-level productivity differences on the other side, using a micro dataset of absolute prices across five European countries: Germany, France, Italy, the U.K., and the Netherlands, in 1975, 1980, 1985, and 1990.

To check the robustness of estimates of the impact of industry-level R&D-induced productivity on individual price differences, I include GDP per capita along with the country's degree of openness on the right-hand side. These control for non-technological factors that might have an impact on prices. I also use industry-country-specific wage rates in place of

[11] This category includes Restaurants, Hotels, Transport, Storage, Communication, Financing, Insurance, and Personal services.

GDP per capita[12]. Moreover, to check whether the link between R&D stocks and prices is due to a scale effect rather than a productivity effect, I include population size along with R&D stocks as explanatory variables of international price differences. Finally, I consider country-specific and industry-specific dummies in order to capture other country and industry factors which might have an impact on international price differences. For example, country effects control for monetary policy differences[13], while industry effects control for differences in the market structure among industries.

I estimate the following specification for every manufacturing good or service i and country pair jk[14]

$$s_{ijk} = \zeta h_{ljk} + \gamma x_{ljk} + u_{ijk}$$

where s_{ijk} =log(π_{ij})-log(π_{ik}) stands for log price differences (product-specific log real exchange rates) between countries j and k for commodity i, π_{ij} and π_{ik} are prices of product i in country j and k respectively converted to US dollars, u_{ijk} is an error term, and h_{ljk} =log($H(R_{lj})$)-log($H(R_{lk})$) is the cross-country difference between R&D stocks in industry l for countries j and k, and ζ the parameter capturing the effect of differences in the knowledge stock on cross-country price differences. I control for additional variables in x_{ljk}. This includes log differences in the degree of a country's openness and population size, as well as log differences in GDP per capita. I also consider a specification with industry wage rates in place of GDP per capita. Finally, I consider country and industry-specific dummies to control for omitted country and industry-specific factors that might influence price differences. Throughout, I apply OLS and correct standard errors for heteroskedasticity.

Table 2 presents the results. Controlling for differences in GDP per capita and the degree of openness, a product is cheaper in the country with the higher industry-specific stock of R&D, with price elasticities for R&D ranging from -.114 in 1990 to -.023 in 1980. Replacing GDP per capita with industry wage rate differences, and correcting again for differences in GDP per capita and the degree of openness, we can see in Table 2A that price elasticities for R&D-induced productivity now range from -0.069 in 1975 to -0.015 in 1985. As we can see from Tables 2 and 2A, there is no qualitative change in the results when industry wage

[12]This is consistent with the theoretical framework in the next section.
[13]Likely to be important in the case of Italy and the U.K. for part of this period.
[14]Every country j relative to Germany.

Real Exchange Rates explained by:	Ind. R&D stock	GDPperCapita	Openness	$\bar{R}^2$ in %
1990 (364 goods,1456 obss)				
	-.017 (-2.87)*			3.9
	-.099 (-10.27)*	1.72 (10.40)*		6.9
	-.114 (-11.03)*	1.898 (10.98)*	-.112 (-4.23)*	7.9
with population[-.067(-1.38)]	-.112 (-10.78)*	2.206 (7.75)*	-.213 (-2.76)*	7.9
with industry dummies	-.078 (-6.02)*	1.645 (8.23)*	-.077 (-2.73)*	9.7
with country dummies	-.112 (-9.97)*			7.8
country&industry dummies	-.047 (-2.78)*			10.1
1985 (532 goods,2128 obss)				
	-.009 (-1.77)***			0.1
	-.019 (-2.57)*	.213 (1.65)***		0.3
	-.026 (-3.35)*	.283 (2.21)**	-.095 (-4.66)*	1.0
with population[-.071(-2.05)**]	-.021 (-2.64)*	.489 (2.88)*	-.202 (-3.59)*	1.0
with industry dummies	-.019 (-2.19)**	.174 (1.26)	-.091 (-4.46)*	2.8
with country dummies	-.050 (-4.89)*			2.1
country&industry dummies	-.072 (-5.42)*			4.5
1980 (270 goods, 1080 obss)				
	-.006 (-.81)			0.3
	-.017 (-2.16)**	.632 (5.48)*		1.8
	-.023 (-2.53)*	.634 (5.49)*	-.055 (-1.68)***	2.0
with population[.002 (.04)]	-.023 (-2.49)*	.631 (4.70)*	-.051 (-.64)	1.9
with industry dummies	.005 (.47)	.715 (5.12)*	-.026 (-.79)	6.7
with country dummies	-.074 (-6.49)*			7.1
country&industry dummies	-.061 (-4.65)*			10.2
1975 (331 goods, 1324 obss)				
	-.054 (-7.11)*			3.1
	-.055 (-7.84)*	.979 (10.60)*		6.0
	-.069 (-9.19)*	1.064 (11.41)*	-.202 (-9.00)*	8.9
with population[-.053 (-1.89)***]	-.067 (-8.96)*	1.094 (11.55)*	-.293 (-5.19)*	9.2
with industry dummies	-.065 (-8.11)*	.988 (9.81)*	-.185 (-7.70)*	13.3
with country dummies	-.045 (-5.15)*			10.0
country&industry dummies	-.025 (-2.28)**			14.9

Table 2: Explaining cross-country price differences using industry-level R&D stock differences.

Notes: t-statistics in parentheses.

Real Exchange Rates explained by:	Ind. R&D stock	Wages	Openness	$\bar{R}^2$ in %
1990 (364 goods,1456 obss)				
	-.017 (-2.87)*			3.9
	-.018 (-2.98)*	.088 (2.37)*		2.4
	-.020 (-3.15)*	.102 (2.59)*	-.033 (-1.15)	2.9
with population[.292(9.42)*]	-.098 (-9.46)*	.152 (3.75)*	.319 (6.63)*	5.1
with industry dummies	-.018 (-1.49)	.052 (1.28)	-.029 (-0.97)	6.2
with country dummies	-.112 (-9.97)*			7.8
country&industry dummies	-.047 (-2.78)*			10.1
1985 (532 goods,2128 obss)				
	-.009 (-1.77)***			0.1
	-.010 (-1.88)***	.026 (1.07)		0.1
	-.015 (-2.61)*	.067 (2.51)*	-.106 (-4.83)*	0.9
with population[.020(.73)]	-.019 (-2.44)*	.069 (2.54)*	-.079 (-1.72)***	0.9
with industry dummies	-.014 (-1.68)***	.057 (1.92)***	-.103 (-4.57*)	2.8
with country dummies	-.050 (-4.89)*			2.1
country&industry dummies	-.072 (-5.42)*			4.5
1980 (270 goods, 1080 obss)				
	-.006 (-.81)			0.3
	-.009 (-1.19)	.069 (1.93)***		0.1
	-.022 (-2.29)**	.121 (2.92)*	-.108 (-2.82)*	0.3
with population[.121(3.43)*]	-.030 (-3.02)*	.108 (2.64)*	.121 (1.56)	0.3
with industry dummies	-.001 (-0.11)	.074 (1.71)***	-.052 (-1.29)	4.7
with country dummies	-.074 (-6.49)*			7.1
country&industry dummies	-.061 (-4.65)*			10.2
1975 (331 goods, 1324 obss)				
	-.054 (-7.05)*			3.1
	-.061 (-7.89)*	-.021 (-5.99)*		4.1
	-.069 (-8.42)*	-.018 (-5.00)*	-.142 (-6.27)*	4.3
with population[.016 (.62)]	-.070 (-8.49)*	-.018 (-5.00)*	-.112 (-1.98)**	4.3
with industry dummies	-.065 (-7.57)*	-.003 (-0.76)	-.112 (-4.64)*	7.2
with country dummies	-.045 (-5.15)*			10.0
country&industry dummies	-.025 (-2.28)**			14.9

Table 2A: Explaining cross-country price differences using industry-level R&D stock differences controlling for wage rates.

Notes: t-statistics in parentheses.

rates replace GDP per capita as explanatory variables in the regression. The same is true when we remove potential scale effects by including population size in the set of explanatory variables. We conclude that the estimates for the impact of R&D-induced productivity on prices are robust across the different cross-sections and specifications.

Finally, looking again at Tables 2 and 2a, we can also see that countries with a higher GDP per capita or higher wage rates are characterized by higher prices, and countries with a higher degree of openness have lower prices.

4. A two-sector Model

The previous section documents a relation between R&D-induced productivity and prices across industries and countries. Here, I investigate this relation further by considering a two-sector model where R&D is performed in the economy. The model considered here assumes two perfectly competitive final goods sectors in each country, the non-R&D performing service sector which uses only labor inputs, and the R&D performing manufactured goods sector which uses both labor and capital.[15] Labor flows freely across sectors and capital flows freely across countries so that wages are equalized across the sectors of the domestic economy and the interest rate is equalized across countries.[16]

Countries with higher R&D stocks are more productive relative to countries with lower stocks of R&D. Thus, productivity differences between countries exist due to different domestic stocks of knowledge which do not diffuse across countries. As a result, the price of the final good is not equalized across countries. Instead, it is cheaper in the most productive country. Such price differences are maintained in the absence of trade.

Balassa (1964) and Samuelson (1964) assume that manufacturing goods flow freely and thus have identical prices across countries. In addition, more productive countries have higher prices of services relative to manufactures, resulting in a higher overall price level. The framework I consider here allows high-productivity countries to maintain lower manufacturing prices relative to low-productivity countries. Intuitively, in a world without any trade the more productive country requires less inputs and incurs lower costs of production

[15] Alternatively, one could allow for labor and capital to be used in both sectors and assume the service sector to be labor intensive.

[16] This means that supply is so elastic that demand has no effect on the relative price of services.

relative to less productive countries.[17]

The model presented here is a variant of the Schumpeterian framework of Aghion and Howitt (1998). The innovation process uses only the manufacturing sector's final output to produce inventions which can be thought of as new forms of capital services that benefit the domestic manufacturing sector. As a result, the productivity level of the manufacturing sector is increasing over time while the productivity level of services remains constant.[18] Thus, aggregate technological progress is induced by R&D performed in the domestic manufacturing sector. Finally, there are no international spillovers of knowledge and there is a scale effect so that countries with higher accumulation of R&D are presumed to have higher levels of productivity. We assume that both goods are not traded so that productivity-determined price differences are maintained across countries.

The production functions for manufactures and services in each country are given respectively by

$$\begin{aligned} Y_{Mt} &= (A_{Mt}L_{Mt})^{1-\alpha}K_{Mt}^{\alpha} \qquad \text{(E1)} \\ Y_{St} &= A_S L_{St} \end{aligned}$$

where Y_{Mt} (Y_{St}), A_{Mt} (A_S), L_{Mt} (L_{St}), and K_{Mt} stand for output, technology level, labor input, and capital input, and the subscripts M and S indicate the Manufactures and Service sectors respectively. The innovation process uses the manufacturing sector's final output to produce inventions which can be thought of as new forms of capital services that benefit the domestic manufacturing sector. Thus, the aggregate level of technology grows at the rate $g_t = (1-\beta)\frac{\dot{A}_{Mt}}{A_{Mt}}$ where $(1-\beta)$ is the output share of the manufacturing sector in the domestic economy. The rate of technological progress in the manufacturing sector is $\frac{\dot{A}_{Mt}}{A_{Mt}} = \sigma\lambda\frac{R_{Mt}}{A_{Mt}}$, where σ stands for innovation size and λ stands for research productivity both assumed to be time-invariant. I assume constant returns to R&D so that technological progress is proportional to R&D-intensity, and the level of technology is proportional to the stock of knowledge implied by the accumulated stock of R&D expenditures. The level of technology

[17] The in-between case of goods that are traded but face transportation costs is also compatible with lower prices in the more productive country.

[18] Alternatively, one could assume that both sectors benefit from the accumulation of R&D but the manufacturing sector benefits more so than the service sector.

in the manufacturing sector as of period t is thus given by

$$A_{Mt} = \int_{s=0}^{t} \dot{A}_{Ms} ds = \sigma\lambda \int_{s=0}^{t} R_{Ms} ds \tag{E2}$$

Setting the value of the marginal product of capital equal to the world interest rate, and the value of the marginal product of labor in each sector equal to the wage rate, I obtain conditions (E3) to (E5):

$$P_{Mt} \alpha A_{Mt}^{1-\alpha} k_{Mt}^{\alpha-1} = r_t \tag{E3}$$

$$P_{Mt}(1-\alpha) A_{Mt}^{1-\alpha} k_{Mt}^{\alpha} = w_{Mt} \tag{E4}$$

$$P_{St} A_S = w_{St} \tag{E5}$$

where $k_{Mt} = K_{Mt}/L_{Mt}$ is the capital-labor ratio in manufacturing.

Solving equation (E3) for k_M gives $k_{Mt} = (r_t/P_{Mt})^{\frac{1}{\alpha-1}} \alpha^{\frac{1}{1-\alpha}} A_{Mt}$. Substituting for k_{Mt} in equation (E4) gives $w_{Mt}(r_t, A_{Mt}) = \Gamma A_{Mt} P_{Mt}$, where $\Gamma \equiv (1-\alpha)\alpha^{\frac{\alpha}{1-\alpha}}(r_t/P_{Mt})^{\frac{\alpha}{\alpha-1}}$ Assuming international mobility of capital equalizes the real return of capital across countries, and that the share of capital is the same across countries, then equation E5 implies

$$\frac{P_{Mt}}{E_t P_{Mt}^*} = \frac{A_{Mt}^*}{A_{Mt}} \frac{w_{Mt}}{E_t w_{Mt}^*} \tag{E6}$$

so that international differences in prices of manufactures are positively related to international wage differences, and inversely related to international productivity differences.

Using expression (E2) while assuming that innovation size and research productivity are identical across countries so that $\sigma = \sigma^*$, and $\lambda = \lambda^*$, we get

$$\begin{aligned} \frac{P_{Mt}}{E_t P_{Mt}^*} &= \left(\frac{\int_{s=0}^{t} R_{Ms} ds}{\int_{s=0}^{t} R_{Ms}^* ds} \right)^{-1} \left(\frac{w_{Mt}}{E_t w_{Mt}^*} \right) \\ &= \left(\frac{H(R_{Mt})}{H(R_{Mt}^*)} \right)^{-1} \left(\frac{w_{Mt}}{E_t w_{Mt}^*} \right) \end{aligned} \tag{E7}$$

In the empirical application, I proxy $H(.)$ with the accumulated stock of R&D so that $H(R_{Mt}) = \sum_{s=0}^{t} R_{Ms}$.

The above expression implies a relation between real exchange rates and cross-country differences in accumulated R&D expenditures of the manufacturing sector. Taking logs, then expression (E7) can be written as

$$\log P_{Mt} - \log E_t P^*_{Mt} = \xi[\log(H(R_M)/w_{Mt}) - \log(H(R^*_M)/E_t w^*_{Mt})] \tag{E8}$$

where ξ is negative according to theory. I estimate this relation for manufacturing as specification (I). I also decompose the effect of the knowledge stock and the wage rate to consider

$$\log P_{Mt} - \log E_t P^*_{Mt} = \zeta[\log(H(R_M) - \log H(R^*_M)] + \gamma[\log w_{Mt} - \log w^*_{Mt}] \tag{E9}$$

where ζ is negative and γ positive according to theory. I estimate this relation for manufacturing as specification (II), using GDP per capita to instrument for the wage rate in the first instance, and using the wage rate in the second instance.

Finally, assuming wage equalization across sectors, substituting for w_t in expression (E5), and rearranging, we get $\frac{P_{St}}{P_{Mt}} = \Gamma \frac{A_{Mt}}{A_S}$, so that the relative price ratio of services to manufactures is positively related to the productivity of the manufacturing sector and inversely related to the productivity of the service sector. The latter expression can be used to express the domestic to foreign price ratio of services to manufactures as $(\frac{P_{St}}{P_{Mt}})/(\frac{EP_{St}}{EP_{Mt}}) = \frac{A_{Mt}}{A_S}/\frac{A^*_{Mt}}{A^*_S}$. Assuming that the level of technology in the service sector is similar across countries so that $A_S = A^*_S$[19] then the above equation is consistent with the following relation

$$\log P_{St} - \log E_t P^*_{St} = \varphi(\log H(R_M) - \log H(R^*_M)) \tag{E9\^{}}$$

where φ is negative according to theory. I estimate this relation for the service sector as specification (II). Finally, relaxing the assumption about $A_S = A^*_S$, I also consider the implicit relation

$$\log P_{St} - \log E_t P^*_{St} = \psi(\log H(R_M)/H(R_S) - \log H(R^*_M)/H(R^*_S)) \tag{E10}$$

[19] One of the postulates of the Balassa model (and consistent with the Baumol-Bowen effect) is that productivity levels for non-tradeables are closer across countries than those for tradeables. Indeed, for 1985 the mean of absolute differences across countries for R&D stocks in manufacturing was 1.35 compared to 0.89 for services. For 1980, the mean was 1.5 for manufacturing compared to 0.73 for services.

where ψ is negative according to theory. I estimate this relation for the service sector as specification (III).

Finally, the price level for any one country is given by weighting manufactures and services prices as follows,

$$\begin{aligned} P_t &= P_{St}^{\beta} P_{Mt}^{1-\beta} \\ P_t^* &= (P_{St}^*)^{\beta^*} (P_{Mt}^*)^{1-\beta^*} \end{aligned} \tag{E11}$$

where β stands for the output share of the service sector in the economy. Thus, a large productive sector (small β) can sustain a lower overall price level in the most productive country.

Estimation and results

Specifications E8 to E10 are assumed to hold for every manufacturing good or service i and country pair jk[20] so that

$$s_{ijk} = \zeta h_{jk} + \gamma x_{jk} + u_{ijk} \tag{E12}$$

where s_{ijk} =log(π_{ij})-log(π_{ik}) stands for log price differences (product-specific log real exchange rates) between countries j and k for commodity i, π_{ij} and π_{ik} are prices of product i in country j and k respectively converted to US dollars, u_{ijk} is an error term, and $h_{jk} = \log(H(R_M)/w_{Mt}) - \log(H(R_M^*)/E_t w_{Mt}^*)$ is the cross-country difference of ratios of R&D stocks to the wage rate for specification I.[21] In specification II, h_{jk} =log$H(R_{Mj})$-log$H(R_{Mk})$, are cross-country differences in manufacturing sector R&D stocks, and in specification III, $h_{jk} = \log H(R_M)/H(R_S) - \log H(R_M^*)/H(R_S^*)$ are cross-country differences of ratios of R&D stocks in manufacturing relative to the service sector. For all specifications, ζ is the parameter capturing the effect of differences in R&D-induced productivity on international price differences.

I perform robustness checks for the basic specifications by including a set of explanatory variables, x_{jk}, on the right hand side of E12. The two-sector model implies that wages play

[20] Every country j relative to Germany.

[21] This specification may suffer from endogeneity problems since wages are likely to be affected by prices over the business cycle. Nevertheless, the estimates for the impact of R&D stocks are not sensitive to the inclusion of the wage rate, as can be seen by comparing estimates in specification (I) with those for specification (II). Moreover, instrumenting wages with real GDP per capita gives very similar results.

a role in the determination of prices. I first consider a specification that includes GDP per capita, instrumenting for wage rates.[22] I use the log of cross-country differences in GDP per capita. As an additional robustness check, I include the degree of a country's openness. This extends the empirical specification beyond the narrowly defined structural link between R&D and price differences implied by the two-sector model above. Finally, I also estimate the relationship between productivity and prices by replacing GDP per capita with the wage rate for specifications II and III.

I perform separate regressions for price differences of manufacturing goods and services. Considering bilateral price differences between the six countries for manufacturing goods (and services) provides 1305 (245) observations in 1975, 1195 (230) observations in 1980, 1840 (425) in 1985, and 1185 (270) in 1990. I report estimates and t-statistics in Tables 3 and 4 for manufactures and services respectively. The standard errors are heteroskedasticity-corrected.

In the first three columns of Table 3, I report results for manufacturing goods while adjusting R&D stocks with the wage rate as implied by equation E8 and specification (I.) Higher productivity countries are shown to have lower prices of manufacturing goods. Correcting for differences in GDP per capita, and the degree of openness, price elasticities for R&D range from -.090 in 1990 to -.069 in 1975.

In columns four to six of Table 3 and columns one to three of Table 3A, I report estimates of the impact of aggregate R&D stock differences on international price differences as implied by equation E9 and specification II. In Table 3, I present estimates of the price impact of productivity controlling for cross-country differences in GDP per capita and the degree of openness, and in Table 3A I present estimates controlling for differences in wage rates and the degree of openness. The results from specification II reported in Tables 3 and 3A are similar to the estimates for specification (I), with higher productivity countries exhibiting a tendency to have lower prices of manufacturing goods. Correcting for differences in GDP per capita, and the degree of openness, price elasticities for R&D now range from -.084 in 1990 to -.067 in 1975. Replacing GDP per capita with wage rate differences, and

[22] Intuitively, wages are higher in countries with higher real GDP per capita. At the same time, unlike wages, real GDP per capita is a variable determined by long-run factors unrelated to the business cycle and the short-run behavior of prices.

	specification (I)			specification (II)		
1975						
R&D-stock	-.025 (-5.24)*	-.022 (-4.63)*	-.069 (-9.29)*	-.018 (-3.62)*	-.021 (-4.29)*	-.067 (-9.04)*
GDP-per-capita		.776 (8.03)*	.875 (9.11)*		.829 (8.54)*	1.039 (10.37)*
Openness			-.324 (-9.36)*			-.315 (-9.22)*
$\bar{R}^2$ in %	6.1	5.5	10.7	5.3	5.2	10.2
1980						
R&D-stock	-.035 (-5.62)*	-.047 (-7.11)*	-.074 (-7.83)*	-.029 (-4.86)*	-.049 (-7.17)*	-.069 (-7.56)*
GDP-per-capita		.583 (4.69)*	.676 (5.35)*		.710 (5.38)*	.828 (6.13)*
Openness			-.198 (-4.46)*			-.158 (-3.80)*
$\bar{R}^2$ in %	3.6	4.4	5.7	3.1	4.5	5.4
1985						
R&D-stock	-.052 (-11.98)*	-.058 (-12.69)*	-.077 (-14.76)*	-.049 (-11.98)*	-.057 (-12.97)*	-0.073 (-14.68)*
GDP-per-capita		.374 (3.51)*	.559 (5.32)*		.445 (4.13)*	.618 (5.79)*
Openness			-.216 (-8.94)*			-.196 (-8.31)*
$\bar{R}^2$ in %	2.4	3.4	6.3	2.5	3.8	6.3
1990						
R&D-stock	-.043 (-7.51)*	-.069 (-9.26)*	-.090 (-10.52)*	-.038 (-7.09)*	-.068 (-9.15)*	-.084 (-10.21)*
GDP-per-capita		.921 (5.78)*	1.224 (7.53)*		1.031 (6.13)*	1.305 (7.62)*
Openness			-.189 (-6.05)*			-.166 (-5.45)*
$\bar{R}^2$ in %	6.7	7.2	9.6	6.4	7.1	8.9

Table 3: Explaining cross-country price differences for Manufactures

Notes: t-statistics in parentheses, (I) $h_{jk}=\ln(H(R_{Mj})/W_{Mj})-\ln(H(R_{Mk})/W_{Mk})$, (II) $h_{jk}=\ln H(R_j^M)-\ln H(R_k^M)$

	specification (II)		
1975			
R&D-stock	-.018 (-3.62)*	-.015 (-3.08)*	-.059 (-8.25)*
Wages		.346 (9.28)*	.412 (10.63)*
Openness			-.310 (-9.04)*
$\bar{R}^2$ in %	5.3	6.6	11.6
1980			
R&D-stock	-.029 (-4.86)*	-.039 (-6.28)*	-.088 (-8.69)*
Wages		.192 (4.26)*	.393 (6.96)*
Openness			-.341 (-6.67)***
$\bar{R}^2$ in %	3.1	3.6	6.4
1985			
R&D-stock	-.049 (-11.98)*	-.047 (-9.26)*	-0.092 (-12.14)*
Wages		-.049 (-0.76)	.444 (4.97)*
Openness			-.295 (-8.79)*
$\bar{R}^2$ in %	2.5	2.5	5.7
1990			
R&D-stock	-.038 (-7.09)*	-.068 (-9.16)*	-.126 (-12.59)*
Wages		.429 (5.84)*	.995 (10.58)*
Openness			-.372 (-9.52)*
$\bar{R}^2$ in %	6.4	6.6	12.4

Table 3A: Explaining cross-country price differences for Manufactures, controlling for wage rates.

Notes: t-statistics in parentheses, (II) h_{jk} =lnH(R_j^M)-lnH(R_k^M)

correcting again for differences in the degree of openness, we can see in Table 3A that price elasticities for R&D now range from -.126 in 1990 to -.059 in 1975. As we can see from Tables 3 and 3A, there is no qualitative change in the results when wage rates replace GDP per capita in the regressions. We conclude that the estimates for the impact of R&D-induced productivity on prices of manufacturing goods are robust across the different cross-sections and specifications.

Overall, the estimates of price elasticities for manufacturing goods in this section, using aggregate productivity measures are very similar to (albeit typically somewhat bigger than) those in the previous section which considered industry productivity measures.

Turning now to the impact of aggregate productivity on the prices of services, we see in Tables 4 and 4a that the estimates are quite different compared to those for manufacturing goods. In columns one to three of Tables 4 and 4A, I report estimates of the impact of differences in aggregate manufacturing R&D stocks on cross-country differences in the prices of services, as implied by specification II. The estimates of the impact of productivity differences on price differences of services do not exhibit the negative impact we saw in the case of manufactures. In most cases, the impact of productivity on services prices is either positive or statistically indistinguishable from zero. Controlling for differences in GDP per capita and the degree of openness, we can see from Table 4 that the price elasticities of R&D range from -.053 in 1990 to .045 in 1980. Controlling for differences in wage rates and the degree of openness, the price elasticities reported in Table 4A for specification II range from .052 in 1980 to .004, statistically indistinguishable from zero, in 1975.

In columns four to six of Tables 4 and 4A, I present estimates for specification III. This specification considers dependence of international price differences on the R&D stock of manufacturing relative to the R&D stock in the service sector (the relative productivity across the two sectors,) relaxing the assumption that productivity-enhancing R&D is accumulated only in the manufacturing sector. Controlling for differences in GDP per capita and the degree of openness, the price elasticities of productivity reported in Table 4 range from .086 in 1980 to -.117 in 1990. Comparing the results using GDP per capita in Table 4 to those using wage rates in Table 4A, it appears that the latter provide stronger support for a positive relation between R&D-induced productivity and the prices of services. Controlling for differences in wage rates and the degree of openness, the price elasticities reported in Table 4A range from .205 in 1980 to .084 in 1985, and are positive and statistically significant beyond the one percent level for every cross-section in this fifteen year period.

Comparing the estimates for the impact of productivity on the prices of services with those for the impact of productivity on prices of manufactures, it appears that the relative price of services to manufactures is increasing with productivity. This is so since higher productivity is almost always associated with a bigger fall in the prices of manufactures than in the prices of services. In many instances, higher productivity is associated with an absolutely (not just relative to manufactures) higher price for services.

Nevertheless, within the theoretical framework I consider here, the latter result no longer implies a higher overall price level for more productive countries since the prices of manufactures are lower in these countries. Indeed, the most robust result here is that higher R&D stocks are associated with lower prices for manufacturing goods. Thus, the overall impact of productivity on the price level depends on the relative size of the manufacturing and service sectors. A large enough manufacturing sector can sustain a lower price level in the most productive country.

In Tables 3, 3A, 4, and 4A, we also see that differences in GDP per capita have a strong positive impact on cross-country price differences for manufacturing goods and for services. This confirms the well known empirical regularity that price levels are positively related to real per capita incomes. Moreover, the estimates for the impact of differences in GDP per capita on cross-country price differences for services are always higher than for manufactures. To understand this result we note that, assuming non-homothetic preferences, differences in GDP per capita are consistent with different demand elasticities across countries. Different demand elasticities combined with some market segmentation imply a role for price discrimination across locations. If markets are more segmented for services than for manufactures, we should expect such effects to be stronger for services prices as evidenced in the results.

Finally, we note that wage rates have a positive impact on the prices of manufactures and services, and that this impact is almost always stronger for services. We also see that openness has a negative impact on the prices of manufactures in any one country while its impact on the prices of services is much weaker.

	specification (II)			specification (III)		
1975						
R&D-stock	.009 (.59)	.001 (.04)	-.038 (-1.63)	.109 (5.21)*	.025 (1.07)	-.004 (-.12)
GDP-per-capita		2.183 (7.89)*	2.357 (8.19)*		1.981 (6.00)*	2.281 (5.84)*
Openness			-.259 (-2.66)*			-.138 (-1.71)***
$\bar{R}^2$ in %	6.3	12.8	14.3	0.4	12.0	12.5
1980						
R&D-stock	.071 (3.69)*	.026 (1.27)	.045 (1.59)	.138 (5.41)*	.076 (1.90)***	.086 (2.04)**
GDP-per-capita		1.636 (4.64)*	1.530 (4.33)*		1.039 (2.11)**	.956 (1.93)***
Openness			.142 (1.11)			.072 (.72)
$\bar{R}^2$ in %	.04	3.8	3.9	3.5	5.4	4.9
1985						
R&D-stock	.010 (.87)	-.007 (-.62)	-0.007 (-.51)	.028 (1.32)	-.019 (-.88)	-.019 (-.82)
GDP-per-capita		1.047 (3.34)*	1.041 (3.39)*		1.131 (3.39)*	1.123 (3.43)*
Openness			.007 (.09)			.011 (.18)
$\bar{R}^2$ in %	.02	3.3	3.1	.1	3.2	2.9
1990						
R&D-stock	.025 (1.41)	-.049 (-2.12)**	-.053 (-2.03)**	.039 (1.55)	-.117 (-3.02)*	-.117 (-3.03)*
GDP-per-capita		2.555 (4.98)*	2.608 (4.87)*		3.268 (5.56)*	3.265 (5.57)*
Openness			-.032 (-.35)			.076 (.89)
$\bar{R}^2$ in %	.9	7.2	6.9	2.5	8.9	8.9

Table 4: Explaining cross-country price differences for Services

Notes: t-statistics in parentheses, * the estimate is statistically significant beyond the one percent level, ** the estimate is statistically significant beyond the five percent level, *** the estimate is statistically significant beyond the ten percent level, (II) $h_{jk}=\ln H(R_j^M)-\ln H(R_k^M)$, (III) $h_{jk}=\ln\frac{H(R_j^M)}{H(R_j^S)}-\ln\frac{H(R_k^M)}{H(R_k^S)}$.

	specification (II)			specification (III)		
1975						
R&D-stock	.009 (.59)	.039 (2.45)*	.004 (.19)	.109 (5.21)*	.149 (7.09)*	.141 (6.51)*
Wages		.715 (7.99)*	.765 (8.15)*		1.852 (5.48)*	2.194 (5.37)*
Openness			-.254 (-2.58)*			-.141 (-1.73)***
$\bar{R}^2$ in %	6.3	13.96	15.5	0.4	9.8	10.2
1980						
R&D-stock	.071 (3.69)*	.069 (3.70)*	.052 (1.93)***	.138 (5.41)*	.197 (5.69)*	.205 (5.79)*
Wages		.513 (4.58)*	.595 (4.46)*		1.09 (2.72)*	1.436 (2.96)*
Openness			-.162 (-1.09)			-.146 (-1.26)
$\bar{R}^2$ in %	.04	5.6	5.6	3.5	6.7	6.8
1985						
R&D-stock	.010 (0.87)	.012 (0.99)	0.006 (0.50)	.028 (1.32)	.077 (2.67)*	.084 (2.91)*
Wages		.299 (2.67)*	.370 (3.15)*		.625 (3.20)*	.769 (3.75)*
Openness			-.094 (-1.30)			-.109 (-1.64)
$\bar{R}^2$ in %	.02	1.8	1.9	.1	2.9	3.1
1990						
R&D-stock	.025 (1.41)	.031 (1.78)***	.029 (1.61)	.039 (1.55)	.087 (2.77)*	.096 (2.89)*
Wages		.422 (3.07)*	.449 (2.92)*		.502 (2.48)*	.590 (2.62)*
Openness			-.039 (-.37)			-.078 (-.78)
$\bar{R}^2$ in %	.9	1.4	1.1	2.5	.9	.7

Table 4A: Explaining cross-country price differences for Services, controlling for wage rates.

Notes: t-statistics in parentheses, (II) $h_{jk} = \ln H(R_j^M) - \ln H(R_k^M)$, (III) $h_{jk} = \ln\frac{H(R_j^M)}{H(R_j^S)} - \ln\frac{H(R_k^M)}{H(R_k^S)}$

5. Conclusions

Using a unique microeconomic dataset of prices in six European countries, I show that there is a negative relation between international price differences and cross-country productivity differences implied by differences in R&D stocks at the industry level and at the aggregate economy level.

First, we see that the product of an industry is cheaper in the country with the higher stock of R&D in that industry. Then, at the aggregate economy level, we note that a higher R&D stock for a country is associated with lower prices for manufactures. We conclude that the law of one price fails even for manufacturing goods. This reverses the usual Balassa-Samuelson result of a higher overall price level for higher productivity countries. The overall impact of productivity on the price level will depend on the relative size of the two sectors. A large productive sector can sustain lower prices in the most productive international location.

We also see that wage rates have a positive impact on the prices of manufactures and services and that this impact is almost always stronger for services suggesting a wage markup in excess of productivity gains for that sector. Similarly, we note a positive impact of GDP per capita on international price differences that is always stronger for the service sector compared to the manufacturing sector. An explanation for this is that differences in GDP per capita are consistent with different demand elasticities across countries which combined with a certain degree of market segmentation implies a role for price discrimination across locations. Thus, to the extent that markets are more segmented for services than for manufactures, then this source of law of one price deviations becomes more important for the service sector.

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