European University Institute
Department of Economics

Three Essays on Exchange Rate Pass-Through

Aurora Ascione

Thesis submitted for assessment with a view to obtaining the degree of
Doctor of Economics of the European University Institute

Florence, January 2009

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DEDICATION

This dissertation is dedicated to Mom, Dad, Marica and Carolina.

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Part I

Introduction

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Exchange rate movements have potentially important implications for the domestic macroeconomy, as they affect inflation, current account adjustments, and the effectiveness of monetary policy. The importance of these implications depends in part on how much of the exchange rate movements are passed through to changes in import prices. The empirical literature has shown that the transmission of exchange rate movements to import and consumer prices is modest: on average, over the long run (four quarters), the degree of exchange rate pass-through is close to zero on consumer prices and it is around 64% on import prices, in the OECD countries. Moreover the most recent empirical evidence shows that while the degree of pass-through is increasing on consumer prices, it is declining on import prices. This evidence has cast doubts on the ability of the exchange rate to affect domestic economies and in some circumstances has been used as argument in favor of fixed against flexible exchange rate regimes.

This thesis provides a theoretical foundation to several stylized facts highlighted by the empirical literature on exchange rate pass-though. The first chapter of this thesis proposes a theory able to explain diverging dynamics of exchange rate pass-through on consumer and import prices, the second reconciles the observed low degrees of pass-through with positive expenditure switching and finally the third chapter provides a theoretical framework to explore the declining degree of exchange rate pass-through on import prices. The models proposed in the thesis build on Dornbush (1987): in a partial equilibrium framework, strategic interactions between domestic and foreign firms together with a linear demand specification can generate incomplete exchange rate pass-through on imports and consumer prices.

The **first chapter** proposes a model able to explain the diverging dynamics of exchange rate pass-through on import and consumer prices. The empirical evidence shows that while the degree of pass-through has declined on imports prices, it has increased on consumer prices. To our knowledge, the theoretical literature has not investigated the increment in pass-through on consumer prices, and has not developed a model able to reconcile the different exchange rate pass-through dynamics on import and consumer prices.

The theoretical literature which has explained incomplete pass-through on consumer price through the presence of distribution services, up to now has assumed perfect competition in the distribution sector. The effect of this assumption is that the exchange rate pass-through on consumer prices mirrors import price exchange rate pass-through dynamics. When instead distributors have market power, they do adjust their margins in response to exchange rate shocks. For a given shock, the adjustment in the margins of the distributors is a function of their market power: the bigger is the market power, the wider the margin adjustment and the lower the degree of pass-through. If the market power of the distributors changes over time, so does the degree of pass-through on consumer prices. Therefore by introducing market power in the distribution sector, the model is able to generate diverging pass-through dynamics on import and consumer prices.

In the **second chapter** we propose a mechanism which can explain why substantial expenditure switching occurs even if the degree of pass-through is low.

A limited degree of pass-through can dampen the expenditure switching effect of exchange rate changes on trade volumes, as it forestalls movements in relative trade prices. For this reason, part of the international macroeconomic literature has interpreted the low degree of pass-through as evidence of no expenditure switching. However, a number of empirical works document that exchange rate changes do indeed redirect global expenditure. We show that if firms engage also in non price competition expenditure switching is stronger for a given degree of consumer price pass-through.

The model proposed in this chapter builds on Dornbush (1987) introducing quality competition. In an economy where consumers value quality, which is costly for producers to supply, firms optimally insulate profits from exchange rate fluctuations by adjusting the quality of the product they supply. This intervention can take both the form of substituting the product with a new one that has a smaller content of quality, or changing some features of the existing product. The way in which the two firms operate in the market can be described using a two stage game; first firms compete in qualities, then they compete in prices. Both games are static and of complete information, since in each period both firms decide price and qualities after the realization of the exchange rate shock has occurred. We assume that quality is a continuous choice variable. The main result of the model is that for a given degree of exchange rate pass-through expenditure switching is higher when firms also engage in non price competition. When a depreciation of the domestic currency hits the economy, the quality of the foreign product falls while its price increases by less than in the standard duopoly models. The size of the expenditure switching effect is bigger than in the standard duopoly models, due to the demand's adjustment along the quality dimension.

The **third chapter** proposes a theoretical framework for exploring the decline of exchange rate pass-through on import prices. In the last years the empirical literature has shown that the degree of exchange rate pass-through on import prices has decreased over time. The theoretical literature has proposed different theories to account for this empirical evidence, but none of them has found convincing empirical support. In the third chapter of this thesis we propose an alternative explanation for the observed decline in the exchange

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rate pass-through. Starting from evidence that in the last fifteen years the costs of product development has fallen sharply, we suggest that competition among firms has switched from price-based to non-price-based. As a result, price stickiness has increased over time, and the degree of pass-through has declined.

We embed non-price competition into an infinitely repeated dynamic duopoly game. Building on the standard dynamic duopoly models developed in the late eighties, the third chapter shares with the previous literature the dynamic supply-side effects, the partial equilibrium analysis, and the assumption that prices are completely flexible, but add on top of it non-price competition.

The way in which the two firms operate in the market can be described using a two stage game; first firms compete in quality, then they compete in prices. The price competition is a static game of complete information, since in each period both firms observe the realization of the exchange rate shock, and because current prices do not have any effect on future demand or profits. The quality choice, also referred to as non-price competition, is instead a dynamic problem, since any time the product varies from the previous period, firms must pay an adjustment cost that is assumed to be invariant through time. Given the structure of the problem it is possible to define a unique Markov-Perfect equilibrium that is also a rational expectation equilibrium: the beliefs of a firm about its competitor quality in equilibrium are correct and equal to the true amount of quality chosen by the competitor.

The model has three main results. First, the degree of exchange rate pass-through crucially depends on the sector of analysis: the least costly is to change the product after an exchange rate shock, the lower is the degree of pass-through. Second, the degree of pass-through is lower the higher the persistence of the shock or the bigger the magnitude of the shock. This result is motivated by the fact that since it is costly for the firm to adjust quality, the firm will do it for bigger or more persistent shocks. Quality adjustments reduce the profitability of price changes generating thus a lower degree of pass-through than in the standard case. Third, if product adjustment costs decrease, firms adjust quality more often: as a consequence the degree of pass-through decreases. This is consistent with the observation that as the costs of changing products have dropped dramatically in the recent years, the degree of exchange rate pass-through has substantially declined.

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Part II

Chapters

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CHAPTER 1

COMPETITION AMONG FIRMS, DISTRIBUTION SECTOR AND EXCHANGE RATE PASS-THROUGH

1.1 Introduction

In the last years empirical evidence has shown diverging dynamics of exchange rate pass-through on import and consumer prices. Some studies present evidence that pass-through into import prices of industrialized countries has declined in the past decade, especially on finished goods.[1] Some others report that retail price sensitivity to the exchange rate has increased over the past decade.[2] The literature has devoted particular attention to the former evidence.[3] However, to our knowledge, the theoretical literature has not investigated the increment in pass-through on consumer prices, and has not developed a model able to reconcile the different exchange rate pass-through dynamics on import and consumer prices.

The primary purpose of this paper is to provide a theoretical framework to account for both the declining pass-through on import prices, and the increasing pass-through on consumer prices. The presence of a distribution sector with market power is the key element of the model.[4] Up to now the theoretical literature on pass-through has assumed a perfect competitive distribution sector.[5] This assumption, while able to deliver extremely neat results on the role of domestic currency costs, attributes a passive role to the distribution sector; if this assumption holds, a declining degree of pass-through on import prices, can only result in a declining degree of pass-through on consumer prices. The assumption that distributors have market power instead attributes an active role to the distribution sector, that can actively modify the degree of pass-through by adjusting markups. As shown by the empirical literature, distributors do adjust markups in response to exchange rate shocks.[6] The degree of markups' adjustments crucially depends on the distributors' market power: the

[1] Among others see Marazzi et al. (2005), Frankel et al (2005), Olivei (2002).

[2] See Campa and Goldberg (2006b)

[3] See for example Bergin and Feenstra (2007), Gust et al (2006), Taylor (2000).

[4] Given the assumptions of the model, there exists an inverse relation between "distributors' market power" and "numerosity of distributors": the lower the number of distributors, the higher the distributors' market power; for this reason in the text we use the two terms interchangeably.

[5] See among others Corsetti and Dedola (2004) and Burstein et al (2003).

[6] See Hellerstein (2004), Goldberg and Verboven (2001), and Berger et al (2007).

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more concentrated is the market (the higher the market power of the distributors), the higher the markup's adjustment to exchange rate shocks, the lower the degree of pass-through. The distributors' market power is thus a key determinant of consumer price exchange rate pass-through. Everything else equal, a variation in distributors' market power, generates a change in consumer prices pass-through, which could eventually have an opposite dynamic from import price exchange pass-through.

Empirical evidence shows that in the last ten years there has been a progressive liberalization of the distribution sector in all OECD countries, with the exception of the US and Belgium. Policy to increase competition and thus to reduce the market power of distributors have been implemented all over the OECD countries. The reduction of distributors' market power could have generate an increment of pass-through on consumer price, even if pass-through on import price has declined. Supportive evidence in favor of this theory is provided also by the cases of US and Belgium, where a declining degree of pass-through on consumer prices was coupled with an increasing concentration of the distribution sector.

To model the effects that the market power of the distributors has on pass-through, we consider a one sector economy in which a foreign firm competes with a number of domestic firms. The product sold in the market is homogeneous and needs distribution services to reach consumers. It is assumed that distributors' marginal costs are in domestic currency and that distributors possess a degree of market power. The economy is exposed to exchange rate shocks via the marginal costs of the foreign producer, which are expressed in foreign currency. The consumers' demand is linear and exchange rate shocks modify the markups of both producers and distributors.

Following Dornbush (1987) the degree of pass-through on import prices is a function of the relative number of domestic and foreign firms: the larger the number of domestic firms, the lower the degree of exchange rate pass-through. The degree of pass-through on consumer prices depends both on import price pass-through and on the market power of the distributors.

The model delivers an incomplete degree of exchange rate pass-through in response to an exchange rate shock. In particular, the larger is the number of domestic firms, the lower is the degree of pass-through on import prices. The larger is the number of distributors, the higher is the degree of pass-through on consumer prices. Therefore, under certain conditions, an increment of the number of domestic producers and distributors, can generate a declining pass-through on import prices together with an increasing pass-through on consumer prices.

The rest of the paper is organized as follows. The next section provides the motivating

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evidence of the paper. In section (1.3) we describe the model. Section (1.4) explains in detail the effects that exchange rate shocks have on prices and markups. Section (1.5) discusses the results and section (1.6) concludes.

1.2 Motivating Evidence

In this section we report the empirical evidence that motivates the paper. The first part of this literature review is devoted to evidence on exchange rate pass-through on import and consumer prices. The second part reports the distribution sector concentration dynamics of the last 15 years.

We first report the empirical studies of Campa and Goldberg on the variation of consumer price pass-through through time. We then concentrate on the literature on pass-through and distribution sector. There is vast consensus that distribution costs strongly contribute to explain the scarce responsiveness of consumer prices to exchange rate variations. The studies which have used micro-dataset also identify an active role of distributors, which, by strategically adjusting markups, contribute to isolate consumer prices from exchange rate shocks.

The second part of the section highlights that in the majority of OECD countries, policies have been promoted to reduce the market power of the distributors. The degree of distributors' concentration is likely to have decreased in the last 15 years in most OECD countries. A notable exception are the US where the concentration of the distributors has increased.

1.2.1 Distribution Sector and Exchange Rate Pass-through

The degree of exchange rate pass-through on consumer and producer prices is a crucial variables to understand the transmission of international shocks and the relation between different countries' economies. The empirical literature has devoted considerable attention to the measure of the exchange rate pass-through finding that the degree of exchange rate pass-through on consumers' prices is far to be complete also in a one year horizon. In the last years the empirical literature has started to analyze more in detail the reason of this scarce responsiveness of prices. The empirical research has used macroeconomic and microeconomics datasets identifying the distribution sector as the most important source of consumer price unresponsiveness to exchange rates' variations.

The empirical literature presents evidence that pass-through into import prices of in-

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dustrialized countries has declined in the past decade, particularly on finished goods.[7] On consumer prices instead the degree of exchange rate pass-through has increased in the last decade: Campa and Goldberg (2006b) look at the evolution over the past decade in the sensitivity of consumption prices of goods with respect to the exchange rate. They build on Campa and Goldberg (2006a) analyzing the changes in distribution margins and imported inputs through time. The analysis studies 16 OECD countries for the period that goes from 1971 to 2004. The authors compare the transmission rate of border price into consumption price for data around 1995 with data for the year 2000. Their results show that the degree of pass-through on consumer prices has increased in all the countries of the sample, with the exception of the United States, Italy, Belgium and Sweden. For the United States and Italy the decline of consumer price exchange rate pass-through has been mainly due to increases in expenditure on distribution services.[8] Overall the authors also document an increment of imported inputs in the production of non-traded goods in the majority of countries and the increase of imported inputs in domestic tradables in all the countries of the sample. The expenditure on distribution services has had different patterns across countries.

Campa and Goldberg (2006a) study the role of distribution costs and imported input components. They find that the degree of exchange rate pass-through on consumer price on a one year horizon for the period that goes from 1975 to 2003 is 17%. In order to explain this scarce responsiveness of prices, the authors study the effects that exchange rate fluctuations have on distribution margins and imported inputs for twenty-one OECD countries. They measure distribution margins for 29 manufacturing and primary-industry groupings, finding that margins vary considerably across industries and that there are common patterns across countries in the incidence of high and low margins for industries. Overall across industries the total distribution margins in household consumption vary from 32% to 50%. The results of the paper show that distribution margins and imported input expenditures are crucial features to explain the degree of exchange rate pass-through across countries.

Burstein, Neves and Rebelo (2003) propose a model in which distribution costs, mainly expressed in local currency, do not respond much to exchange rate variations, and thus drive a wedge between border and retail prices generating a degree of pass-through less than complete. The authors study the role of distribution costs in shaping the behavior of the real exchange rate during exchange rate stabilizations finding that their model is able to replicate the observed real exchange rate dynamics for Argentina in 1991. The authors measure the

[7]See among others Marazzi et. al (2005), Otani et al. (2005), and Frankel et al. (2005).
[8]Distribution services are represented by distribution costs and distributors' margins.

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distribution costs associated with consumption goods in the US and in Argentina finding that the distribution margin in the US is around 46% while in Argentina around 61%. For the US they document different margins for different products: for example the distribution margin for agricultural products vary from 54% to 82%.

Berger et al. (2007) analyze retail prices and the at-the-dock prices of selected items in the CPI and IPP databases of the Bureau of Labor Statistics. The simultaneous use of the two datasets allows them to compare prices of identical goods at two different stages of the distribution chain. The period covered by the data goes from January 1994 to July 2007. The authors find that on average distribution margins are around 50-70%. Moreover distribution margins vary considerably across items; this observation can be explained by brand effects and the type of retail outlet and sales. Finally the authors find that exchange rates changes only modestly affect distribution margins.

Hellerstein (2004) measures the degree of exchange rate pass-through in the beer market. Given the detailed dataset used, the author is able to measure the producers' and retailers' pass-through of nominal exchange rate changes. In the paper a structural econometric model is estimated, which links firms' pass-through to the strategic interactions among firms and among firms and consumers. The data comes from Dominck's Finer Foods, which is a supermarket chain in the Chicago metropolitan area. The prices are from a scanner dataset over a period of four years. The results show that retailers play an important role in the determination of the degree of pass-through on consumer prices. Retailers absorb part of the exchange rate marginal costs shock, adjusting markups and thus isolating prices from the marginal costs fluctuations. The measured degree of pass-through on producer prices is around 69%, but only 80% of the producers' pass-through is transmitted to final prices. From the prices' dynamics analysis Hellerstein identifies strategic interactions between import-competing domestic producers and foreign producers. Following a depreciation, domestic producers of brands which are close substitute for foreign brands increase their profits by lowering prices to take market shares from the foreign competitors. The strategic response of domestic producers to exchange rate depreciation generates incomplete exchange rate pass-through, not only because domestic prices reduce, decreasing the average price of the market, but also because the foreign producers modifying their markups do not pass-through all the exchange rate shock in order to maintain market shares.

Goldberg and Verboven (2001) analyze the European car market for the period that goes from 1980 to 1993. They conduct a microeconomic empirical study using a multiproduct

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oligopoly model with product differentiation. Among several findings they report local currency price stability in response to exchange rate fluctuations. This stability is attributed approximately for 2/3 to the presence of local components in marginal costs and for 1/3 to markups adjustments correlated with exchange rate volatility.

All the papers reported in this brief literature review confirm, from a macroeconomic and microeconomic perspective, that the distribution sector and markups' adjustment strongly contribute to generate a degree of exchange rate pass-through less than complete. The distribution sector contributes to reduce the degree of pass-through both because distribution costs are expressed in local currency and because distributors can adjust their markups in response to exchange rate variations.

1.2.2 Distribution Sector's Concentration

Distribution margins are made by distributors' markups and marginal costs: under the assumption that distribution costs are mainly expressed in local currency, the higher are the distribution margins the lower is the exchange rate pass-through on consumer prices. The degree of concentration in the distribution sector can affect the distribution margins in two direction. As we will see in the following sections, the higher the degree of concentration, the higher the markups charged by the firms. On the other hand, since the distribution sector presents economies of scale, it is likely that the more concentrated is the sector the lower are the distribution costs and thus the distribution margins. The net effect that the concentration in the distribution sector has on the degree of pass-through is ambiguous and is a function of how much the industry is concentrated and how much concentration reduces costs. Looking at the US Census of Retail Trade in 1992 and in 2002, we see that the degree of concentration for the retail sector in the US has increased; the degree of retail trade concentration is reported in Table 1.

Retail Trade Concentration	**1992**	**2002**
4 largest firms	6.8%	11.0%
8 largest firms	10.2%	15.3%
20 largest firms	15.4%	23.9%
50 largest firms	22.4%	31.7%

Table 1.1: Retail Trade Concetration in US

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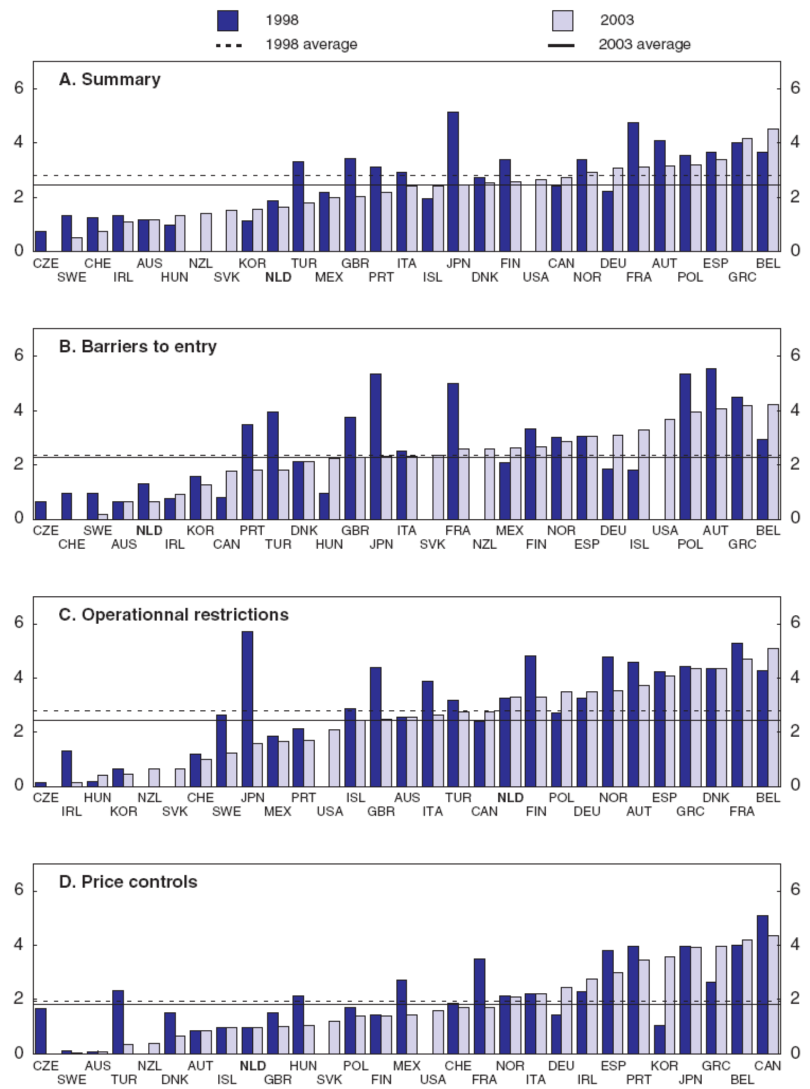
This table shows that the concentration in the retail sector has increased in the US in the last years. From the table it is not possible to infer the net effect that the increment in concentration has had on distribution margins: if the increase of distributors' market power has more than compensate the eventual distribution's costs reduction, the net effect is that distribution margins in the US have increased.

In the EU there have been attempts to increase the degree of competition among distributors in order to reduce retailers' markups and thus consumer prices. For this reason, among different policies implemented by the European authorities, EU countries are slowly reducing their market regulations in the retail sector to increase the degree of competition. The following graphs from the OECD Economic Survey 2006 shows three indicators of regulation in retail distribution, and the summary of the three indicators.



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The three indicators suggest that on average there has been a reduction of market regulation in all the countries of the sample, a part from a few exceptions, such as, for example, Belgium, which is also the most regulated country, and Greece. We can infer that the reduction of regulation in the OECD countries has induced a reduction in the concentration of the retail sector in the majority of the OECD countries. In the next section we present a model able to link the degree of exchange rate pass-through to the concentration in the retail sector; and we will show that, keeping constant the marginal costs of the distributors, there exists a negative relation between distributors' concentration and exchange rate pass-through.

1.3 The model

1.3.1 The market

The market is represented by a single sector in which the product sold is homogenous and needs distribution services to reach consumers. The demand is linear and equal to:

$$Q = 1 - P$$

where P is the price of the homogenous product and $Q = \sum_{j=1}^{m} q_j$ is the total quantity supplied in the market.

1.3.2 Producers

Home (H) and foreign (F) producers compete in quantities. Producers are big enough to consider their strategic interactions in the market, they play a one-shot game and do not have capacity constraints. They have asymmetric marginal costs respectively denominated as c_h and $c_f^* \varepsilon$. The home marginal costs c_h are in home currency, while the foreign marginal costs c_f^* are in foreign currency, and ε is the nominal exchange rate equal to the ratio between domestic and foreign currency. $c_f^* \varepsilon < 1$ and $c_h < 1$ such that the viability of the market is guaranteed and, since we want to rule out the monopoly outcome, we also assume that $1 + c_h > 2c_f^* \varepsilon$ and $1 + c_f^* \varepsilon > 2c_h$. The number of producers is exogenous and equal to n, which can be in turn split in $n - 1$ home producers, and 1 foreign producer.

1.3.3 Distributors

In the market there are m symmetric distributors that compete in quantities, they are risk neutral and have zero bargaining power. Distributors' marginal costs are denoted by c

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and are expressed in domestic currency. They are equal to:

$$c = P^w + c^d.$$

where P^w is the producers' price and c^d is the specific marginal costs associated with the distribution of the product.[9] The contract between producers and distributors is assumed to be linear.[10]

1.3.4 The game

The game is in two stages: first producers choose the quantities and set the price P^w at which they sell to the distributors, then the distributors, taking as given the producers' price P^w, choose the optimal quantities to supply in the market. The game is solved by backward induction: we first solve the problem of the distributors, which maximize their profits taking as given the producers' price P^w and then solve the producers' maximization.

1.3.4.1 Second stage: Distribution

Proposition 1.1 *Suppose the assumptions stated in sections (1.3.1), (1.3.2) and (1.3.3) hold, then in the second stage of the game there exists a unique Cournot-Nash equilibrium characterized by the following price, and quantity:*

$$q^d = \tfrac{1-P^w-c^d}{1+m} \quad P^d = \tfrac{1+m(P^w+c^d)}{1+m}.$$

Proof. The maximization problem of each distributor is:

$$\max_{q^d} \Pi_d = \left(P^d - c\right) q^d$$

or:

$$\max_{q^d} \Pi_d = \left(1 - q^d - \sum_{j \neq d}^{m} q_j - c\right) q^d$$

that yields the optimal quantity and price stated in Proposition 1, which are a function of the producers' price P^w. ■

[9] It is assumed that $c < 1$.

[10] The assumption of linear contracts allows us to analyze in a broader manner the effects that the distribution sector has on prices. In the next section we will see that under linear contracts and vertically separated producers and distributors, the final price is higher than the optimal price firms would set if they were vertically integrated (double marginalization occurs). Instead, when firms are vertically integrated, or there are vertical restraints, such as non-linear pricing or resale price maintenance, producers and distributors internalize the behavior of each other and set prices as if the distribution sector were competitive. When $m \to \infty$, the assumption of linear contracts and vertically separated firms deliver the same price under vertical integration or vertical restraints. The assumption of linear contracts is thus not restrictive and gives us the possibility to analyze all the cases relevant for the analysis of pass-through.

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1.3.4.2 First Stage: Production

Proposition 1.2 *Suppose Proposition 1 holds, then the unique Cournot-Nash equilibrium of the game is characterized by the following price, and quantity:*

$$P^d = \frac{1}{(1+m)} + \frac{m\left(1+(n-1)c_h + c_f^*\varepsilon + nc^d\right)}{(1+m)(n+1)}$$

$$Q = \frac{m}{(1+m)}\left[1 - \frac{\left(1+(n-1)c_h + c_f^*\varepsilon - nc^d\right)}{(n+1)}\right]$$

Proof. The producers' total demand is equal to:

$$Q = \sum_{i=1}^{m} q_i^d = \frac{m}{1+m}\left(1 - P^w - c^d\right).$$

The foreign producer's maximization problem is written:

$$\max_{q_f} \Pi_f = \left(1 - \frac{1+m}{m} q_f - \frac{1+m}{m}\sum_{j=1}^{n} q_j - c^d - c_f^*\varepsilon\right) q_f.$$

Home producers solve symmetrically the same problem. Combining the reaction functions of domestic and foreign producers it is possible to derive the optimal producer price P^w which is equal to:

$$P^w = \frac{1+(n-1)c_h + c_f^*\varepsilon - c^d}{(n+1)}. \tag{1.1}$$

We obtain the optimal values of Proposition 2 by substituting equation (1.1) into Proposition 1. ■

1.4 Prices and Markups

The consumer price in Proposition 2 is a function of the number of distributors m, the number of producers n, and the marginal costs of producers and distributors. The number of distributors enters in the consumer price through the distributors' markups, since P^d can be written as equal to:

$$P^d = \mu^d AMC^d$$

where μ^d is the distributors' markup and is equal to:

$$\mu^d = \frac{m}{(1+m)} + \frac{1}{(1+m)AMC^d},$$

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and AMC^d, which is is the distributors' average marginal costs and equals:

$$AMC^d = \frac{1 + (n-1)c_h + c_f^* \varepsilon + nc^d}{(n+1)}.$$

As expected, there is a negative relation between the markup μ^d and the number of distributors m which can be shown through the use of two benchmark cases:

Benchmark case 1: When $m = 1$ the distribution sector is characterized by a monopoly in which one distributor serves the whole market. In this case the consumer price is equal to:

$$\underline{P}^d = \frac{1 + AMC^d}{2}$$

Benchmark case 2: When $m \to \infty$ $\mu^d \to 1$ and the consumer price is equal to:[11]

$$\overline{P}^d = AMC^d.$$

When distributors and producers are vertically separated and the oligopoly characterizes the market structure of production and distribution, the consumer price is a function of the markups of both distributors and producers. This can be easily shown expressing the distributors' average marginal costs as the sum of producers' prices P^w and distributors' costs c^d:

$$AMC^d = P^w + c^d,$$

and writing P^w as equal to producers' markups over producers' average marginal costs:

$$P^w = \mu^w AMC^w$$

where:

$$\mu^w = \frac{1 - c^d}{(n+1)AMC^w} + \frac{n}{(n+1)}$$

and:

$$AMC^w = \frac{(n-1)c_h + c_f^* \varepsilon}{n}.$$

Combining the equations above we can write the consumer price as:

$$P^d = \mu^d \left(\mu^w AMC^w + c^d \right).$$

The retail price P^d is thus a function of average marginal costs and markups of both producers and distributors.

[11]When $m \to \infty$ the consumer price which prevails in the market is equal to the price one would observe in the case of vertically integrated producers and distributors.

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1.5 Results

1.5.1 Incomplete Exchange Rate Pass-through

When the exchange rate changes the producers' average marginal costs and the distributors' and producers' markups vary. The exchange rate variation changes positively with the producers' average marginal costs:

$$\frac{\partial AMC^w}{\partial \varepsilon} = \frac{c_f^*}{n} > 0.$$

Moreover the larger the number of domestic producers with respect to the foreign producers, the smaller is the effect that the exchange rate has on AMC^w. The model thus predicts that in sectors where the foreign presence is wider, prices react to the exchange rate more than in sector with a small foreign presence. The average marginal costs adjustment is a function of the ratio between domestic and foreign producers: the higher is the number of foreign firms with respect to the total number of producers, the bigger the average marginal costs variation.

Distributors and producers markups negatively adjust to a change in the exchange rate:

$$\begin{aligned} \xi^w &= \frac{\partial \mu^w}{\partial \varepsilon} = \frac{-c_f^* \left(1 - c^d\right)}{n(n+1)(AMC^w)^2} < 0 \\ \xi^d &= \frac{\partial \mu^d}{\partial \varepsilon} = \frac{-c_f^*}{(1+m)(n+1)(AMC^d)^2} < 0. \end{aligned}$$

For example a home currency depreciation, represented by an increase of the nominal bilateral exchange rate, increases the producers' average marginal costs, but reduces the markups of both producers and distributors. Since the distributors' markups change in the opposite direction of average marginal costs, the degree of exchange rate pass-through is smaller than one:

$$\eta_d = \left| \frac{\partial P^d}{\partial \varepsilon} \frac{\varepsilon}{P^d} \right| = \left| \frac{mc_f^* \varepsilon}{1 + n + m\left(1 + (n-1)c_h + c_f^* \varepsilon + nc^d\right)} \right| < 1. \tag{1.2}$$

This result depends on three main assumptions of the model: first, changes in aggregate purchases of the consumption good change the elasticity of demand; second, firms possess some degree of market power; finally, the distribution sector's marginal costs are not a function of the exchange rate. In the following subsections we explain how these assumptions generate incomplete exchange rate pass-through.

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1.5.1.1 Elasticity of Demand

In this model we have assumed that the consumers' demand is linear in order to have that the elasticity of demand is non-constant. When the exchange rate changes, producers' average marginal costs change. The change of average marginal costs, modifies the consumer price and thus the quantity purchased and the elasticity of demand. Since the markup is equal to $e/(e-1)$, where e is the elasticity of demand, markups adjust generating incomplete pass-through.

In the last years the theoretical literature that has studied the exchange rate pass-through has used general equilibrium frameworks with monopolistic competition and CES demand specification. These models are able to match several international macroeconomics stylized facts, but under the assumption of flexible prices, they are not able to generate incomplete exchange rate pass-through. The consumer price equation derived from CES preferences can be written as:

$$p_{it} = \frac{\theta}{\theta - 1} mc_i^* \varepsilon,$$

where θ is the elasticity of demand and mc_i^* is the foreign marginal costs. It is straightforward to show that with flexible prices, the exchange rate pass-through is equal to 1, since the elasticity of demand θ does not change when the exchange rate changes, and neither does the markup, which is equal to $\theta/(\theta - 1)$. Therefore exchange rate shocks fully pass-through to the price.[12]

1.5.1.2 Local Currency Distributors Costs

As pointed out in Burstein et al. (2003), when the consumer price is a function of local currency distribution costs, the degree of pass-through is less than one. This result holds independently of the competition structure among firms. For example, assuming perfect competition at the level of both producers and distributors, the consumer price can be written as equal to:

$$p = P^w + c^d,$$

[12] Ravn (2001) generates incomplete exchange rate pass-through assuming that preferences are CES, and that in each sector of the economy there are two firms, one domestic one foreign, which compete à la Cournot. Even if with CES preferences markups do not adjust to exchange rate shocks, the consumer price does through the average marginal costs variation: exchange rate shocks are idiosyncratic and they only partially affect average marginal costs. The model thus generates incomplete pass-through even if markups stay constant.

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where we assume $P^w = c_f^* \varepsilon$ and c^d is the local currency marginal cost. In this case the degree of pass-through is equal to:

$$\eta_1 = \frac{c_f^* \varepsilon}{c_f^* \varepsilon + c^d} < 1.$$

This result is generated by the fact that the marginal costs of local currency distributors make the price a function p, which is not homogenous of degree one in the exchange rate. This feature generates incomplete pass-through on consumer prices and changes in the distribution margins in response to changes in the exchange rate. The latter result can be derived as follows. Define the distribution margin as equal to:

$$DM = \frac{p - P^w}{p},$$

which represents the fraction of costs due to distribution services in the consumer price. Using the previous example DM is equal to:

$$DM = \frac{c^d}{c_f^* \varepsilon + c^d},$$

and thus,

$$\frac{\partial DM}{\partial \varepsilon} < 0.$$

even under the scenario of perfect competition, an exchange rate variation changes the relative weight between the distribution costs, expressed in domestic currency, and the production costs, expressed in foreign currency, generating an adjustment of the distribution margin in response to exchange rate variations. If distribution margins do not adjust to exchange rate shocks, as reported by Berger et al. (2007), it can be either due to the adjustment of markups at the level of both producer and distribution, or to distribution costs expressed in foreign currency as well as to a combination of the two factors. The empirical evidence shows that distribution costs are mainly expressed in local currency, thus it is more likely that the findings of Berger et al. (2007) derive from some degree of market power at the level of producers and/or distributors.

1.5.1.3 Market Power

As equation (1.2) shows, the degree of exchange rate pass-through η_d is function of m, the number of distributors, and n, the number of domestic producers.

The number of home competitors n, negatively affects the degree of consumer prices pass-through:

$$\frac{\delta \eta_d}{\delta n} = -\frac{1 + c_h + c^d}{\left[1 + n + m\left(1 + (n-1)c_h + c_f^* \varepsilon + nc^d\right)\right]^2} < 0$$

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an increase of domestic competitors reduces the sensitivity of the consumer price to the exchange rate, since it reduces the relative weight of the foreign producers' marginal cost into the consumer price.

The number of distributors m instead positively affects the degree of pass-through:

$$\frac{\delta\eta_d}{\delta m} = \frac{c_f^*\varepsilon(1+n)}{\left[1+n+m\left(1+(n-1)c_h+c_f^*\varepsilon+nc^d\right)\right]^2} > 0.$$

This results derives from the negative relation between the elasticity of distributors' markups to the exchange rate and the number of distributors:

$$\frac{\partial\xi^d}{\partial m}\frac{m}{\xi^d} = \frac{-m}{(1+m)} < 0.$$

The less concentrated is the market, the lower is the elasticity of the markup to the exchange rate, the lower is the negative effect that the exchange rate has on the price through the adjustment of the markup, and thus the higher the degree of pass-through. Therefore, the degree of concentration of both the production and distribution sector crucially affects the exchange rate pass-through on consumer prices: in economies where the distribution sector is highly concentrated the degree of pass-through will be smaller while the opposite will be true in economies where the distribution sector is less concentrated.

An increment in the number of domestic producers causes a reduction of the exchange rate pass-through on import prices. The exchange rate pass-through on import prices is equal to:

$$\eta_w = \left|\frac{\partial P^w}{\partial\varepsilon}\frac{\varepsilon}{P^w}\right| = \left|\frac{c_f^*\varepsilon}{1+(n-1)c_h+c_f^*\varepsilon-c^d}\right|$$

and:

$$\frac{\partial\eta_w}{\partial n} = -\frac{c_f^*\varepsilon c_h}{\left(1+(n-1)c_h+c_f^*\varepsilon-c^d\right)^2}.$$

If the number of the distributors stays constant, the reduction of exchange rate pass-through on import prices is completely reflected in a reduction of consumer price pass-through. If instead the number of domestic distributors contemporaneously increases enough, despite the reduction of pass-through on import prices, the degree of pass-through on consumer prices can increase. In this case we would observe diverging pass-through dynamics at consumer and import prices. We can derive the condition that guarantees an increasing degree of consumer pass-through when both the number of distributors and domestic producers change. This is given by imposing that the total differential with respect to m and n of the consumer

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exchange rate pass-through is positive:

$$d\eta_d(m,n) = \frac{\partial \eta_d(m,n)}{\partial m}dm + \frac{\partial \eta_d(m,n)}{\partial n}dn > 0. \tag{1.3}$$

Equation (1.3) can be rearranged as follows:

$$dm > \frac{m}{1+n}(1+(c_h+c^d)m)dn.$$

Hence, as long as the increase in the number of distributors is larger than the RHS of the expression above, increments in the number of domestic producers can still result in a higher degree of pass-through on consumer prices.

1.5.2 Comments

The model proposed in this paper introduces in the standard model by Dornbush (1987) an imperfect competitive distribution sector. When the distribution sector is perfectly competitive, our model's results are close to those of Dornbush (1987): the degree of exchange rate pass-through is smaller than one and it is a function of the relative number of foreign and domestic competitors in the market. Our results differ by those of Dornbush to the extent that we introduce domestic currency distribution costs. This assumption creates an additional wedge between the marginal costs of the foreign producer and the retail price, generating a degree of pass-through even lower than in Dornbush (1987).

The model's results in the case of a perfectly competitive distribution sector have been deeply investigated by the previous literature.[13] Up to now, the theoretical literature has attributed a passive role to the distribution sector in the determination of the exchange rate pass-through. The main contribution of this paper is the introduction in the analysis of a distribution sector which has market power: in this way the model can generate different pass-through dynamics at the level of producers and consumers. When distributors are perfectly competitive, the degree of exchange rate pass-through at the consumer level is entirely determined by the distribution costs and by the degree of pass-through at the level of producers. When distributors instead have market power, the degree of exchange rate pass-through is also a function of their concentration: for example, a high degree of pass-through at the level of producers can result in a low degree of pass-through at level of consumers if the concentration in the distribution sector is large enough. The model can therefore account for the empirical evidence of different pass-through dynamics at the level

[13] See among others Corsetti and Dedola (2004).

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of producers and consumers: variations in the distribution sector's concentration through time can explain the observed change of the exchange rate pass-through on consumer prices. Higher competition in the distribution sector can increase the degree of pass-through on consumer prices, while lower competition decreases it. As we have seen in section (1.2) in most of the OECD countries in the last decade policies were implemented to promote competition in the distribution sector. The increase in competition, through the reduction of distribution margins, could have generated this increment observed in the degree of consumer price pass-through. Similarly, the increment in the concentration of retailers in the US in the last decade, can explain the reduction of the exchange rate pass-through on consumer prices.

The assumption of market power in the distribution sector can be added to other models: for example Bergin and Feenstra (2008) attribute the declining degree of pass-through to import prices in the U.S. to an import composition shift from countries with flexible exchange rates to countries with fixed exchange rates. If distributors exercise a degree of market power, even if the degree of exchange rate pass-through declines on import prices, consumer prices can still show an increment in the degree of pass-through due to the competition among distributors: the decline of pass-through on import prices tends to reduce the degree of pass-through on consumer prices, but variation of the concentration in the distribution sector can weaken the relation between import and consumer prices.[14]

The model is able to reproduce the empirical finding that the markups of the distributors adjust to the exchange rate changes, as documented by Hellerstein (2004), Goldberg and Verboven (2001) and Berger et al. (2007). It explains the findings of Campa and Goldberg (2006b) that the degree of pass-through varies across sectors and across countries: in sectors (countries) in which only relatively few foreign firms operate, the degree of pass-through will be smaller than in sectors where the foreign presence is more significant; at the same time in a sector (country) where the distribution sector is more competitive the degree of pass-through will be higher.

Through the use of market power, the distribution sector can break the link between import and consumers prices. If a country imports mainly intermediate goods, the demand

[14]As pointed out by Campa and Goldberg (2006b) the transmission of shocks from import to consumer prices can change if the share of imported inputs in the production of non-traded services that enter the distribution sector changes, and/or if the share of the distribution sector into final prices changes. In the model proposed in this paper we have assumed that distributors' marginal costs are not a function of imported inputs, and we have focused the analysis on the concentration in the distribution sector. We believe that variations in the share of imported inputs are crucial determinants for the degree of exchange rate pass-through. However, for the sake of simplicity, we have focused on the role of concentration.

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of imports derives from domestic producers; in this case the degree of pass-through on import prices is the variable to study in order to understand the effects that exchange rate variations are likely to have on the country's economy. If instead a country imports mainly final products, it is the consumers' demand which drives imports; in this case markups' adjustments of the distributors can influence consumers' demand and contribute to orient the demand in favor of domestic or foreign products. By adjusting markups, distributors affect the consumer price degree of pass-through, and thus the demand for foreign products. In this case the study of exchange rate pass-through should concentrate on consumer prices and on the concentration of distributors.

1.6 Conclusions

In the last decade the exchange rate pass-through on consumer prices has increased, while it has declined on import prices. In this paper we propose a model to account for this empirical evidence. In a model where both distributors and producers have market power, exchange rate shocks do not fully pass-through on import and consumer prices. The exchange rate pass-through on import prices is function of the relative number of foreign firms with respect to domestic firms: the bigger the number of domestic firms with respect to foreign firms, the lower the degree of pass-through. On consumer prices, the degree of pass-through is not only a function of the degree of pass-through on import prices, but also of the distributors market power. The higher the distributors' market power the lower the degree of pass-through on consumer prices.

In a market where the number of foreign producers and of domestic distributors changes, the degree of pass-through also changes. If the number of domestic producers increases through time, the degree of pass-through on import prices declines through time. On the other hand if the number of distributors increases, and thus their market power declines, the degree of pass-through on consumer prices tends to increase. An increment of domestic distributors and domestic producers have thus opposite effects on consumer prices pass-through. The net effect will thus depend on which of the two forces prevails. If the increase of domestic distributors is big enough, the decline of pass-through on import prices can be more than compensated by a change in the number of distributors, and opposite pass-through dynamics can be observed on import and consumer prices.

The model can be extended in several directions. A relevant extension would be to embed it in a general equilibrium framework. In this way it would be possible to study how competition among producers and distributors change the analysis on optimal monetary policy and optimal exchange rate regimes. The empirical literature suggests that the distribution

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sectors presents economies of scale. In this case, an higher degree of concentration would generate a decrease in distributors' costs. An interesting extension would be thus to study under which conditions an increment in the concentration of distributors increases, rather than decreases, the degree of consumer price pass-through via a reduction of distributors' marginal costs. Finally, it would be interesting to endogenize the number of producers in the industry to study the effects that an imperfect competitive distribution sector has on pass-through and entry of foreign firms in the market. We leave these analyses for future research.

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CHAPTER 2

INCOMPLETE EXCHANGE RATE PASS-THROUGH IN A MODEL OF QUALITY SWITCHING

2.1 Introduction

A vast body of empirical literature has shown that exchange rate pass-through to consumer prices is close to zero in the short run, and far from being complete in the long run.[1] The degree of exchange rate pass-through is key variable for explaining the role of exchange rates in the process of external adjustment. A limited degree of pass-through can dampen the expenditure switching effect of exchange rate changes on trade volumes, as it forestalls movements in relative trade prices. For this reason, part of the international macroeconomic literature has interpreted the low degree of pass-through as evidence of no expenditure switching. However, a number of empirical works document that exchange rate changes do indeed redirect global expenditure.[2] In this paper we propose a mechanism which accounts for unresponsive prices to exchange rates together with expenditure switching.

The model presented here investigates the relationship between exchange rate pass-through and expenditure switching, assuming that firms can compete in price and in non-price dimensions. Dornbush (1987) and Marston (1990) analyze the relationship between market structure and the degree of exchange rate pass-through in partial equilibrium frameworks, considering prices as the unique control variable of producers. A common result of these models is that exchange rate changes are only partially transmitted to prices. Since consumers' purchase decisions depend only on the price level, a low degree of pass-through has moderate effects on expenditure switching.

Our model shares with these studies the partial equilibrium framework but introduces the idea that firms may be able to adjust the quality of the good; in other words, we introduce non-price competition features. We consider a duopoly in which a domestic and a foreign firm compete in the domestic market. Exchange rate shocks affect not only firms' markups, market shares and prices, but also the quality of products.

[1]See among others Crucini, Telmer and Zachariadis (2001), Engel and Rogers (1996), Campa and Goldberg (2002, 2006).

[2]For an overview see among others Krugman (1991) and Obstfeld (2001).

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We adopt the product differentiation framework of Hotelling (1929); products are defined as a triple of characteristics, price, and quality. It is assumed that consumers are heterogenous in the evaluation of characteristics, and homogenous in the evaluation of quality. More specifically, for a given price, all consumers prefer higher quality content, but they differ in their evaluation of the characteristics.[3] The domestic firm's price and costs are expressed in the domestic currency. The foreign firm, instead sets its price in domestic currency, but incurs marginal costs in a different currency. This feature exposes the market to exchange rate fluctuations. In particular, an exchange rate depreciation of the domestic bilateral exchange rate increases the foreign firm's costs expressed in domestic currency.[4] The foreign firm, in order to insulate its profits from exchange rate fluctuations, may find it profitable to change its costs, and this can be done by changing the quality of the product supplied in the domestic market. This intervention can take both the form of substituting the product with a new one that has a smaller content of quality, or the form of changing some features of the existing product.

The way in which the two firms operate in the market can be described using a two stage game; first firms compete in qualities, then they compete in prices. Both games are static and of complete information, since in each period both firms decide the price and qualities after the realization of the exchange rate shock has occurred. We assume that quality is continuos choice variable.

The main result of the model is that even when the degree of exchange rate pass-through is low, expenditure switching does occur. When a depreciation of the domestic currency hits the economy, the quality of the foreign product falls while its price increases by less than in the standard duopoly models. The size of the expenditure switching is even bigger than in the standard duopoly models, due to the demand's adjustment along the price and the quality dimensions.

The rest of the paper is organized as follows. Section (2.2) provides an overview of the empirical evidence relevant to the paper. Section (2.3) describes the model. Section (2.4) concludes.

[3]Supposing that bicycles are the products of this economy: the quality is represented by the metal used in production, and the characteristic by their model (for example race bikes, mountain bikes, etc...).

[4]Notice that since in the price game reaction functions are positively sloped, when the costs of one of the two firms increase, both firms increase their prices, but the firm that has the costs shock increases the price more than its competitor.

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2.2 Motivating Evidence

This section is dedicated to a brief review of the macroeconomic literature on expenditure switching, and to the marketing literature on non-price competition.

2.2.1 Exchange Rate Variation and Expenditure Switching

In the international macroeconomic literature, the limited responsiveness of prices to the exchange rate, has cast doubts on the capacity of exchange rate variations to generate expenditure switching, that is, the ability of the exchange rate variations to orient the product demand in favor of the goods whose currency has depreciated. There is, however, empirical evidence that exchange rate changes do indeed redirect global expenditure, though perhaps with lags.

Faruqee (2006) studies the degree of exchange rate pass-through and the expenditure switching in the euro area for the period that goes from 1990 to 2002. The author performs an empirical analysis using a vector autoregression (VAR) on the time-series behavior of the euro exchange rate and a system of euro area prices. Specifically, the empirical analysis investigates the degree of exchange rate pass-through in a set of prices along the pricing chain. Faruqee also performs an impulse-response functions' analysis which is used to calibrate the key behavioral parameters able to reproduce the pattern of pass-through and the pattern of the external adjustment in the euro area. With regard to the relation between exchange rate pass-through and expenditure switching, Faruqee finds that in the European countries, even if there is local currency pricing and pricing to market behavior, expenditure switching effects still operate. In particular, there is evidence that exchange rate depreciations, by redirecting the demand in favor of the depreciated currency goods, improve the trade balance.

Freund (2000) studies 25 episodes of current account reversal in 25 industrialized countries finding that nominal exchange rate variations play a crucial role for current account adjustments. He examines the effects that eight variables have on current accounts adjustments. The variables analyzed are: the exchange rates, the real incomes, the trade balances, savings and investments, the short-term interest rates, the budget balances, and the net international investment positions in the ten-year period surrounding the reversals' date. During current accounts reversal, the extent of depreciation varies significantly across countries, and in many cases exceeds 10 percent in one year of adjustment. Typically, the real depreciation begins one year before the current account hit its trough and continues depreciating for three years, with an overall real depreciation of about 20 percent. These variations

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are linked to trade account adjustments: on average in the first two years, trade balances improve due to the decline in the import-GDP ratio as real import growth slows sharply. In the second and third year of recovery the surge in real export growth is responsible for most of the improvement in the trade balance over the adjustment period.

Debelle and Galati (2005) analyze 21 industrialized countries for the period that goes from 1974 to 2003. The authors find that on average the real effective exchange rate declined by about 4% during current account reversals, and in some cases the domestic currency fell sharply generating important variations in the trade balance. The depreciation typically started two years before the current account deficit reached its peak and continued for another year. This is consistent with a J-curve effect, whereby the trade balance initially worsens as the currency starts to depreciate, before improving after about three years. Overall, Debelle and Galati find that the exchange rate and output growth contribute significantly to the process of adjustment.

Finally, Krugman (1991) analyses the behavior of the dollar exchange rate and the US trade deficit during the eighties. Krugman derives three conclusions about expenditure switching and exchange rate variations: exchange rate changes cause expenditure switching, they are necessary to observe expenditure switching and the relation between trade and exchange rate is stable. Krugman finds that after the dollar declined, export increased considerably even if with a time length. The exchange rate variations helped the adjustment process to save some of the real costs that otherwise would have being observed. On the basis of the evidence about exchange rate movements and trade flows, Krugman concludes that exchange rate variations do contribute to the expenditure switching process.

2.2.2 Non-price Competition

The evidence that non-price competition is frequently used as optimal reaction to shocks by firms is widely documented in the marketing literature.

In his study of the impact of price control in the U.S. after the WWII Rockoff (1984) finds that price controls held the nominal price of several consumption goods constant, with a contemporaneous deterioration of the goods' quality in response to change in the market prices.

Rotemberg (2005) cites two cases discussed in the October 1994 issue of *Consumers' Reports*. The first case is that of Gütterman, which changed the design of its threads'

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packages. The company made its plastic spools fatter so that, when filled with 110 yards of thread, they would have the same outside dimensions as a previous version of 220 yards of thread. The price of the newer version was $1.25 while the previous one was $1.45. The second case regards the Minute Maid Company that significantly reduced the concentration of its 12 oz. can of Raspberry Lemonade while keeping the price constant. The company, questioned about this action, explained that this product variation was motivated by an increase in the price of the raspberries, which would otherwise have caused a rise in the price of the lemonade.

Koelln and Rush (1993) collect data of the "text pages" and prices for seven magazines in the U.S for a period that covers 1950 to 1989. The authors identify the possibility of altering the number of pages text as a potential means of offsetting declines in real price during the interval between price changes. Koelln and Rush note that the magazine with the most inflexible number of pages over this period also had by far the largest number of nominal price changes. They interpret this result as supporting the hypothesis that variation in quality is a potential important alternative to changing the price. The authors also find a statistical significant positive relationship between the number of text pages in a magazine and the real price of the magazine. That is, as inflation erodes the real price of a magazine during the interval between nominal price changes, the number of text pages tends to decline.

In the study of Blinder et al. (1989), firms are asked directly about their pricing behavior: a sample of two hundred managers and price setters of the Northeastern United States were asked to rank or assign scores to a number of twelve popular economic theories which were explained to them in non-technical terms. The results show that across sectors of the economy the theory of "non-price competition" belongs to the top group scores, being the third most used way to keep prices constant. When the results are divided by sector, non-price competition is the first method used by firms to avoid changes in prices in the manufacturing sector, the second in the trade sector, the third in the service sector. Quoting Blinder et al.:

> "*... many firms appear to leave prices fixed in the face of shocks because they prefer to use one or more avenues of non-price competition to adjust. Rather than cut prices in the face of sagging demand, firms can and do shorten delivery lags, raise product quality, improve term of service, or make greater selling efforts. Non-price competition raises both microeconomic and macroeconomic questions that have barely been addressed by theorists. Why do firms prefer non-price competition to price competition even though the former appears to entail*

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real resource costs that the latter avoids? What are the welfare implications of markets that clear along non-price dimensions? The answers to these and other questions must be left to future research."

2.3 The Model

In this section we analyze the conditions which ensure that it is optimal for a firm to adjust both quality and prices in response to a change in the exchange rate. We consider an exporting foreign firm that operates in the domestic market, and assume that changes in its marginal costs are due to changes in the bilateral exchange rate. The analysis is performed using a modification of the standard product differentiation model of Hotelling (1929).

2.3.1 The Environment

It is assumed that products can differ in their "characteristic" and in their "quality". A characteristic is defined as a peculiarity perceived as relevant by consumers, which does not affect the product's quality or costs (an example of a characteristic might be the color of a good). The characteristic of a good is defined on a support that ranges between 0 and 1. This index can be represented on a segment of unit length in which firms and consumers are located. Quality is defined as a feature on which all consumers agree over the preference ordering: given the price and the characteristic, each consumer prefers the good with higher quality (an example of quality might be the raw material used in the production of a good).

2.3.2 Consumers

Consumers are homogenous in their quality evaluation but heterogenous in their evaluation of the other characteristic. That is, while at equal price higher quality is always preferable for the consumer, the same is not true for the characteristic. We assume that each consumer has a preferred characteristic, "x", and that their utility decreases in the distance between the good's characteristic and x. Moreover, the distribution of x among consumers is assumed to be uniform in the support $[0, 1]$. It is assumed that consumers have a unit demand. The consumers' utility is:

$$U = \begin{cases} s_f - p_f - \tau \left| x - f \right| & \text{if they buy good } F \\ s_d - p_d - \tau \left| d - x \right| & \text{if they buy good } D \\ 0 & \text{if they do not buy} \end{cases}$$

s_f and s_d denote the quality of goods F and D, respectively, and p_f and p_d denote their prices. $x \in [0, 1]$ is the position of the consumer along the segment. τ is the marginal cost

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for the consumer of moving away from her preferred characteristic. It is assumed that the domestic firm produces a good with characteristic "d", located at point 0, and the foreign firm a good with characteristic "f", located at point 1. Consumers are willing to buy good F as long as $s_f \geq p_f + \tau |x - f|$, and willing to buy good D as long as $s_d \geq p_d + \tau |d - x|$; so consumers still buy the good as long as the effective price, represented by the good's price plus the transportation costs, is less than or equal to the quality supplied.

2.3.3 Firms

The domestic and the foreign firm compete in the domestic market. The foreign firm's marginal costs, c_f^*, are expressed in foreign currency, while the domestic firm's marginal costs, c_d, are expressed in the domestic currency. Since both p_f and p_d are expressed in the domestic currency, the relevant marginal costs of firm F are those expressed in the domestic currency; these costs fluctuate following the nominal exchange rate variations.

The cost of quality is modeled as a fixed cost proportional to the amount of quality supplied and equal to as_f^2 and as_d^2 respectively for firm F and firm D. It is also assumed that $a > 0$. An example of a fixed cost of quality is the product's costs of advertisement. Both firms' fixed costs are expressed in the domestic currency.

2.3.4 The game

The interaction between the two firms in the market can be described by a two stage game in which firms first compete in quality and then compete in prices. In order to analyze the duopoly outcome we assume:

ASSUMPTION 1:

$$\left| c_d - c_f^* e + s_f - s_d \right| < 3\tau.$$

Assumption 1 is necessary for a duopoly equilibrium to hold: this is the case when the marginal costs of the two firms are not too different relative to the consumers' unit transportation costs τ. Indeed, if $c_d > c_f^* e - s_f + s_d + 3\tau$ firm D has marginal costs which are too high with respect to firms F to compete in that market, and if $c_f^* e > c_d + s_f - s_d + 3\tau$, the same would be true for firm F. Given Assumption 1, we can solve the duopoly game by backward induction. We characterize the price competition equilibrium in the following proposition.

Proposition 2.1 *Suppose assumption 1 holds, firms F and D play a duopoly price competition game, that has a unique Bertrand-Nash equilibrium characterized by the following*

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prices, quantities and profits:

$$p_f = \frac{s_f - s_d}{3} + \frac{3\tau + c_d + 2c_f^* e}{3} \qquad p_d = \frac{s_d - s_f}{3} + \frac{3\tau + 2c_d + c_f^* e}{3}$$
$$q_f = \frac{s_f - s_d}{6\tau} + \frac{3\tau + c_d - c_f^* e}{6\tau} \qquad q_d = \frac{s_d - s_f}{6\tau} + \frac{3\tau - c_d + c_f^* e}{6\tau}$$
$$\Pi_f = \frac{\left(s_f - s_d + 3\tau + c_d - c_f^* e\right)^2}{18\tau} - as_f^2$$
$$\Pi_d = \frac{\left(s_d - s_f + 3\tau - c_d + c_f^* e\right)^2}{18\tau} - as_d^2$$

Proof. Let $x \in [0,\ 1]$ denote the location of the consumer that is indifferent to purchasing from firm F or from firm D. Thus:

$$s_F - p_F - \tau\widehat{x} = s_D - p_D - \tau(1 - \widehat{x}). \tag{2.1}$$

Solving equation (2.1) for $\widehat{x}$ provides:

$$\widehat{x} = q_f = \frac{s_f - s_d}{2\tau} + \frac{p_d - p_f + \tau}{2\tau} \qquad q_D = 1 - \widehat{x} = \frac{s_d - s_f}{2\tau} + \frac{p_f - p_d + \tau}{2\tau}. \tag{2.2}$$

It follows from equation (2.2) that the profits of firms F and firm D are respectively:

$$\Pi_f = (p_f - c_f^* e)\left(\frac{s_f - s_d}{2\tau} + \frac{p_d - p_f + \tau}{2\tau}\right) - as_f^2 \tag{2.3}$$

and

$$\Pi_d = (p_d - c_d)\left(\frac{s_d - s_f}{2\tau} + \frac{p_f - p_d + \tau}{2\tau}\right) - as_d^2. \tag{2.4}$$

Where as_f^2 and as_d^2 are respectively the fixed cost of supplying quality for firm f and fixed cost of supplying quality for firm d. Maximizing equation (2.3) with respect to p_f and maximizing equation (2.4) with respect to p_d, and then solving the two equations simultaneously provides:

$$p_f = \frac{s_f - s_d}{3} + \frac{3\tau + c_d + 2c_f^* e}{3} \quad p_d = \frac{s_d - s_f}{3} + \frac{3\tau + 2c_d + c_f^* e}{3} \ . \tag{2.5}$$

Equation (2.2), together with the two equilibrium prices, reveals that the equilibrium output levels for F and D, respectively, are:

$$q_f = \frac{s_f - s_d}{6\tau} + \frac{3\tau + c_d - c_f^* e}{6\tau} \quad q_d = \frac{s_d - s_f}{6\tau} + \frac{3\tau - c_d + c_f^* e}{6\tau} \ .$$

We can thus derive the equilibrium profits for firm F and firm$D$ respectively:

$$\Pi_{f,t} = \frac{\left(s_f - s_d + 3\tau + c_d - c_f^* e\right)^2}{18\tau} - as_f^2 \quad \Pi_{d,t} = \frac{\left(s_d - s_f + 3\tau - c_d + c_f^* e\right)^2}{18\tau} - as_d^2 \tag{2.6}$$

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■

Given the equilibrium in the price game, we solve the quality game maximizing for each firm the optimal profits in eq.(2.6), with respect to its own quality, and subject to the optimal quality of the competitor. The maximization problem of each firm is given by:

$$\begin{aligned} \max_{s_i} \Pi_i &= \frac{(s_i - s_{-i} + 3\tau + c_i - c_{-i})^2}{18\tau} - a s_i^2 \\ s.t. \quad s_{-i} &= \bar{s}_{-i} \qquad\qquad for\ i = f, d \end{aligned}$$

The reaction functions of firm D and firm F are respectively:

$$\begin{aligned} RFD &= s_d = \frac{c_d - c_f^* e + \bar{s}_f - 3\tau}{1 - 18a\tau} \\ RFF &= s_d = c_d - c_f^* e + 3\tau + (1 - 18a\tau)\bar{s}_f \end{aligned}$$

Solving the two equations simultaneously, s_f and s_d can be written as follows:

$$\begin{aligned} s_f &= \frac{1}{6a} + \frac{c_f^* e - c_d}{2(1 - 9a\tau)} \\ s_d &= \frac{1}{6a} + \frac{c_d - c_f^* e}{2(1 - 9a\tau)} \end{aligned} \qquad (2.7)$$

The conditions above are a maximum as long as $\frac{\partial^2 \Pi_i}{s_i} \leq 0$, which implies $a\tau \geq 1/18$. In order to prove that the pair of qualities above are an equilibrium, it is necessary to show that the firms do not have an incentive to deviate in the second stage of the game, by undercutting the price and covering all the demand in the market. Taking as given the equilibrium qualities in (2.7) and its opponent price, the range of undercutting prices for the foreign firm satisfy the following condition:

$$p_f^u \leq s_f - s_d + p_d - \tau. \qquad (2.8)$$

This inequality implies that also the worker located in the domestic firm prefers to buy the foreign good. Noting that profit maximization implies that (2.8) must hold with equality, substituting s_f and s_d form (2.7) and $\bar{p}_d$ from (2.5) into (2.8) yields:

$$p_f^u = \frac{6ac_d\tau + c_f^* e\,(3a\tau - 1)}{9a\tau - 1}.$$

The foreign firm has no incentives to deviate as long as the undercutting profits are lower than the duopoly profits, that is, as long as $p_f^u - c_f^* e - a s_f^2 - \Pi_{f,t}\,(s_f, s_d) \leq 0$. Substituting for s_f and s_d it is possible to show that:

$$p_f^u - c_f^* e - a s_f^2 - \Pi_{f,t}\,(\bar{s}_f, \bar{s}_d) = -\frac{\tau\left[1 + 3a\left(c_d - c_f^* e - 3\tau\right)\right]^2}{2\,(1 - 9a\tau)^2} < 0.$$

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The condition above therefore implies that it is never profitable for the foreign firm to undercut prices. Following the same steps, it is possible to prove that also the domestic firm has no incentives to deviate. Substituting s_f and s_d into the optimal values of Proposition 1, it is then possible to summarize the outcome of the quality game in the following Proposition:

Proposition 2.2 *Suppose Assumption 1 holds and the unique Bertrand-Nash equilibrium of the game is defined in Proposition 1. An equilibrium in the duopoly quality competition game exists and is unique, and it can be characterized by the following qualities, prices, quantities and profits:*

$$
\begin{aligned}
s_f &= \frac{1}{6a} + \frac{c_f^* e - c_d}{2(1-9a\tau)} & s_d &= \frac{1}{6a} + \frac{c_d - c_f^* e}{2(1-9a\tau)} \\
p_f &= \frac{(c_f^* e - c_d)}{(1-9a\tau)3} + \frac{3\tau + c_d + 2c_f^* e}{3} & p_d &= \frac{(c_d - c_f^* e)}{(1-9a\tau)3} + \frac{3\tau + 2c_d + c_f^* e}{3} \\
q_f &= \frac{(c_f^* e - c_d)}{(1-9a\tau)6\tau} + \frac{3\tau + c_d - c_f^* e}{6\tau} & q_d &= \frac{(c_d - c_f^* e)}{(1-9a\tau)6\tau} + \frac{3\tau - c_d + c_f^* e}{6\tau} \\
\Pi_f &= \frac{\tau}{2}\left(\frac{1-3a\left(3\tau + c_d - c_f^* e\right)}{(1-9a\tau)}\right)^2 - a\left(\frac{1}{6a} + \frac{c_f^* e - c_d}{2(1-9a\tau)}\right)^2 \\
\Pi_d &= \frac{\tau}{2}\left(\frac{1-3a\left(3\tau - c_d + c_f^* e\right)}{(1-9a\tau)}\right)^2 - a\left(\frac{1}{6a} + \frac{c_d - c_f^* e}{2(1-9a\tau)}\right)^2
\end{aligned}
$$

The remainder of the paper will investigate how changes in the exchange rate affect the equilibrium. Quality maximization implies that the relevant range for the analysis is the interval of $a\tau \in [1/18, \infty)$. The behavior of the model for $a\tau \in [1/18, 1/9)$ is opposed in every dimension to its behavior when $a\tau \in (1/9, \infty)$, and violates the standard empirical finding that imported goods decrease as the exchange rate depreciates. In what follows I will therefore restrict the analysis to the relevant range of $a\tau \in (1/9, \infty)$, implying:

$$\frac{\partial \bar{q}_f}{\partial e} = \frac{9a\tau}{1-9a\tau} < 0.$$

2.3.5 Profits

In this section we study the effects of exchange rate changes on foreign firm's profits. The profits of the foreign firm are decreasing along the entire domain of e: the higher the exchange rate, the bigger the foreign firm's marginal costs expressed in domestic currency. Foreign firm prices per unit of quality will thus be higher, reducing its demand and therefore its profits.

In the foreign firm's profit figure the straight line represents the profits of firm F when quality is fixed, while the convex curve represents the profit of firm F when quality can be optimally adjusted. The convex curve is always above the straight line. The fixed quality profits have been drawn assuming that the two firms are perfectly symmetric and choose the same quality for each value of the exchange rate. In the variable quality case, firms are again perfectly symmetric but, since the choice of quality depends on the difference between the marginal costs of the two firms, they choose the same quality only when they have the same marginal costs, that is when $e = 1$. At that point the profits are the same in both scenarios and the two profit curves are tangent.

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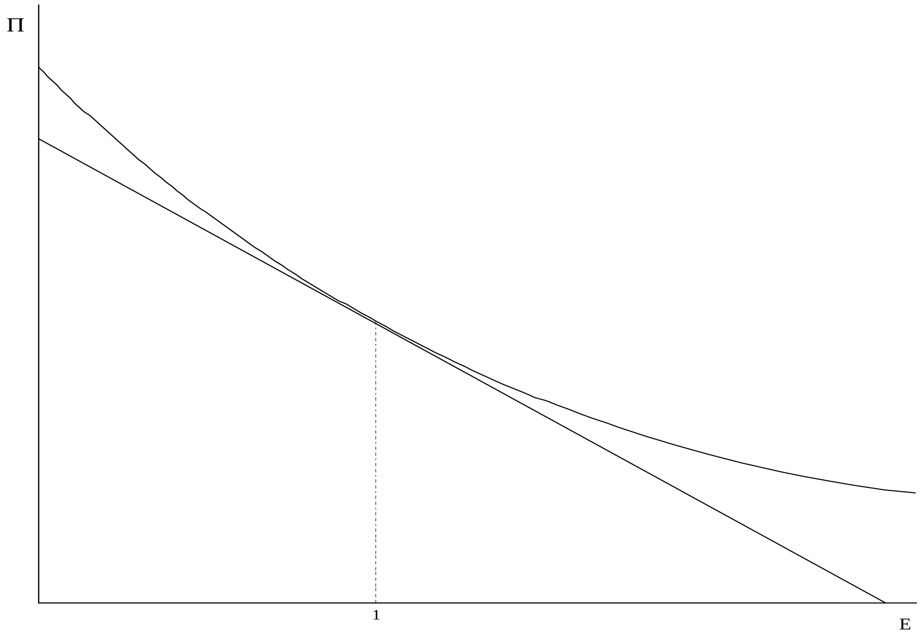

Figure 2.1: Foreign firm's profits

2.3.6 Qualities

In this section we analyze the effects that an exchange rate variation has on the optimal choice of qualities. We first study why firms optimally adjust quality, and then we analyze the adjustment's direction.

To determine how the exchange rate's fluctuations affect the optimal foreign quality we analyze how marginal costs and revenues changes when the exchange rate change. Firm F's total revenues are equal to:

$$TR_f = \left(\frac{s_f - s_d}{3} + \frac{3\tau + c_d + 2c_f^* e}{3}\right)\left(\frac{s_f - s_d}{6\tau} + \frac{3\tau + c_d - c_f^* e}{6\tau}\right).$$

The marginal revenues of supplying quality are thus equal to:

$$MR_{s_f} = \frac{\partial TR_f}{\partial s_f} = \frac{2\left(s_f - s_d + 3\tau + c_d\right) + c_f^* e}{18\tau}$$

Firm F's total costs are equal to:

$$TC_f = c_f^* e\left(\frac{s_f - s_d}{6\tau} + \frac{3\tau + c_d - c_f^* e}{6\tau}\right) + a s_f^2$$

and the marginal costs of supplying quality are equal to:

$$MC_{s_f} = \frac{\partial TC_f}{\partial s_f} = \frac{c_f^* e}{6\tau} + 2a s_f$$

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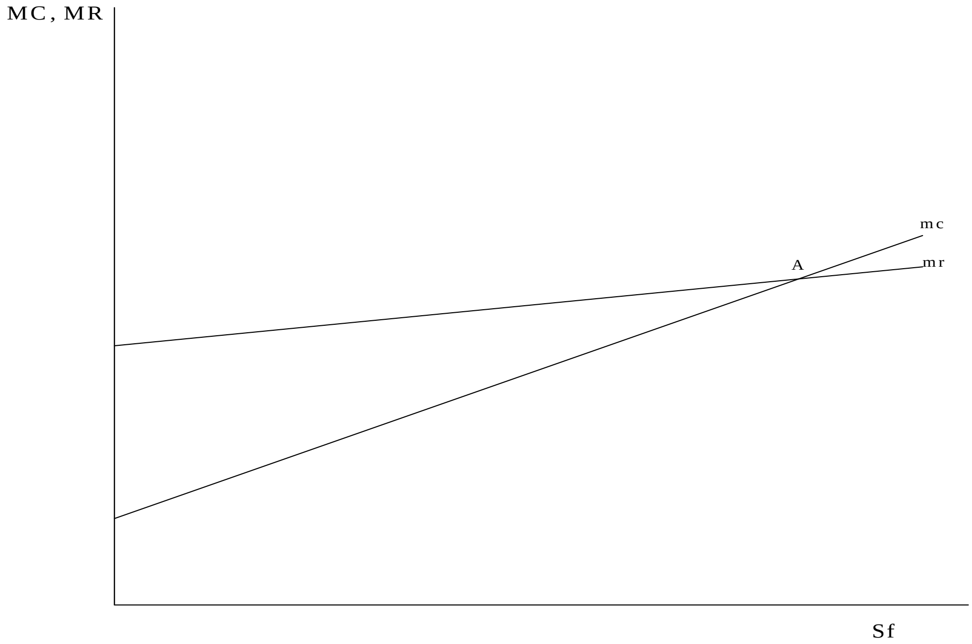
We plot marginal revenues and marginal costs of supplying quality in the picture below.



We notice that the slope of marginal costs ($2a$) is bigger than that of marginal revenues ($1/9\tau$) given the condition of maximum for the qualities. An exchange rate depreciation increases both the intercept of marginal revenues and that of marginal costs, but the marginal costs change is bigger than that of marginal revenues since:

$$\frac{\partial MR_f}{\partial e} = \frac{c_f^* e}{18\tau} < \frac{\partial MC_f}{\partial e} = \frac{c_f^* e}{6\tau}$$

The effects that an exchange rate depreciation have on the curves is represented in the following plot:

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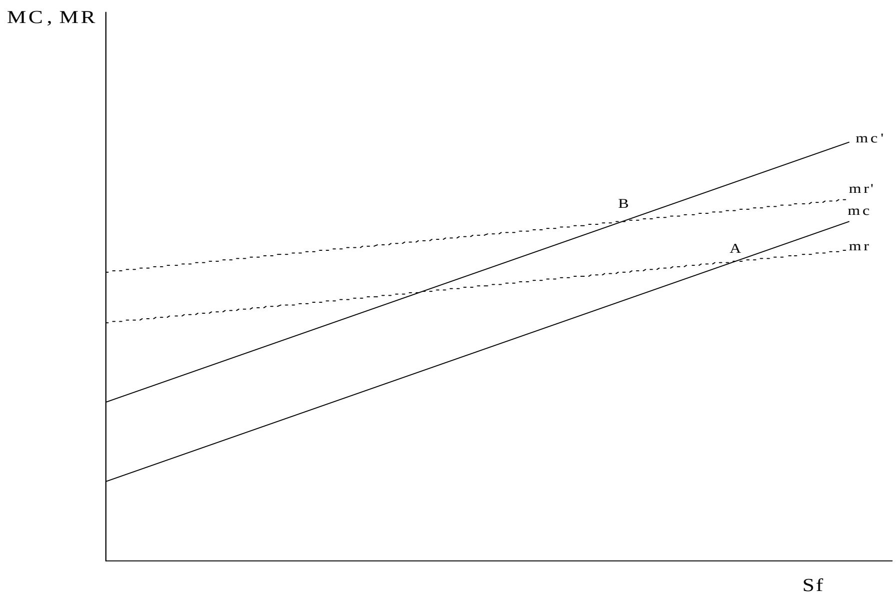

The two curves shift up in parallel, but since the shift of marginal costs is bigger than that of marginal revenues the optimal foreign firm's quality decreases. Marginal costs of supplying quality increases more than marginal revenues for supply side and demand side considerations. As we will see in detail in the next section, the supply side effect is that for each unit of the good that is sold, the profit margin decreases following an exchange rate depreciation, and the degree of pass-through is smaller than one. On the demand side on the other hand, following a depreciation the marginal utility derived by quality stays constant, while its price increases. Since for each firm the quality enters with a negative sign in the firm's markup, by reducing the amount of quality supplied firms can recover a part of the markup reduction due to the exchange rate shock, and for each value of the exchange rate earn a higher amount of profits than in the fixed quality model, as the foreign firm's profits picture shows.

We now turn to study how quality adjusts to exchange rate shocks; we first look at the equations of qualities at equilibrium, and we then analyze the firms' reaction functions. The negative (positive) relation between the exchange rate and the foreign (domestic) firm can be found taking the derivative of s_f (s_d) with respect to e :

$$\frac{\partial s_f}{\partial e} = \frac{c_f^*}{2(1-9a\tau)} < 0$$
$$\frac{\partial s_d}{\partial e} = \frac{-c_d}{2(1-9a\tau)} > 0.$$

The signs of the two derivatives above is determined by the condition $9a\tau > 1$, discussed

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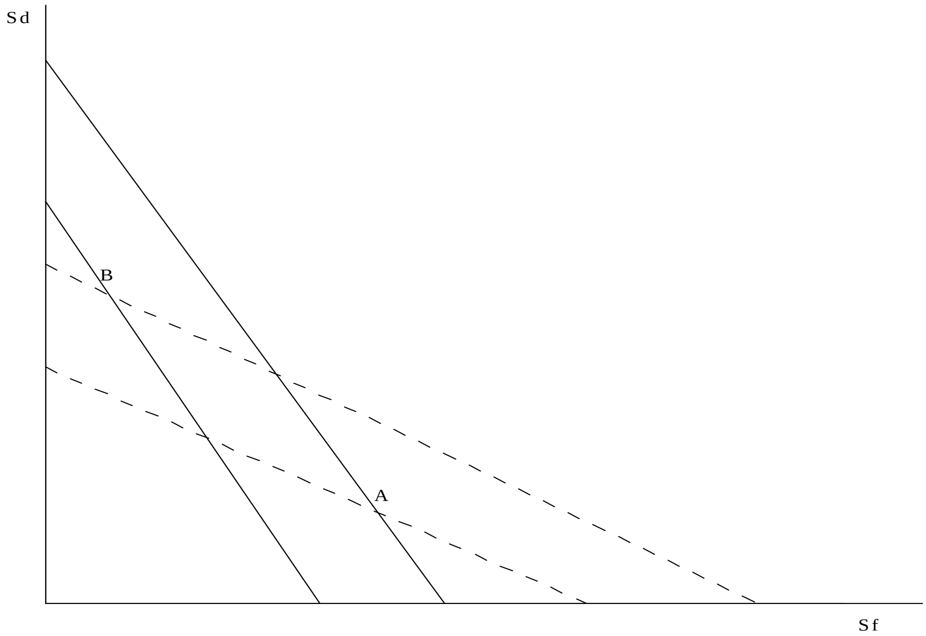

before. The reaction functions of firm D and firm F are respectively:

$$RFD = s_d = \frac{c_d - c_f^* e + s_f - 3\tau}{1 - 18a\tau}$$
$$RFF = s_d = c_d - c_f^* e + 3\tau + (1 - 18a\tau)s_f$$

The reaction functions can be drawn in the space s_d, s_f. Both functions have a positive intercept and are negatively sloped since $1 < 18a\tau$. The slope of the domestic reaction function is smaller than that of the foreign firm as long as $1 < 9a\tau$; in this case RFD is flatter than RFF. In the plot below the flatter dotted curves represent the reaction function of the domestic firm, while the steeper solid curves are those of the foreign firm.

A depreciation of the exchange rate moves to the left the reaction function of firm F, and shifts up the domestic firm's reaction function. The equilibrium qualities therefore change. As represented in the figure above, the equilibrium switches from point A to point B, where the domestic firm's quality has increased and the foreign one's has decreased.

2.3.7 Prices

In order to define a benchmark scenario to compare our results, our analysis on prices starts from the case in which firms' quality is not a control variable. To simplify the analysis and without loss of generality we assume that each firm chooses the same quality. In this case prices are equal to:

$$\widetilde{p}_f = \frac{3\tau + c_d + 2c_f^* e}{3} \qquad \widetilde{p}_d = \frac{3\tau + 2c_d + c_f^* e}{3}$$

We can rewrite these prices as follows:

$$\widetilde{p}_f = \mu_f c_f^* e \qquad \widetilde{p}_d = \mu_d c_d$$

where μ_f and μ_d are the firms' markups that are equal to:

$$\begin{aligned} \mu_f &= \frac{\zeta_f}{\zeta_f - 1} = \frac{3\tau + c_d + 2c_f^* e}{3c_f^* e} \\ \mu_D &= \frac{\zeta_D}{\zeta_D - 1} = \frac{3\tau + 2c_d + c_f^* e}{3c_d}. \end{aligned}$$

and ζ_f and ζ_d are the demand curves elasticities at the optimal points. These are given by:

$$\begin{aligned} \zeta_f &= \frac{2\tau\left(3\tau + c_d + 2c_f^* e\right)}{3\tau + c_d - c_f^* e} \\ \zeta_d &= \frac{2\tau\left(3\tau + 2c_d + c_f^* e\right)}{3\tau + c_f^* e - c_d}. \end{aligned}$$

Given the linear demand curve specification and the structure of the market, an exchange rate variation affects both markups and marginal costs. When an exchange rate depreciation occurs neither the foreign nor the domestic price react one to one to the depreciation. This is due to the fact that markups vary when the exchange rate changes. This mechanism can be observed computing the derivative of the price with respect to the exchange rate:

$$\frac{\partial p_f}{\partial e} = \frac{\partial \mu_f}{\partial e} c_f^* e + \frac{\partial c_f^* e}{\partial e} \mu_f.$$

The first term of the derivative is negative and equal to:

$$\frac{\partial \mu_f}{\partial e} = \frac{\frac{2}{3} c_f^* e - c_f^* e p_f}{(c_f^* e)^2}.$$

When the exchange rate depreciates markups decrease; this reduction is bigger than the increase of the second term that is positive and bigger than 1, such that $\partial p_f / \partial e = 2c_f^*/3$. We can hence compute the exchange rate pass-through when a depreciation occurs:

$$\xi_{f1} = \left| \frac{2c_f^* e}{3p_f} \right|, \tag{2.9}$$

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which is less than 1.

The exchange rate fluctuation also affects the domestic producer's price. As we can see above, the domestic firm's price is equal to a markup μ_d over the marginal costs c_d. Domestic marginal costs are not directly affected by an exchange rate variation, while the price is instead influenced through the markup. The derivative of the domestic price with respect to the exchange rate is equal to:

$$\frac{\partial p_d}{\partial e} = \frac{\partial \mu_d}{\partial e} c_d = \frac{c_f^*}{3} > 0,$$

that is positive, and less than the same derivative computed on the foreign price. An increment of the exchange rate translates into an increase in the foreign firm's marginal costs, and consequently of p_f. Since the reaction functions are positively sloped, an increase in the foreign firm's price positively affects the domestic price, increasing the markup.

Overall, the combined effect of the reduction of the foreign firm's markup and the increase of the foreign firm's marginal costs, is bigger than the increment of the domestic firm's markup. As a consequence, the degree of pass-through on the domestic price is smaller than the degree of pass-through on the foreign price. A positive degree of pass-through on both foreign and domestic prices generates two opposite effects on the process of expenditure switching. Everything else being equal, higher pass-through to foreign prices will enhance the expenditure switching effect of an exchange rate change. In contrast, a positive degree of pass-through on domestic prices will reduce the expenditure switching effects. The net effect is that we do observe expenditure switching but less than what is predicted by the standard Mundell-Fleming model.

In the model presented in this paper, the elasticity of the foreign price with respect to the exchange rate is given by:

$$\xi_{f2} = \left| \left(1 + \frac{1}{2(1 - 9a\tau)}\right) \frac{2c_f^* e}{3p_f} \right| < \xi_{f1}.$$

The degree of exchange rate pass-through is lower than the one observed in the standard duopoly price competition model, since the foreign producer reduces the quality of the good. The product's adjustment along the quality dimension, thus generates a degree of exchange rate pass-through lower than in the standard models.

2.3.8 Market Shares

The negative relation between foreign firms market shares and the exchange rate has been fully investigated by Dornbusch (1987): a depreciation of the domestic currency reduces

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foreign firms' market shares but increases those of domestic firms. In Dornbusch's analysis the price is the only control variable and foreign firms' market shares decrease for each value of the exchange rate.

In our model, quality is introduced as an additional control variable. Market shares are sensitive to quality, since quality is fully observable and it enters in the consumers' utility function. When firms can adjust the quality of the product supplied in the market, market shares vary more in response of an exchange rate shock, than in the standard duopoly price competition model. Suppose that an exchange rate depreciation occurs and the quality of the foreign firm decreases. The quality reduction generates an extra channel of market share loss for the foreign firm. In the standard model:

$$\frac{\partial q_f}{\partial e} = -\frac{c_f}{6\tau}$$

when firms also compete in the non-price dimension:

$$\frac{\partial q_{fn}}{\partial e} = -\frac{c_f}{6\tau} - \frac{c_f}{(9a\tau - 1)6\tau} < \frac{\partial q_f}{\partial e}$$

The foreign firm loses market shares because of the price increase (represented by term $-c_f/6\tau$), but also because consumers observe the quality reduction (represented by the term $-c_f/(9a\tau - 1)6a\tau$), and realize that the price per unit of quality has increased even further; consumers thus reward the domestic firm whose quality has instead increased. The expenditure switching effect in favor of the domestic firm is magnified by the quality variation. In response to an exchange rate shock, the market clears both through the price and through the real channel of quality. The result is a lower degree of pass-through and a higher degree of expenditure switching with respect to the standard Dornbush model of duopoly competition.

2.3.9 Welfare analysis: surplus variation

When producers adjust the quality of their products, the price adjustment to the exchange variation is smaller than in the standard model. The quality adjustment generated by the exchange rate affects the consumers' welfare. For example, the welfare's change of a consumer that buys good f:

$$\frac{\partial W_{fn}}{\partial e} = \left| \frac{c_f}{(1 - 9a\tau)} - \left(\frac{2}{3} + \frac{1}{3(1 - 9a\tau)} \right) \right| .$$

This variation is partly due to the price change (represented by the term $2/3 + 1/3(1 - 9a\tau)$), and partly due to the quality change (represented by the term $c_f/(1 - 9a\tau)$). The latter

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variation is seldom measured by econometricians who usually observe only prices, and rarely have information on the quality of the products. Since quality variation are not reported, it is assumed that quality stays constant. Relying on this assumption the measure of the surplus variation would thus be equal to:

$$\frac{\partial W_{fnn}}{\partial e} = \left| -\left(\frac{2}{3} + \frac{1}{3(1-9a\tau)}\right)\right|.$$

which is smaller than $\partial W_{fn}/\partial e$. The unobservability of quality, typically translates into the assumption that quality stays constant through time. This assumption is not innocuous since it might lead to an underestimation of the true welfare change. When quality is taken into account instead, changes in the exchange rate have a bigger impact on consumer surplus and therefore also on expenditure switching.

2.4 Conclusions

The empirical literature documents a scarce responsiveness of prices to the exchange rate. A part of the theoretical literature explains this evidence relying on the assumption on nominal rigidities.[5] If imports as well as domestic prices are rigid, the exchange rate fluctuations cannot switch domestic demand in favor of the goods whose currency has depreciated. The flexible exchange rate becomes powerless to alter international relative prices, and loses its allocative role. As a consequence, exchange rate fluctuations have no expenditure switching power: that is, the ability of orienting the demand in favor of the goods whose currency depreciates. While these theories are able to match the empirical evidence on the exchange rate pass-through, they fail to reconcile the behavior of pass-through with the documented effect of expenditure switching.

Our model can fulfill this task. Through quality adjustments the model breaks the link between prices and quantities, showing that a low degree of pass-through is compatible with a positive expenditure switching. The assumptions that firms compete in prices and in qualities, and that consumers care about quality are crucial for this result. While empirical studies on pass-through can only observe prices and not qualities, consumers observe both, and form their consumption decisions accordingly. After an exchange rate depreciation, the foreign price modestly increases, and its quality decreases. Part of the consumers who were buying the foreign good before the shock, switch to the domestic good whose quality-price ratio increases relatively to the foreign firm. We thus observe a positive expenditure switching in favor of the domestic product together with a low degree of pass-through.

[5] See among the others Devereux and Engel (2003) and Devereux and Yetman (2005).

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Our model shows that exchange rate fluctuations can modify not only prices but also other features of the good: for example through the non-price channel the exchange rate can perform its role of international adjustment mechanism. We believe that it would be interesting to study dynamic supply side and demand side effects. If dynamic considerations are introduced into the analysis it is very likely that the effects of permanent and transitory changes in the exchange rate value will affect prices and market shares in a different way. From a demand side perspective it would be interesting to study how the results change when qualities are not observable by consumers. Intuition suggests that firms will most likely cheat on the consumers, selling low quality goods at high quality prices. In this case the expenditure switching will probably be lower than in the model presented in this paper. These issues are probably worth considering in future research.

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CHAPTER 3

DECREASING EXCHANGE RATE PASS-THROUGH AND NON-PRICE COMPETITION

3.1 Introduction

In the last years the empirical literature on exchange rate pass-through has shown that the degree of price stickiness has increased over time. Gopinath and Rigobon (2006) find that the average probability of a change in prices has declined by 10% from 1994 to 2004. Taylor (2000), Campa and Goldberg (2005) and Marazzi et al (2005) have documented that the degree of pass-through was substantially lower in the 1990s, compared to earlier decades. Frankel, Parsley and Wei (2005) also report evidence of declining pass-through using eight narrowly defined brand commodities. Several hypotheses have been proposed to account for this decline. These explanations rely on the assumption that the composition of imported goods has shifted either from homogenous goods to differentiated goods or from goods imported from developed economies to goods imported from developing countries. However, these stories have failed to find convincing empirical support. Gopinath and Rigobon (2006) test these theories and show that almost all of the decline in the degree of pass-through is explained by within-sector and within country time trends, the role played by composition effects being negligible.

In this paper we propose an alternative explanation for the observed decline in the exchange rate pass-through. The main idea starts from the fact that the reduction of the costs required for the development of new products has made non-price competition cheaper. Competition among firms has therefore switched from price-based to non-price-based. As a result, price stickiness has increased over time, and reduced the degree of exchange rate pass-through.

There is by now a common consensus in the literature of business and management that the costs of developing new products has dropped dramatically in the last 15 years. This reduction has been mainly motivated by the increased use of information technology in the production process, and by the improvement in the software for product design. The new technology has improved product characteristics, and reduced the costs and the time

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required to develop a new product. Changing the quality of a product often involves the substitution of an old product with a new one, and therefore lower costs to develop a new product directly translate into lower quality adjustment costs. For instance, in the last 15 years the cost of simulating a car's performance has decreased 250 times. Substituting a given car component with one of a different quality is therefore much less costly than 15 years ago.

We embed non-price competition into an infinitely repeated dynamic duopoly game. This paper builds on the standard dynamic duopoly models developed in the late eighties. Froot and Klemperer (1989) consider a two-period duopoly competing in the domestic market in which for each firm the residual demand is a function of the market share in the first period. The expected value of the exchange rate affects the value of the market share in the second period, and therefore determines the optimal price in the first period. The authors show that the magnitude and the sign of the exchange rate pass-through depend on whether exchange rate changes are perceived to be temporary or permanent. The model proposed in this paper presents a dynamic supply-side effect as in Baldwin (1988) and Baldwin and Krugman (1989). In these papers, the basic assumption is that firms incur significant sunk costs when entering foreign markets. These models predict that the exchange rate pass-through will depend both on the expected duration and on the size of the exchange rate change. Another model focusing on dynamic-side effects is the model of Kasa (1992). As in Froot and Klemperer, a critical factor affecting the degree of exchange rate pass-through is the relative importance of the transitory component of exchange rate fluctuations. Exchange rate changes that are perceived to be transitory are absorbed by changes in profits margins, resulting in a low degree of pass-through to import prices. The model proposed in this paper shares with the previous literature the dynamic-side effects, the partial equilibrium analysis, and the assumption that prices are completely flexible.

Unlike the previous literature, this model introduces non-price competition. Building on Hotelling (1929), products are defined as a triple of quality, price, and "characteristics". It is assumed that consumers are heterogenous in the evaluation of characteristics, and homogenous in the evaluation of quality. More specifically, for a given price, all consumers prefer higher quality, but they differ in their evaluation of the characteristic. A foreign and a domestic firm compete in a duopoly framework. The domestic firm's price and costs are expressed in the same currency. The foreign firm instead sets the price in the local market currency, but has costs in a different currency. This feature exposes the market to the fluctuations of the exchange rate. In particular, in a flexible price framework, if quality

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cannot be changed, an exchange rate depreciation of the domestic bilateral exchange rate increases the foreign firm's costs expressed in domestic currency, increasing its prices and decreasing its market shares.[1] The foreign firm, in order to insulate its profits from exchange rate fluctuations, optimally changes its costs by changing the quality of the product supplied in the domestic market. This requires that the old product be substituted with a new one of lower quality.

The way in which the two firms operate in the market can be described using a two stage game; first firms compete in quality, then they compete in prices. The price competition is a static game of complete information, since in each period both firms observe the realization of the exchange rate shock, and because current prices do not have any effect on future demand or profits. The quality choice, also referred to as non-price competition, is instead a dynamic problem, since any time the product varies from the previous period, firms must pay an adjustment cost that is assumed to be invariant through time. Given the structure of the problem it is possible to define a unique Markov-Perfect equilibrium that is also a rational expectation equilibrium: the beliefs of a firm about its competitor quality in equilibrium are correct and equal to the true amount of quality chosen by the competitor.

The model has three main results. First, the degree of exchange rate pass-through crucially depends on the sector of analysis: the least costly is to change the product after an exchange rate shock, the lower is the degree of pass-through. Second, the degree of pass-through is lower, the higher the persistence of the shock or the bigger the magnitude of the shock. The reason is that it is optimal for the firms to adjust the quality of the product more, when the shock is bigger or more persistent. Third, if product adjustment costs decrease, then pass-through is lower. This is consistent with the observation that as the costs of changing products have dropped in the recent years, the degree of exchange rate pass-through has substantially decreased.

With respect to the static framework of non-price competition, the model has the advantage of being able to break the link between exchange rate value and quality variation; in the dynamic framework we observe that quality is adjusted only when the shock is persistent or it is big.

The rest of the paper is organized as follows. Section (3.2) reviews the management literature on product development. Section (3.3) describes the model. Section (3.4) explains the game. Section (3.5) describes the results. Section (3.6) concludes.

[1] Notice that in a duopoly setting, when the costs of one of the two firms increase, both firms increase their prices, but the firm hit by the costs shock increases the price more than its competitor.

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3.2 Literature Review on Product Development

The business and management literature extensively shows that the costs and the speed of products development have considerably changed in the last fifteen years. The main reason for this change is the more widespread use of information technology (IT) in the product development process.

Banker at al. (2006) study the impact of collaboration software on product design and development. The so called Collaborative Product Commerce software (CPCs), is a relatively new, web-based technology, used to improve product design and development processes. CPCs allow product design engineers to collaborate with each other, by facilitating the sharing of product data used in the design, by improving the timing of product design, and by accelerating the product development cycle management.[2] Using product design and development data collected from a cross-sectional survey of 72 companies, the paper tests the hypotheses regarding the implementation of CPCs and its impact on product design and development. The authors find that CPCs has a significant impact on the level of collaboration among product design teams. Furthermore, improving the frequency and intensity of collaboration among workers, CPCs leads to improved performance, in terms of greater product design quality, lower design cycle time, and reduced product development cost. Finally the authors find that the software have both direct and indirect effects on product development productivity, since the impact of CPCs is also mediated through improvements in team collaboration.

Krishnan and Ulrich (2001) document that in recent years there has been an increasing reliance on the use of IT to manage the product development life cycle. By reducing the product development life cycle, IT have reduced the costs of supplying new products in the market. The IT has increased considerably the team collaboration which is a well known source of faster and cheaper products development.[3] Finally it has also contributed to the creation of new software able to simulate the effects that different raw materials used in production have on the products supplied. This type of software has dramatically reduced the costs associated with product developments also in terms of working time. These innovations have dramatically reduced product life cycles, leading to a much higher product turnover.

Davis et al. (2001) identify the way in which IT helps the development of new products. The main argument is that IT facilitates collaboration within the environment of product

[2] See for example Welty and Becerra-Fernandez, (2001) and Carrol (2001).
[3] See for example Tushman (1977).

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development. The nature of collaboration during product design and development ranges from face-to-face meetings and electronic communications involving phone, fax and e-mails, to the exchange of formal design documents through shared databases and groupware. The frequency and intensity of such interactions depends on several factors including missing product data, ease of access, data definition, and identification and evaluation of alternative design trade-offs. The authors find that in firms where the interactions are not well structured, and design engineers lack the ability to collaborate effectively, due to the shortfall of a single platform and appropriate standards to exchange product design data, the introduction of the appropriate technology considerably improves the product development process.

Yassine at al. (2004) study the role of IT in customizing product design. They identify the beginning of the eighties as the period in which the earlier IT tools were introduced in the market. However, only in the nineties the use of IT boomed. Technology has reduced so dramatically the costs of changing and adjusting products quickly, that product customizing has become a feasible strategy for a firm: GM, for example, through its "Order-To-Delivery" program is able to build and deliver customized cars in between fifteen and twenty days.

The authors divide the IT tools used in product developments according to three categories: communication, visualization and calculation tools. Communication tools are typically used for sharing business and technical informations. These tools ranges from simple telephones and fax to videoconferencing, shared database and e-Business solutions. Visualization tools are important for the display, sharing and communication in non-contextual information such as product designs and engineering drawings. Such tools consist mainly in CAD systems. These systems (especially 3D-CAD technologies) provide the possibility for creating "digital mock-ups" which replace the need for building physical prototypes at early stages of product development. Calculation tools allow for the manipulation of data and the creation of new knowledge. Such tools consist mainly of simulation software and mathematical prototypes/models. These tools dramatically reduce the costs and time of product development: for example, building an automotive physical prototype takes between four and six months to construct at an average cost of $500,000. With these tools an engineer can prepare the designed model and simulate it in two or three days for about $2000.[4]

Ozer (2000) presents a survey of business publications showing that companies are extensively using IT in their product development activities. The author identifies 9 categories in which IT can facilitate new product development. These categories are speed, productivity, collaboration,communication, coordination, versatility, knowledge management, decision

[4]See Crabb (1998) and Thomke (1998)

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quality, and product quality. Ozer reports several case studies in which companies quantify the effects that the introduction of IT has had in their products' development process. All the companies report huge improvements in all the categories mentioned above. We mention just one of the examples reported in the article, the Protodigm, a British drug development company, that through the use of IT was able to reduce the time of developing a new drug from seven to four years and to reduce the cost by 30%–40%.

These empirical studies testify that in the last years the use of IT has reduced the costs of creating new products. This cost reduction has undoubtedly made it more profitable to launch new products in reaction to both demand side and supply side shocks. Even if the IT effect might have been stronger for products with a higher technological content, it seems that it has affected the time and costs required to change all sorts of goods, including cars or fruit juices. In the case of fruit juice, for example, the IT has reduced the time of communications along the production line, the time of changing the design of the product's container or its label, the time and the costs necessary to implement marketing analysis able to assess whether the new product will have success or not. In the next section we study the effects that the reduced cost of changing products has on price rigidity.

3.3 The Model

3.3.1 Products

The world market is a linear city, where two firms produce two differentiated products. Each product is characterized by the triple ($s_{i,t}$, $p_{i,t}$, $x_{i,t}$), where subscript t denotes time, and subscript $i \in \{d, f\}$ denotes the country of origin of the firm, domestic or foreign.

The linear city is a segment of unit length in the closed interval $[0, 1]$. Firms are located at the extremes of the city, and without loss of generality, it is assumed that the domestic firm is located at $x_{d,t} = 0$ and the foreign firm at $x_{f,t} = 1$. $x_{i,t}$ represents the "characteristic" of the product and is defined as a peculiarity perceived as relevant by consumers, but which does not affect production costs (an example of a product's characteristic is its color). Consumers are uniformly distributed along the segment and their location defines their preferences over the characteristics $x_{i,t}$.

$s_{i,t}$ represents the amount of quality in the product and is defined as a feature on which all consumers agree over the preference ordering: for a given price and a given characteristic, the product with a higher amount of quality is preferred by each consumer (an example of quality is the product's raw material). Differently from the characteristic, the quality is positively related both to variable and fix costs. $s_{i,t}$ and $x_{i,t}$ are assumed to be independent.

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Finally $p_{i,t}$, defines the price of the good.

3.3.2 Consumers

Consumers are fully characterized by their location x in the segment $[0,1]$. They are thus heterogenous in the evaluation of the characteristic and homogenous in the quality evaluation.[5] We assume that the consumers' utility is decreasing in the distance between the good's characteristic x_i and x, decreasing in the price of the product p_i, and increasing in its quality s_i. The consumers' behavior is static and demand is unitary. In every period t, consumers have full information on characteristics and prices of the two firms, and they decides whether to buy or not a unit of a good, and if so, from which firm to buy. The utility of consumer x that buys good i at time t is:

$$u_{i,t} = k + s_{i,t} - p_{i,t} - \tau \left| x - x_i \right|,$$

where $\tau \left| x - x_i \right|$ represents the consumer's transportation costs, and τ is the unit transportation costs. This parameter must be interpreted as the marginal cost for a consumer of moving away from her ideal type of good. The utility of the outside alternative, i.e. not purchasing the good, is normalized to zero. k is a parameter which ensures that the market is always covered.

A consumer purchases a unit of good i if $u_{i,t} \geq 0$ and if $u_{i,t} \geq u_{-i,t}$. The above condition can be rewritten as $k + s_{i,t} \geq p_{i,t} + \tau \left| x - x_i \right|$. We derive now the time invariant consumers' demands for each product; we omit the time subindex for notation clarity. Let $\widehat{x} \in [0,\ 1]$ denote the location of the consumer that is indifferent between purchasing from firm i and firm $-i$. Thus:

$$s_i - p_i - \tau \left| \widehat{x} - x_i \right| = s_{-i} - p_{-i} - \tau \left| \widehat{x} - x_{-i} \right|. \tag{3.1}$$

Since $x_i = 0$, and $x_{-1} = 1$, solving equation (3.1) for $\widehat{x}$ provides:

$$\widehat{x} = q_i = \frac{s_i - s_{-i}}{2\tau} + \frac{p_{-i} - p_i + \tau}{2\tau}. \tag{3.2}$$

3.3.3 Firms

A "domestic" firm and a "foreign" firm compete in the domestic market. Both firms therefore set prices in the domestic currency. We define as domestic (foreign) the firm whose

[5] In the textbook version of vertical product differentiation, when consumers are homogenous in the evaluation of quality, if goods of different quality are supplied, all consumers always prefer the good with the highest quality, if they purchase at all (see Tirole 1988). This means that the low quality product is dominated. In our setting instead, since consumers are concerned also about the characteristic of the good, in equilibrium it is possible to observe different qualities without having to assume consumers' heterogeneity in the evaluation of quality.

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costs are expressed in the domestic (foreign) currency. The foreign firm's costs are converted in the domestic currency through the nominal bilateral exchange rate. The nominal bilateral exchange rate is a stochastic variable that evolves according to a Markov process given by:

$$e_t = e_{t-1}^{\rho} \exp \varepsilon_t \text{ where } \varepsilon_t \sim N(0, \sigma_\varepsilon^2) \tag{3.3}$$

The realization of e_t is common knowledge for both firms and consumers, and its future realization is the only source of uncertainty of the economy. For a given amount of quality, a depreciation (appreciation) of the exchange rate increases (decreases) foreign firm's costs expressed in domestic currency, leaving the domestic firm's costs unchanged. A variation of the nominal bilateral exchange rate thus leads to fluctuations of the relative costs of the two firms. However, firms can insulate these fluctuations in the relative costs, by changing the quality of the goods. This behavior can be described using a stationary discrete-time infinite horizon game explained in the following section.

3.4 The Game

Time is discrete. Every period t firms observe the realization of the exchange rate shock. Given this information, firms choose first the amount of quality and then compete in prices. The Bertrand game is static because current prices do not have any effect on future demand or profits. The equilibrium prices of the Bertrand game determine the equilibrium profits for each firm at time t as a function of the amount of quality they choose. Firms decide simultaneously the amount of quality that maximizes their profits given the optimal response of the competitor. This problem is dynamic because it is assumed that every time firms change the quality with respect to the previous period, they incur a quadratic cost of adjustment. The dynamics of the model are thus generated by the exogenous stochastic process of the nominal bilateral exchange rate, and by the forward looking choice of quality over time.

3.4.1 Price Competition: the Spot Market

In this subsection we omit the time subscript for notational simplicity. The price competition game is a static game of complete information. Firms maximize profits taking as given the value of the nominal bilateral exchange rate and both their own and their competitor's previous period quality. In order to restrict the analysis on the duopoly outcome the following assumption must hold:

A.1 $\forall s \in S, \quad |C_i(s_i, e) - C_{-i}(s_{-i}, e) + s_{-i} - s_i| < 3\tau;$

where $C_i(s_i, e)$ $(C_{-i}(s_{-i}, e))$ represents firm i $(-i)$ marginal costs that are function of their own quality and of the nominal bilateral exchange rate e. Assumption (A.1) is a necessary condition for a duopoly equilibrium to emerge. If A.1 is violated, the marginal costs of the two firms are too different to allow both firms to compete in the same market. It also states that $\forall s$ does not exist a characteristics level for which one of the two firms could be monopolist. Since in the dynamic game firms choose the level of characteristics and therefore their marginal costs, at that stage it must checked that the firms endogenously choose levels of characteristics that satisfy assumption (A.1). In appendix (3.2) we show that this indeed will be the case for each given level of characteristics s.

Given assumption (A.1) we can define the Bertrand-Nash equilibrium of the static game:

Proposition 3.1 *Suppose assumption (A.1) holds, then firm i and $-i$ play a duopoly price competition game characterized by the following prices, quantities and profits:*

$$\begin{aligned} p_i(e, s_{-i}; s_i) &= \frac{s_i - s_{-i}}{3} + \frac{3\tau + C_{-i}(s_{-i}, e) + 2C_i(s_i, e)}{3}, \\ q_i(e, s_{-i}; s_i) &= \frac{s_i - s_{-i}}{6\tau} + \frac{3\tau + C_{-i}(s_{-i}, e) - C_i(s_i, e)}{6\tau}, \\ \Pi_i(e, s_{-i}; s_i) &= \frac{(s_i - s_{-i} + 3\tau + C_{-i}(s_{-i}, e) - C_i(s_i, e))^2}{18\tau}. \end{aligned}$$

Proof. Each firm maximizes profits taking the price of the other firm as given. It follows from equation (3.2) that the static maximization problem of the two firms is:

$$\max_{p_i} \quad (p_i - C_i(s_i, e)) \left(\frac{s_i - s_{-i}}{2\tau} + \frac{p_{-i} - p_i + \tau}{2\tau} \right). \tag{3.4}$$

Each firm maximizes its profit by choosing its best-response price. The best-response of firm i is characterized by the first order condition:

$$\frac{s_i - s_{-i} + p_{-i} - 2p_i + \tau}{2\tau} - \frac{C_i(s_i, e)}{2\tau} = 0,$$

that combined with the reaction function of the competitor delivers the equilibrium prices, and hence the quantities and the profits stated in Proposition 1. ■

For each level of characteristics in the characteristics state space we find a unique Bertrand-Nash equilibrium given by that described in Proposition 1.

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3.4.2 Non-Price Competition: the Dynamic Analysis

3.4.2.1 The Primitives

The interaction among the two firms in the dynamic setting can be described by the following set of primitives which are common knowledge to the two firms:

$$\{(S,\mathcal{S}),(E,\mathcal{E}),\Omega,\Gamma,\Pi_i(e,s_{-i};s_i),R_i(s_{i,-1,},s_{-i},e;s_i),e,\beta\}.$$

$(S,\mathcal{S})$ and $(E,\mathcal{E})$ are measurable spaces which define the support for the endogenous variables s,and the exogenous state variable e, respectively; in particular:

A.4 $s\in S\subset\mathbb{R}_+$; $e\in E\subset\mathbb{R}_+$;

A.5 S is a convex Borel set in $\mathbb{R}^2_+$, with its Borel subsets $\mathcal{S}$;

The state space is $\Omega = S\times S\times E\subset\mathbb{R}_+\times\mathbb{R}_+\times\mathbb{R}_+$, and $\Gamma:\Omega\to S$ is a correspondence describing the feasibility constraint. It is further assumed that:

A.6 Γ is nonempty, compact valued, and continuous;

$\Pi_i(e,s_{-i};s_i)$ denotes the profit function of firm i, computed at the equilibrium of the price game, as written in Proposition 1. It is assumed that the quality can be changed in each period, but quality changes are associated with quadratic costs of adjustment. In each period the objective function of each firm is therefore given by the equilibrium profit of the price competition game in Proposition 1, minus the fixed costs associated with the quality level, minus the quadratic adjustment cost associated with the quality change; that is:

$$R_i(s_{i,-1},s_{-i},e;s_i)=\Pi_i(e,s_{-i};s_i)-A_i(s_i)-B(s_i-s_{i,-1})^2.$$

for each $e\in E$ we assume that $R_i(s_{i,-1},s_{-i},e;s_i)$ is strictly concave. This restriction on the one period return function ensures the unicity of steady state equilibrium. In particular the term $A_i(s_i)$ guarantees the intersection of the reaction functions of the two firms with respect to qualities; finally, β is the common discount factor of the firms and satisfies:

A.7 $\beta\in(0,1)$;

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3.4.2.2 Dynamic Game

At any time t the dynamic problem of the two firms is to choose simultaneously the optimal quality levels that maximize their expected present value of net cash flows given the state of the economy $(s_{i,-1}, s_{-i,-1}, e)$. Firms choose their amount of quality simultaneously after the exchange rate shock is realized. Both firms have complete information on the realization of the shock and on their own and their competitor's costs. The intertemporal problem of the two firms can be written as:

$$\begin{aligned} \max_{s_i} \boldsymbol{L}_{i,t}(e, s_{-i}; s_i) &= E_0 \left(\sum_{t=0}^{\infty} \beta^t R_{i,t}(s_{i,t-1}, s_{-i,t}, e_t; s_{i,t}) \right) \qquad (3.5) \\ s.t. \quad \max_{s_i} \boldsymbol{L}_{-i,t}(e, s_{-i}; s_i) &= E_0 \left(\sum_{t=0}^{\infty} \beta^t R_{-i}(s_{-i,t-1}, s_{i,t}, e_t; s_{-i,t}) \right). \end{aligned}$$

For any given $s_{i,t}$ the distribution used to form expectations in (3.5) can be derived from the firm's perception of the Markov transition kernel for its competitor, and the controlled Markov stated in (3.3). This formulation has a stationary Markovian structure. That is, the current states $(s_{i,-1}, s_{-i,-1}, e)$ and the current decision, s_i are sufficient to determine the evolution to the next state (s_i, s_{-i}, e'). This implies that for each of the two firms the optimal quality strategy, if it exists, can be chosen from the class of stationary Markov strategies. Therefore, the optimal quality choice, denoted by the policy function $G_i(s_{i,-1}, s_{-i,-1}, e)$, depends only on the current states $(s_{i,-1}, s_{-i,-1}, e)$. This implies that the problem is recursive, and if a solution exists, it must satisfy the Bellman equation:

$$\begin{aligned} V_i(s_{i,-1}, s_{-i,-1}, e) &= \max_{s \in \Gamma} \{R_i(s_i, s_{-i}, e) + \beta E_t V_i(s_i, s_{-i}, e')\} \qquad (3.6) \\ s.t. \quad s_{-i} &= G_{-i}(s_{i,-1}, s_{-i,-1}, e) \qquad (3.7) \end{aligned}$$

In any state, for each firm, the optimal quality choice must solve the above Bellman equation given the symmetric policy function of the competitor.

3.4.2.3 The Equilibrium

We study the dynamic equilibrium of the market arising from the competitive interaction between the domestic and the foreign firm. The equilibrium is one of "rational expectations", in the sense that, in equilibrium, the beliefs of firm i on the optimal decision strategy of its competitor, must be equal to firm $-i$ true policy function. The two firms solve a dynamic programming problem that is interdependent only through the states of the economy $(s_{i,-1}, s_{-i,-1}, e)$, such that their quality strategies remain optimal at every state, regardless

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of how that state was reached, against the optimal decision of the competitor. Thus we can say that the equilibrium is also a Markov-Perfect Nash Equilibrium in the sense of Maskin and Tirole (1988) and (2001). Given Assumptions (A.4)-(A.7), and equation (3.3) we can therefore define:

DEFINITION $\forall(s_{i,-1}, s_{-i,-1}, e) \in \Omega$ The Markov Perfect Equilibrium is given by a pair of value functions $V_i(s_{i,-1}, s_{-i,-1}, e)$ and a pair of policy function $G_i(s_{i,-1}, s_{-i,-1}, e)$ such that:

1. Given $G_{-i}(s_{i,-1}, s_{-i,-1}, e)$, $V_i(s_{i,-1}, s_{-i,-1}, e)$ satisfies (3.6);
2. The policy function $G_i(s_{i,-1}, s_{-i,-1}, e)$ solves (3.6) and satisfies:

$$\frac{\partial}{\partial s_i} R_i(s_{i,-1}, s_{-i,}, e; s_i) + \beta E_t \frac{\partial}{\partial s_i} V_i(s_i, s_{-i}, e') = 0.$$

Given our definition of the equilibrium we want now to show that the equilibrium exists and is unique;

Proposition 3.2 *Consider the firm's decision problem (3.6).* $\forall s_i \in [\underline{s}_i, \overline{s}_i] \subset S$ *and* $\forall e \in [\underline{e}, \overline{e}] \subset E$ *under the Assumptions (A.4)-(A.7):*

a. *there exist a unique* $V_i(s_{i,-1}, s_{-i,-1}, e)$, $V : \mathbb{R}^3_+ \to \mathbb{R}_+$ *, monotonic increasing in* s_i*, uniformly bounded, and satisfying (3.6);*

b. *there exists a unique optimal policy function,* $G_i(s_{i,-1}, s_{-i,-1}, e)$, $G : \mathbb{R}^3_+ \to \mathbb{R}_+$.

Proof. a. Monotonicity:

Let $W_i(s_{i,-1}, s_{-i,-1}, e) \leq V_i(s_{i,-1}, s_{-i,-1}, e)$ $\forall s_i \in [\underline{s}_i, \overline{s}_i] \subset S$ then:

$$\max_{s\in\Gamma} \{R_i(s_{i,-1}, s_{-i,}, e; s_i) + \beta E_t V_i(s_i, s_{-i}, e')\} \geq \max_{s\in\Gamma} \{R_i(s_{i,-1}, s_{-i,}, e; s_i) + \beta E_t W_i(s_i, s_{-i}, e')\}$$

and:

$$TV_i(s_{i,-1}, s_{-i,-1}, e) \geq TW_i(s_{i,-1}, s_{-i,-1}, e)$$

Discounting:

Take an $a \geq 0$. We have:

$$\begin{aligned} T(V_i + a)(s_{i,-1}, s_{-i,-1}, e) &= \max_{s\in\Gamma} \{R_i(s_{i,-1}, s_{-i,}, e; s_i) + \beta E_t [V_i(s_i, s_{-i}, e') + a]\} \\ &= \max_{s\in\Gamma} \{R_i(s_{i,-1}, s_{-i,}, e; s_i) + \beta E_t V_i(s_i, s_{-i}, e') + \beta a\} \\ &= \max_{s\in\Gamma} \{R_i(s_{i,-1}, s_{-i,}, e; s_i) + \beta E_t V_i(s_i, s_{-i}, e')\} + \beta a \\ &= TV_i(s_{i,-1}, s_{-i,-1}, e) + \beta a \end{aligned}$$

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that satisfies the discounting property.

b. The proof of uniqueness of the policy function $G_i(s_{i,-1}, s_{-i,-1}, e)$ is straightforward since the concavity of the one period return with respect to the endogenous state variable ensures that the sequence of the approximated policy functions $\{G_n\}$ converges to the optimal policy function $G_i(s_{i,-1}, s_{-i,-1}, e)$. ■

3.5 Results

In this section we describe the results of the model. The algorithm we have used to solve the model is described in Appendix (3.1). The results discussed in this section have an absolute error of 10^{-9} and a relative error of 10^{-8}. Solving for the optimal policy functions shows that the quality choice of each firm depends positively on their previous period quality, and negatively on the previous period amount of the competitor's quality. The first result can be explained in the light of adjustment costs, the second by the fact that firms find profitable to slightly differentiate their products also along the quality dimension. The exchange rate affects positively the quality of the domestic firm and negatively the quality of the foreign firm. The higher the exchange rate, the higher the costs of the foreign firm, the more the foreign firm will find optimal to reduce its quality in order to reduce its costs.

We have performed an impulse response analysis of a depreciation of the domestic exchange rate. We have analyzed a symmetric equilibrium in which before the shock the two firms have the same costs, prices and characteristics. In order to analyze the role of the persistence of the shock, we have analyzed a case in which $\rho = 0.7$, defined as high persistency, and a case in which $\rho = 0.2$, defined as low persistency. We have also analyzed the impact of two shocks of different magnitude.

As in Baldwin (1990), for a given parametrization of the model, increasing the persistency or the size of the shock delivers similar qualitative predictions. We thus limit the description of the results to the comparison of high and low persistency shocks, since the insights that we could get by comparing big and small exchange rate shock are identical.

In the static model of non-price competition, when quality is a continuous choice variable, a change in the exchange rate generates a quality adjustment.

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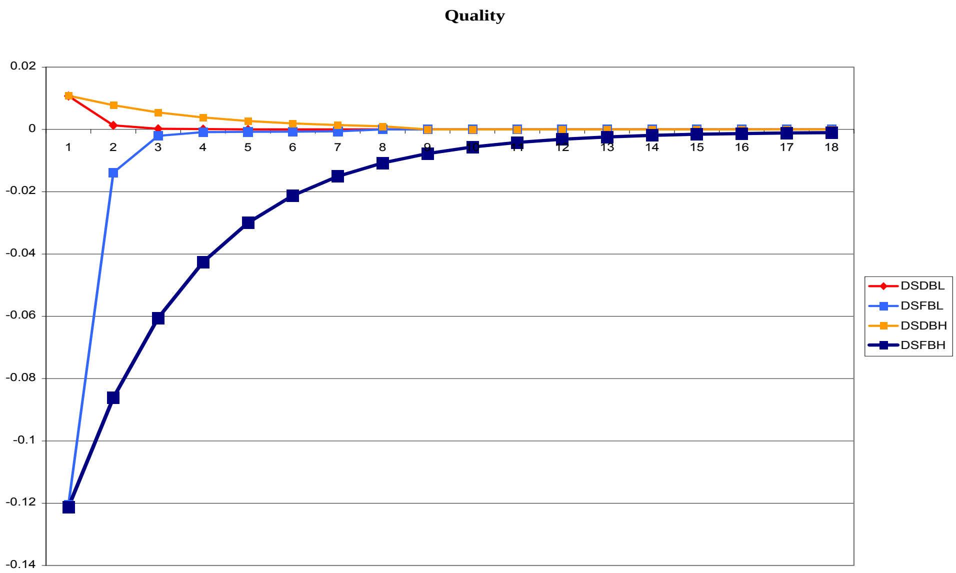

The figure above plots the domestic and foreign qualities in percentage deviations from the steady state, for different degrees of persistence, and in the case in which there are no adjustment costs, i.e., $B = 0$. In this limit case, the outcome of the model collapses to the equilibrium of a static game of quality competition. A depreciation of the exchange rate causes a reduction of the foreign quality and an increment of the domestic quality. The magnitude of quality adjustments is the same for both high and low persistency, but the higher the persistency of the shock the slower the quality goes back to its steady state value. No matter what the persistence of the shock is, quality always decreases by the same amount in the first period.

At the same time prices of both firms increase and market shares change in favor of the domestic firm. These results are shown in the following pictures.

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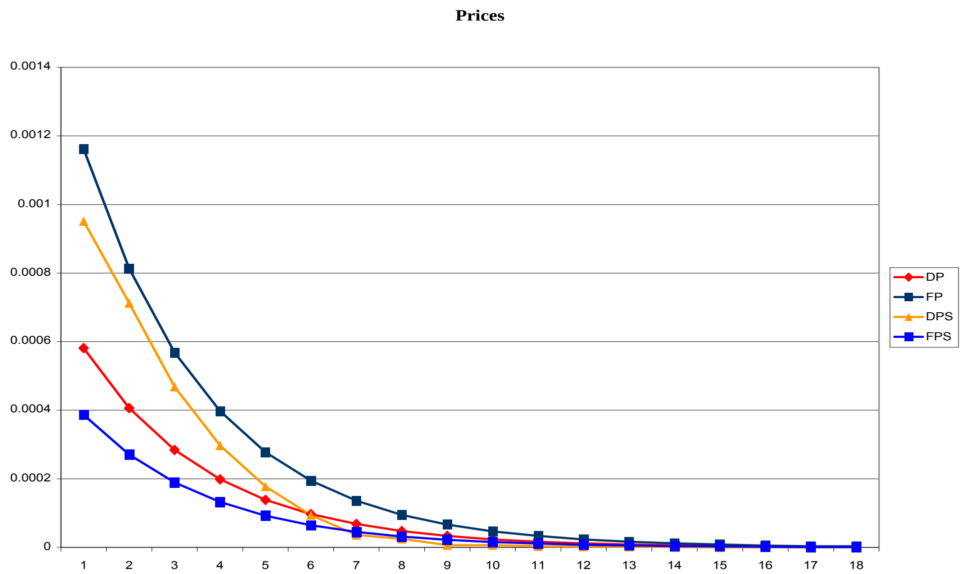

The above figure shows the response of prices to an exchange rate shock, with and without quality changes. Prices are expressed in percentage deviations from the steady state. An exchange rate depreciation increases prices: the highest line represents the price change of the foreign firm when quality is held constant. When firm F adjusts the quality, the price adjustment is much more moderate: it is represented in the lowest line in the plot above. Also for the domestic firm, prices increase less when quality can be adjusted: this can be seen in the plot, where the second highest line represents the domestic price with quality change, and the third highest line represents the domestic price's increment when quality is held constant. It is possible to notice that when quality can be changed, the domestic price reacts more than the foreign price, while the opposite is true when quality is kept constant. After an exchange rate depreciation, when quality can be changed p_D increases relatively more than p_F since firm's D quality is higher than firm's F quality. The quality gap between the two firms decreases the relative demand elasticity of firm D's consumers, allowing firm D to set a higher mark-up. This explains why the domestic firm sets higher prices than firm F following an exchange rate depreciation.

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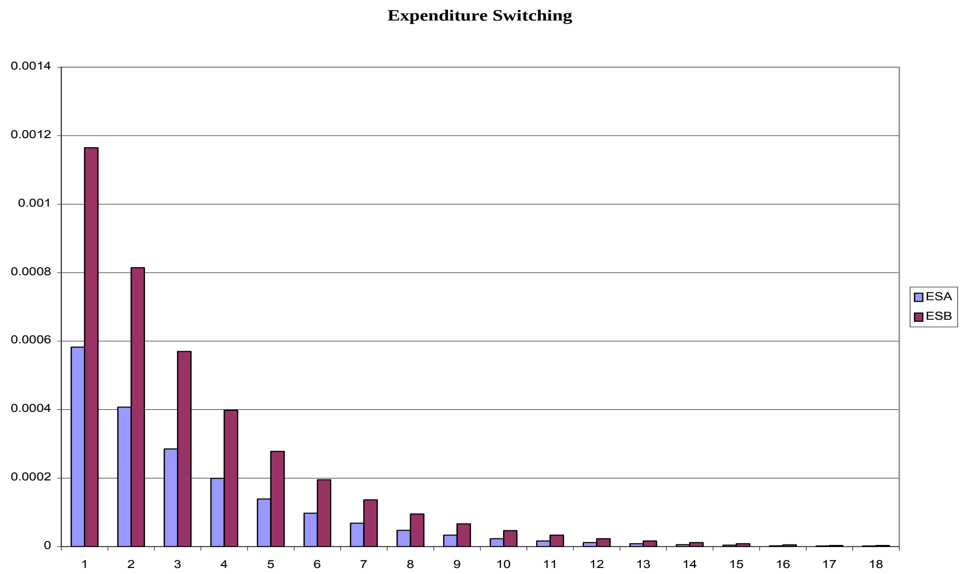

The expenditure switching in favor of the domestic good is much higher when firms are allowed to change quality. This result is shown in the picture above. The logic behind this result is the following: for a given level of quality, a depreciation of the exchange rate increases the marginal costs of the foreign firm expressed in domestic currency. The impulse response shows that the foreign firm reduces the amount of quality and increases the prices. The domestic firm increases the quality level slightly and the price level more. Overall the two firms increase prices less than in the case in which the quality is held constant, leading to a smaller exchange rate pass-through than in standard models with strategic interaction. The domestic firm's market shares increase more than in the standard duopoly models due to an increase in the relative quality of the domestic product. With respect to the standard duopoly models, allowing the market to clear along the quality dimension generates lower pass-through and a higher degree of expenditure switching.

The foreign firm decreases the quality of the product supplied even if this entails a lower market share. Following a depreciation, marginal revenues, expressed in the foreign currency, decrease. The foreign producer optimally curbs the reduction in profits by cutting its costs. This can be done by diminishing the quality content of the good. The decrease of the quality, as well as the increase in prices, has a negative effect on the foreign firm market shares. The combination of a low degree of exchange rate pass-through together with an expenditure switching effect is a result that relies on our assumptions on both the costs structure and non-price competition among firms. Quality adjustment costs do not matter for these results.

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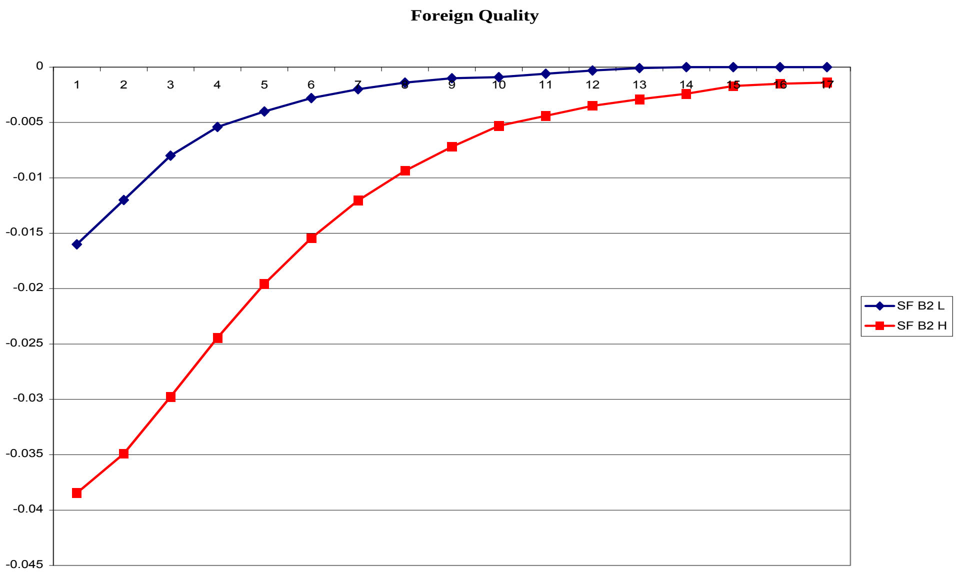
3.5.1 The role of the quality's adjustment cost

When $B = 0$ the model reproduces the results of the static game of non-price competition. When $B > 0$ instead firms incur a cost every time they change the quality. This cost induces firms to adjust the quality taking into account the size and the persistence of the shock. When $B > 0$ the impulse response of the foreign quality for different degrees of persistency is represented in the following figure:



When firms incur in costs of adjustment, the persistence of the shock plays a much important role. The higher the persistence of the shock the bigger the quality adjustment in the first period, and the slower the return to the steady state.

As a consequence, for shocks of high persistency we observe bigger expenditure switching together with a lower degree of pass-through. This result is at odds with the previous theoretical literature that predicts that the higher the persistency, the bigger the degree of pass-through. However, it is reasonable to think that when shocks are more persistent, firms have higher incentives to adjust their quality than if shocks are less persistent. The adjustment of quality depends also on the value of B. Taking constant the dimension of the shock and its persistency, the bigger the value of B the smaller the quality adjustment.

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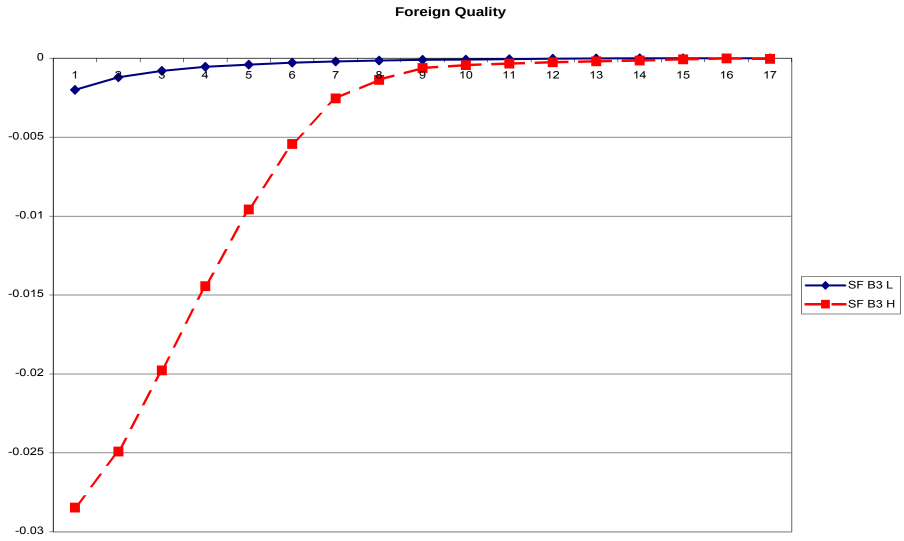
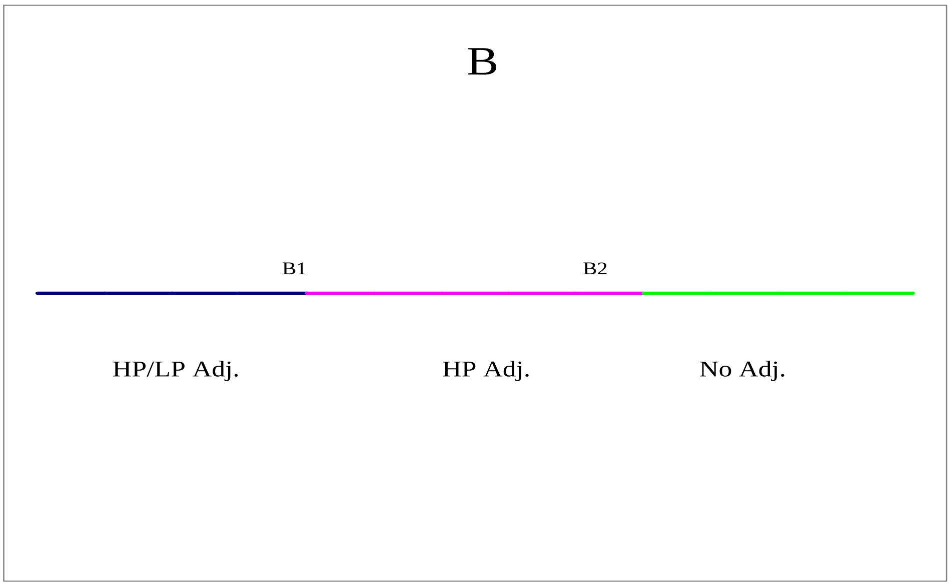


The picture above plots the outcome of the same impulse as in the previous picture, but given a higher B. For shocks of low persistency, quality exhibits little reaction. The same holds true in the opposite case. We can define two threshold values for B.[6]



[6] In the following picture the abbreviation "HP/LP Adj". identifies the region for quadratic costs of adjustment smaller that the treshold $B1$; in this region firms always adjust quality: for both high persistency (big) shocks and low persistency (small) shocks. The abbreviation "HP Adj." means that when $B1 < B < B2$ firms adjust quality only if the shocks have high persistency or are big. Finally "No Adj." identifies the region on the left of $B2$, where firms never adjust quality independetly of the persistence and the magnitude of the exchange rate shocks.

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When $B \leq B1$ firms adjust quality regardless of the size and persistence of the exchange rate shock. When $B1 \leq B \leq B2$ firms adjust quality only for high persistency (big size) exchange rate shocks, finally when $B > B2$ firms never adjust quality. The relation between costs of adjustment and persistence of the shock has novel effects on the degree of pass-through. When the costs of adjusting quality are less than $B1$, the degree of pass-through is always smaller than in the standard case, since quality always adjusts. When $B > B2$ we are back to the standard duopoly model. With respect to the static non-price competition model, the novel result relies on the case of $B > B1$: above this threshold the quality adjusts depending on the persistence and on the magnitude of the exchange rate shock.

The model introduces a novel result also with respect to the previous dynamic literature on exchange rate pass-though. The papers by Froot and Klemperer, and Baldwin predict that bigger and/or more persistent shocks are associated with a higher degree of exchange rate pass-through with respect to smaller and less persistent shocks. In the model proposed in this paper, when $B1 \leq B \leq B2$ and if the persistence is low, quality does not adjust, and the degree of pass-through is the same as in the standard model. If instead the persistence of the shock is high enough, given the same value of B, quality adjusts and the degree of pass-through is smaller than in the standard model. Shocks with higher persistence, or of bigger size, are thus associated with quality variations and with lower degree of exchange rate pass-through. The relation between prices and the persistence of the shock may seem counter intuitive, but it is perfectly plausible to expect that product modifications occurs for bigger shocks or for shocks that are expected to last for longer.

The cost B is a parameter that represents the state of technology required to change a product or given features of it. We can imagine that B differs from sector to sector, or also that it changes over time. For example in the apparel sector, in which product change very frequently, we can imagine that B is much smaller in than in the sector of machinery, where it is very difficult to adjust the product after a design is made.

One of the implications of the model is thus that in sectors in which B is relatively smaller the degree of pass-through will be lower than in sectors where B is higher. Firms adjust the quality easily and can do it for both high and low persistence shock. This behavior implies a low degree of pass-through since the exchange rate shock can be transmitted more through the real channel of quality than through the nominal channel of prices. In sectors where the costs of changing quality are instead prohibitive, we expect producers not to resort to quality changes. Our model thus predicts that prices should be more flexible in these sectors.

The second implication comes from the consideration that due to technological progress it is less costly to change products today than it was in the past. As the empirical evidence

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presented in Section 3.2 shows, the IT revolution has dramatically reduced all the costs related to the design and product development. If the costs of developing a new product decrease, also the costs of changing the quality will fall, since changing quality requires the development of a new product. If technological process has decreased the value of B over time, more and more sectors in the economy have enjoyed the possibility of adjusting quality in response to shocks. This has most likely generated a gradual increment of product variation in response to shocks, reducing the degree of exchange rate pass-through.

The dynamic model is thus able to offer a potential explanation either for the different degree of exchange rate pass-through across sectors, or, in an intertemporal perspective, for the reduction of exchange rate pass-through in the last 15 years.

3.6 Conclusion

In recent years the empirical literature has shown that the degree of exchange rate pass-through has been decreasing over time. In this paper we propose an explanation for this evidence, attributing the decline of exchange rate pass-through to the increment of competition in non-price dimension among firms to the prejudice of price competition. The increase of non-price competition has been due to the reduction of the costs of products development: the technological process has thus created the opportunity to substitute products in the market more quickly and cheaply. The reduction of the costs of changing products has had an effect on prices which appear to be more sticky. According to our theory prices are only apparently constant, since if it were possible to control for quality, prices would change.

This hypothesis is formalized as an equilibrium outcome of an infinitely repeated game in which a domestic and a foreign firm compete both in price and in non-price dimensions. If exchange rate shock occurs, the firms can adjust or not the quality of the product they supply, depending on adjustment costs. If the cost of changing quality is low enough, firms not only adjust prices but also qualities. If the cost of changing quality is high, firms adjust the quality only if the shock is big enough or the persistence is high enough. The adjustment of quality affects prices that react more if the shock has a low persistence or it is small. These results have important implications: first, the degree of pass-through will be sector specific. In the sector where it is less costly to adjust the quality, we expect to observe more quality adjustment also when shocks are small and less persistent, and thus we expect a lower degree of exchange rate pass-through. Second, since the costs of adjusting products have declined in the last twenty years, it is plausible to expect that firms have resorted to non-price competition more extensively, thus generating an apparent increase in price stickiness.

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The model can be extended in several directions. It might be interesting to see what the properties of the model are in a general equilibrium framework, and to study the testable implication of the model proposed in this paper. We leave this analysis for future research.

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APPENDICES

Appendix

3.1 Numerical Solution

The usual way of solving a dynamic game is implementing the Linear Quadratic algorithm (L-Q). In order to solve the L-Q algorithm, the one period return function must be quadratic, or, if it is not, it should be possible to determine the deterministic steady state before the algorithm is computed in order to compute the second order Taylor approximation around it to reshape the problem in a quadratic form. The one period return function of the problem described above can neither be expressed as quadratic, nor is possible to solve for the steady-state equilibrium. We therefore use the collocation method to solve the model.[7] We describe in the next subsection the algorithm used to compute the policy functions.

The Algorithm

The collocation method provides a straightforward strategy to solve for functional equations. Using the collocation method the policy functions of the two firms can be considered as an unknown functions that can be approximated using a linear combination of n basis functions.

$$\widehat{G}_{-i}(s_{i,-1}, s_{-i,-1}, e) = \sum_{j_1=0}^{1}\sum_{j_2=0}^{1}\sum_{j_3=0}^{1} d_{j_1 j_2 j_3}\varphi_{j_1 j_2 j_3}(s_{i,-1}, s_{-i,-1}, e). \tag{3.8}$$

where the policy function is expressed as a linear combination of a set of n linearly independent basis functions $\varphi_{j_1 j_2 j_3}$ and $d_{j_1 j_2 j_3}$ basis coefficients that are the unknowns of the function. In tensor notation, the approximant can be written:

$$\widehat{G}_{-i}(s_{i,-1}, s_{-i,-1}, e) = \left[\phi_i(s_i) \otimes \phi_{-i}(s_{-i}) \otimes \phi_e(e)\right] d$$

[7] See Miranda and Fackler (2002).

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where d is a$n \times 1$ column vector and each ϕ_ι is the $1 \times n_\iota$ row vector of basis functions over the dimension ι. $n = \prod_{\iota=1}^{l} n_\iota$ basis coefficients are fixed by requiring the approximant to satisfy the functional equation, not at all possible points of the domain, but rather at n prescribed points in the approximation space, called the collocation nodes. Given the multivariate nature of the problem and the values of the relative residual function that we obtain, we report the results that we get for $n_\iota = 2$ for each of the states of the economy. $n_\iota = 2$ for each of the states implies eight collocation nodes, and eight unknown basis coefficients for each policy function.

Step 1: Definition of functional forms and parameter values. In order to solve the firms' maximization problem, we need to specify functional forms for the model. Marginal and fixed costs functional equations are defined as:

$$\begin{aligned} C(s_{i,t}, e_t) &= \begin{cases} c_i s_{i,t} & \text{for } i = d \\ c_i^* s_{i,t} e_t & \text{for } i = f \end{cases} \\ A_{i,t}(s_{i,t}) &= a_i s_{i,t}^2 \qquad \text{for } i = d, f. \end{aligned}$$

Foreign firm's marginal costs are expressed in foreign currency, while foreign firm's fix costs are expressed in domestic currency. This specification allows to analyze just the effects that an exchange rate shock has on the spot market. If both the foreign firm's costs of adjustment and the fix costs were expressed in foreign currency, the foreign firm's decision of changing characteristics would depend exclusively on the importance of these costs with respect to revenues. Also in the case of a small depreciation, the costs of selling high characteristics goods would be not compensate by the associated revenues, and foreign firm will always decrease the amount of characteristics. When only marginal costs are function of the exchange rate instead, we are able to capture how selling an extra unit of the good in the domestic market increase the costs of the foreign firm, and thus to consider only the direct effect of selling an extra unit of characteristics. In each period, given the costs specification, the concavity of R_i is guaranteed if:

$$(1 - c_i e)^2 < 18\tau(a_i + B) \quad \text{with } e = 1 \text{ if } i = d.$$

The parameter values have been chosen in order that Assumption (A.1)-(A.7) hold given the functional forms of the model and the above condition on the concavity of the one period return holds as well.

Step 2: Definition of the approximation space. we have to define a compact set of (s_i, s_{-i}, e) pairs over which solve the algorithm. The choice consists in four parameters $\overline{s}$, $\underline{s}$,

$\overline{e}$, $\underline{e}$. The choice of the upper and lower bound of s must be done in order to obtain a steady state value that is contained in the interval, similarly for the value of e.

Step 3: Computation of the Euler equations. Once the control variable of the competitor is defined as the unknown function, we compute the Euler equations of the two firms. For each firm the Euler equation is equal to:

$$
\begin{aligned}
0 \;=\; & \frac{(s_i(1-c_i)+G_{-i}(s_{i,-1},s_{-i,-1},e)(c_{-i}e_t-1)+3\tau)}{18\tau} - a_i s_{i,t} - B(s_i - s_{i,-1}) + \\
& \beta E_t\left\{\left[\frac{(s_{i,t+1}(1-c_i)+G_{-i}(s_i,s_{-i},e_{t+1})(c_{-i}e_{t+1}-1)+3\tau)}{18\tau}\right]\frac{\partial G_{-i}(s_i,s_{-i},e_{t+1})}{\partial s_i}(c_{-i}e_{t+1}-1)+\right. \\
& \left. B(s_{i,t+1}-s_i)\right\}
\end{aligned}
$$

we thus obtain a system of two equations (the two Euler), in two unknowns (the two policy functions). In each Euler equation we approximate the expectation operator using a Gauss-Hermite quadrature choosing the number of nodes equal two.[8]

Step 4: Solution of the collocation equations we solve the collocation equations in order to find the given Chebicev nodes.

Step 5: Computation of the basis coefficients. Given the Euler equations evaluated at the Chebicev nodes, we find, by Newton's method, the sixteen basis coefficients that solve for the zeros of the equations.

3.2 Time Consistency

In this subsection we analyze the conditions under which assumption (A.1) holds in the static and the dynamic game; this is equivalent to say that when firms have the possibility of reoptimize their quality in the dynamic game, they choose an amount of quality that satisfies assumption (A.1). In the dynamic game firms could find profitable to deviate from assumption (A.1), reducing their quality and hence their marginal costs such that assumption (A.1) does not hold anymore; in this occurrence the firm that deviates becomes the monopolist. This scenario however does not realize if the following assumptions hold:

A.2 $C_i(s_i, e) < 1$;

[8] A higher number of nodes does not change the results and the relative error.

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A.3 $\forall s \in S$, and $\forall e \in E$:

$$
\begin{aligned}
& R^{M}_{i,t}(s_{i,t-1}, s_{-i,t-1}, e_t; s_{i,t}) + E_1\left(\sum_{t=1}^{\infty} \beta^t R^{D}_{i,t}(s_{i,t-1}, s_{-i,t-1}, e_t; s_{i,t})\right) \\
< \quad & E_0\left(\sum_{t=0}^{\infty} \beta^t R^{\overline{D}}_{i,t}(s_{i,t-1}, s_{-i,t-1}, e_t; s_{i,t})\right)
\end{aligned}
$$

(A.2) follows from the static maximization problem of the firms and guarantees that $\Pi_i(e, g\left(s_{-i}\right); s_i)$ is strictly increasing in s_i. This assumption leads to the possibility of observing in equilibrium a quality level different from the lowest possible level. If the intratemporal profits were decreasing in s_i indeed, firms would offer always the lowest possible quality and it would never be observed characteristics changes.

(A.3) follows from (A.1) and (A.2), and relates the expected stream of profit of a firm that reduces its quality in order to be the monopolist in the market (L.H.S.), and the expected stream of profits of a firm always playing a duopoly in the highest possible characteristics level (R.H.S.). It is assumed that given the realization of the exchange rate, once a firm chooses a quality lower than the highest possible in order to get the monopoly profits ($R^{M}_{i,t}(s_{i,t-1}, s_{-i,t-1}, e_t; s_{i,t})$), the firm gets them for just one period but from the next period on, it receives the lowest possible characteristics duopoly profits. This is due to the reaction of the firm that has not deviate by the duopoly strategy who punish the competitor supplying the lowest possible quality for ever ($R^{\overline{D}}_{i,t}(s_{i,t-1}, s_{-i,t-1}, e_t; s_{i,t})$).

Even when an exchange rate shock occurs such that assumption (A.1) does not hold anymore, the firms' best strategy is to choose a new level of quality that restores assumption (A.1). Suppose that after a large depreciation of the exchange rate, foreign firm's marginal costs are too high with respect to those of the domestic firms, to compete in the market. In order to sell a positive quantity, the foreign firm will reduce its amount of quality, but by (A.2) and (A.3), it will choose the highest possible quality level compatible with the new value of the nominal bilateral exchange rate. On the other hand, due to assumption (A.3) the domestic firm, whose marginal costs are not increased, cannot do better than choose a new quality level compatible with (A.1). This can be equal or lower than that of the period before.

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