Exchange Rate Pass-through and the Welfare Effects of the Euro

Michael B. Devereux[1]

University of British Columbia and CEPR

Charles Engel

University of Washington and NBER

and

Cédric Tille

Federal Reserve Bank of New York

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Abstract

This paper explores the implications of the European single currency within a simple sticky price intertemporal model. The main issue we focus on is how the euro may alter the responsiveness of consumer prices to exchange rate changes. Our central conjecture is that the acceptance of the euro will lead European prices to become more insulated from exchange-rate volatility, much the way U.S. consumer prices already are. We show that this has profound consequences for both the volatility and *levels* of macroeconomic aggregates in both the U.S. and Europe. We find that European welfare is enhanced, and, more surprisingly, that the U.S. shares in Europe's good fortune. Alternative assumptions about how pricing behavior will change lead to different conclusions, but in all cases we can derive specific implications for expected levels and volatility of macroeconomic variables.

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Introduction

The implementation of the single currency in Europe, to take full effect in January 2002, has received a great deal of attention from the public, the press and the academic literature. Much of the academic literature has discussed the question of whether Europe is an `optimal currency area', in the sense of Mundell (1961) and McKinnon (1963).[2] This literature has assumed that the main effect of the adoption of the euro is to fix permanently the currency exchange rates in Europe. The emphasis has been on the incremental increase in the stability of the exchange rate system when the single currency is finally fully adopted.

Another strand of the academic literature shares the popular view that the adoption of the Euro is a more fundamental change. For instance, this literature has explored the role of the euro as an international currency (see Hartmann (1996) and Portes and Rey (1998)). While at present world trade and financial flows are carried out predominantly in US dollars, the relative importance of the dollar may diminish as the euro becomes more widely acceptable in international transactions. The euro may become a `vehicle currency' which competes with the US dollar, just as the US dollar in a previous epoch competed with (and eventually replaced) the use of sterling.

We focus on one aspect of the adoption of the euro as an international currency that has heretofore been neglected, but which has potentially significant effects for macroeconomic stability. When Europe becomes integrated into a single large currency area, approximately equal in size to the U.S., it is likely that Euro consumer prices will become as insulated in the short run from exchange-rate changes, as indeed U.S. prices have been, since the dollar became the major vehicle currency. It is easy to understand this shift from a transactions-cost perspective. Take the situation of a retail firm that markets US goods in Europe. When there are a dozen European currencies within the EMU, the firm faces two

[2] See for instance Eichengreen (1992), Bayoumi and Eichengreen (1993), De Grauwe (1994), Obstfeld and Peri (1998).

types of costs when exchange rates fluctuate. On the one hand, there are menu costs from altering the price that consumers pay, as the exchange rate changes. This encourages the firm to keep prices stable in consumers' currencies. But if prices are set in the consumers' currencies, and the firm is purchasing goods directly from US exporters, who set their prices in dollars, its profits will be exposed to exchange-rate volatility. With a dozen European currencies, the firm selling U.S. goods in Europe would need a dozen pricing decisions, and a dozen exchange-rate hedging operations. These transactions costs would tend to tilt firms toward stabilizing prices in dollar terms, which would mean that the prices consumers pay would be more sensitive to changes in the dollar exchange rate.

When Europe is consolidated into a single-currency area, the accounting costs for pricing in the European consumers' currency are reduced considerably. For example, it is more likely that U.S. exports will be invoiced in euros. (Currently, there is an asymmetry such that U.S. exports to Europe are heavily invoiced in dollars, but European exports to the U.S. are also invoiced in dollars. See ECU Institute (1995).) Giovannini (1988) observes that the currency of export price invoicing is important for the pass-through of exchange rate changes to goods prices. But even if U.S. export price invoicing does not change, multinational marketers are more likely to view Europe as a single marketing area and will develop pricing plans in terms of euros.[3] The importance of the euro as a payment and invoicing currency has recently been recognized by the European Central Bank:

``*..increasing use of the euro as a payment/vehicle and pricing/quotation currency ..could make the euro area Harmonised Index of Consumer Prices (HICP) less sensitive, in the short run, to US dollar exchange rate movements. … If euro area exports and imports are increasingly invoiced in euro, the short-term effects of exchange rate changes on the goods and services trade balance should be generally reduced*[4] ''

We explore this issue within an international macro model with sticky nominal prices, so that the currency of denomination of imported consumer goods has real effects on

[3] Much as IKEA sets dollar prices for the entire U.S. market (see Haskel and Wolf (1999)).

macroeconomic aggregates and welfare. Our central conjecture is that the introduction of the euro will insulate European consumer goods prices from exchange rate changes. As a consequence, the introduction of the euro will affect the volatility of real money balances, and in turn macro aggregates such as consumption, in Europe. There are two effects that work in opposite directions. First, the impact of European money shocks on the European real money supply is magnified after the adoption of the euro. Pre-euro, when prices of imported U.S. goods are more responsive to exchange-rate changes, there is an automatic stabilizer in effect. If there is, for example, an increase in the money supply in Europe, European currencies depreciate, raising the price that Europeans pay for U.S. goods. The real money supply rises by less than the nominal money supply. That cushioning effect vanishes if euro prices do not respond to exchange rate changes. Working the other way, U.S. money shocks also are directly transmitted to the aggregate price level in Europe, pre-euro, through exchange rates. That channel of real monetary instability is eliminated to the extent that euro prices are unresponsive to dollar exchange-rate movements.

If European and U.S. monetary shocks are about equal in size, and less than perfectly correlated, the introduction of the euro will increase real monetary instability in Europe. Intuitively, pre-euro there is a sort of diversification effect when European prices respond quickly to the exchange rate. The variance of a weighted sum of European and U.S. money shocks determines European real money volatility. Some of the European monetary variance is dissipated through exchange-rate changes, while the exchange rate transmits some of the U.S. monetary variance. But when the exchange-rate effect on European prices diminishes, the diversification effect dwindles. In the extreme case of no short-run price response to exchange-rate changes, European real money variance is determined by the variance of European money shocks (which is greater than the variance of a weighted sum of European and U.S. shocks). If this constituted the entire effect of the euro, then European consumers would be worse off (and U.S. consumers would be unaffected).

[4] European Central Bank (1999).

But there is a second channel through which the euro affects welfare. Our model follows Obstfeld and Rogoff (1998) in that goods prices are set optimally, taking into account the stochastic environment that is faced by the firms. This implies that the introduction of the euro will alter not just the volatility of macroeconomic aggregates, but through the adjustment of goods prices, change the *expected values* of these aggregates (see Devereux and Engel (1998)). We find that the introduction of the euro increases expected aggregate consumption in Europe, through a relative-price stabilizing effect. As Rogoff (1996) has noted "short-term exchange volatility point(s) to financial factors such as changes in portfolio preferences, short-term asset price bubbles, and monetary shocks. Such shocks can have substantial effects on the real economy in the presence of sticky nominal wages and prices." In particular, before the advent of the euro, prices paid by consumers for imported goods are excessively volatile. They respond to exchange rates changes which, in the short run, do not reflect real demand and supply factors, but rather are reacting as asset prices to financial market shocks. We find that when prices are stabilized in euros and unresponsive in the short run to exchange rate fluctuations, the elimination of the volatility of relative prices of imported to domestically-produced goods enhances expected consumption and welfare.

Since our model is utility based, we can ask how the euro affects expected utility of U.S. and European consumers. We find for Europeans that the positive effects from the reduction in relative-price volatility outweigh the increase in real monetary volatility. Some simple numerical calibrations indicate that the gains to Europe from the introduction of the euro are substantial when compared, for example, to the gains that might accrue from elimination all monetary variability.

A common view of the coming of the euro is that while Europe will gain, the U.S. must be a loser.[5] On the contrary, we find that the U.S. shares in Europe's good fortune. The channels that reduce relative price volatility and insulate Europe from U.S. monetary shocks are reflected in increased asset prices. To the extent that Americans are diversified

[5] For example, Portes and Rey (1998) and Bergsten (1999).

internationally – our model assumes full diversification for simplicity – their portfolio of assets will also increase in value.

We briefly explore the implications of alternative assumptions about how pricing might change. We examine the possibility that, to the contrary of our leading assumption, U.S. prices may become more sensitive to exchange rate changes (while European prices either remain as sensitive, or become less responsive.) Our welfare conclusions in some circumstances change substantially depending on the pattern of pricing behavior.

The paper is organized as follows. The next section develops the basic model. Section 2 derives our central positive results, the welfare impact being discussed in section 3. Section 4 discusses a variant of the model where US firms are constrained to set identical dollar prices for domestic sales and exports. Section 5 allows pre-euro Europe to have floating exchange rates. Section 6 discusses alternative changes in pricing practices that may follow from the euro. A numerical example is presented in section 7, and conclusions follow.

1. The Model

Our framework consists of a general equilibrium model in which the world is made of two regions, the United States and Europe. Each region is populated by a continuum of households. We normalize the world population to 1, and assume that households over the $[0, n)$ interval are residents of the United States, while households over the $[n,1]$ interval live in Europe. There also exists a continuum of firms in both regions, with the number of firms in each region equal to the number of households. Within each region, firms are owned by the domestic households. Our framework is characterized by monopolistic competition: each firm is the sole producer of a particular brand, which is an imperfect substitute for the other available brands. Firms therefore enjoy a degree of monopoly power in pricing.

Throughout the analysis, there is only one currency used in the United States, namely the US dollar. By contrast, there are initially several currencies in use in Europe, which are replaced by a unique currency, the euro. To simplify the exposition, we consider Europe as one region, and present our results in terms of European wide per capita values. We could instead write the model by considering a number *N* of European countries. Note however that once the euro has been introduced, all European countries have the same currency and are identical. Furthermore, in the main part of our analysis, we assume that pre-euro European countries follow a fixed exchange rate regime. This implies that the economic situation is the same in all European countries,[6] and nothing is lost by focusing on European wide aggregates.

In each country, there is a monetary authority, and the money supply fluctuates stochastically. Before the introduction of the euro, each European country has its own monetary authority, whose behavior may be constrained by the requirements of fixed intra-European exchange rate. With the set-up of the single currency area, European money supply is taken over by the European Central Bank.

1.1. Households

Households obtain utility from consumption and the liquidity services provided by holdings of real balances, but incur disutility from working. The objective of household *x*, living in region *i* at time *t* is to maximize her intertemporal utility given by:

$$U_{it}(x) = E_t \left\{ \sum_{s=t}^{\infty} \beta^{s-t} \left[\frac{1}{1-\rho} \left(C_{is}(x) \right)^{1-\rho} - \eta L_{is}(x) + \chi \ln\left(\frac{M_{is}(x)}{P_{is}^{i}} \right) \right] \right\} \tag{1.1}$$

where $\beta \in (0,1)$ is the discount factor, $\rho > 0$ is the intertemporal elasticity of substitution, and η and χ are positive scaling parameters. $C_i(x)$ is a consumption basket defined below, $L_i(x)$ is the number of hours worked, $M_i(x)$ denotes the holdings of domestic currency and P_i^k is the price of one unit of the basket consumed in region *i*, expressed in terms of region *k* currency (*k* = *eur* denotes a price in the European currency, whereas *k* = *dol* denotes a price in

[6] Our analysis does not consider the case of asymmetric shocks across European countries. In such a case, the economic situation wouldn't be homogeneous within Europe.

US dollars). This is a quite a special utility function, with a linear cost of effort. But it has the appeal that it allows us to derived *closed form* solutions for consumption and welfare in the face of uncertainty in money supply and differences in pricing arrangements across countries.

The consumption basket $C_i(x)$ is a composite of goods produced in the United States and goods produced in Europe:

$$C_i(x) = \frac{1}{n^n(1-n)^{1-n}} \left(C_{i1}(x)\right)^n \left(C_{i2}(x)\right)^{1-n}$$

where $C_{ij}(x)$ is the consumption by household *x*, living in region *i*, of the goods produced in region *j*. We denote the United States as region 1 and Europe as region 2. The elasticity of substitution between goods from different regions is equal to unity. Each region specific basket $C_{ij}(x)$ is in turn a basket across the different brands produced in that region:

$$C_{i1}(x) = \left[n^{-1/\lambda} \int_0^n \left(C_{i1}(x,v)\right)^{\lambda-1/\lambda} dv \right]^{\lambda/\lambda-1}$$

$$C_{i2}(x) = \left[(1-n)^{-1/\lambda} \int_n^1 \left(C_{i2}(x,v)\right)^{\lambda-1/\lambda} dv \right]^{\lambda/\lambda-1}$$

where $C_{ij}(x,v)$ is the consumption by household *x*, living in region *i*, of the brand produced by firm *v* in region *j*. The elasticity of substitution between brands produced within a region is λ, which we assume to be greater than 1.

Consumption allocation

The optimal allocation of a given overall consumption basket $C_i(x)$ across the various available brands is given by:

(1.2)
$$C_{i1}(x,v) = \frac{1}{n}\left[\frac{P_{i1}^i(v)}{P_{i1}^i}\right]^{-\lambda} C_{i1}(x) = \left[\frac{P_{i1}^i(v)}{P_{i1}^i}\right]^{-\lambda} \frac{P_i^i C_i(x)}{P_{i1}^i}$$

$$C_{i2}(x,v) = \frac{1}{1-n}\left[\frac{P_{i2}^i(v)}{P_{i2}^i}\right]^{-\lambda} C_{i2}(x) = \left[\frac{P_{i2}^i(v)}{P_{i2}^i}\right]^{-\lambda} \frac{P_i^i C_i(x)}{P_{i2}^i}$$

where $P_{ij}^{k}(v)$ is the price, expressed in region *k* currency, charged in region *i* for brand *v* produced in region *j*. P_{ij}^{k} is the price index, expressed in region *k* currency, charged in region *i* for goods produced in region *j*. The price indexes are written as:

$$(1.3)\qquad P_{i1}^{k} = \left[\frac{1}{n}\int_0^n P_{i1}^{k}(v)^{1-\lambda}\,dv\right]^{\frac{1}{1-\lambda}} \qquad P_{i2}^{k} = \left[\frac{1}{1-n}\int_n^1 P_{i2}^{k}(v)^{1-\lambda}\,dv\right]^{\frac{1}{1-\lambda}}$$
$$P_{i}^{k} = (P_{i1}^{k})^{n}(P_{i2}^{k})^{1-n}$$

Optimal Inter-temporal choice

We now turn to the conditions describing the optimal inter-temporal choice of households. We assume that there are complete asset markets, so that residents of each country can purchase state-contingent nominal bonds.[7] As all households are identical within each region, we can drop the *x* index and interpret the variables as per-capita variables. The optimal risk-sharing condition between regions can be derived as:

$$(1.4)\qquad \frac{S_{12t}P_{2t}^{eur}}{P_{1t}^{dol}} = \left(\frac{C_{1t}}{C_{2t}}\right)^{\rho}$$

where S_{12} is the exchange rate between the US dollar and the European currency (number of US dollar per unit of European currency), the latter being a basket of European currencies before the introduction of the euro, and the euro itself thereafter. (1.4) shows that consumption will differ across the two regions only to the extent that there are changes in the real exchange rate. Intuitively, the optimal risk sharing implies that an additional unit of any

[7] As Obstfeld and Rogoff (1998) emphasize, the structure of the utility functions ensures that consumption risk is completely shared when the law of one price holds. But in general, as we see below, the law of one price will not hold. In the absence of complete markets, this would imply a time varying distribution of wealth among countries, and movements in the current account. To incorporate an endogenous wealth distribution with incomplete markets would enormously complicate the analysis of the world equilibrium, probably without giving a lot of further insight the issues addressed here. The redistributive effect of financial markets without risk sharing is likely to a relatively minor factor, from a welfare perspective. It is for this reason that as a first pass at this problem, one is justified in ignoring market incompleteness.

currency has the same marginal utility regardless of the nationality of the household receiving it. We can compute the money demand from household *x* as:

$$\frac{M_{it}(x)}{P_{it}^{i}} = \frac{\chi C_{it}^{\rho}}{(1 - E_t d_{it+1})} \tag{1.5}$$

where $E_t d_{it+1}$ is the inverse of the gross nominal interest rate, and d_{it+1} given by:

$$d_{it+1}(x) = \beta \frac{C_{it+1}^{-\rho} P_{it}^{i}}{C_{it}^{-\rho} P_{it+1}^{i}}$$

The labor supply reflects the trade-off between consumption and leisure and is written as:

$$\frac{W_{it}}{P_{it}^{i} C_{it}{}^{\rho}} = \eta \, , \tag{1.6}$$

where W_{it} is the nominal wage rate.

1.2. Government

The government in each country issues money and makes transfers to residents. Money supply in the United States is set independently of European money supplies. European money supplies are identical if intra-European exchange rates are initially fixed. Seignorage revenue is repaid to households as a lump sum transfer, T_{it}:

$$M_{it} = M_{it-1} + T_{it} \, .$$

1.3. Firms and retailers

1.3.1 Structure of the distribution channel

We assume that goods produced by firms reach the consumers in two steps. In a first step, firms sell their goods to retailers in both countries at wholesale prices. In a second step, retailers in each country sell the goods purchased from domestic and foreign firms to the consumers living in the country, charging retail prices. The distinction between firms and retailers allows us to separate the invoicing of exports from the degree to which consumer prices are affected by exchange rate fluctuations. We consider that there is a representative retailer in each country that behaves competitively. The retailer doesn't incur any cost in addition to the wholesale cost of the goods she buys, and her profits are repaid to the households in her country as a lump sum transfer.

1.3.2. Demand and profits

The demand faced by a retailer for a particular brand *v* is obtained by aggregating the consumption demands (1.2) across all households in the region. As the retailers simply carry the goods from the firms to the consumers, the demand faced by a US and European firm is given by:

$$
\begin{aligned}
Y_1(v) &= Y_{11}(v) + Y_{21}(v) \\
&= n\left[\frac{P_{11}^{dol}(v)}{P_{11}^{dol}}\right]^{-\lambda} \frac{P_1^{dol}C_1}{P_{11}^{dol}} + (1-n)\left[\frac{P_{21}^{eur}(v)}{P_{21}^{eur}}\right]^{-\lambda} \frac{P_2^{eur}C_2}{P_{21}^{eur}} \\
Y_2(v) &= Y_{12}(v) + Y_{22}(v) \\
&= n\left[\frac{P_{12}^{dol}(v)}{P_{12}^{dol}}\right]^{-\lambda} \frac{P_1^{dol}C_1}{P_{12}^{dol}} + (1-n)\left[\frac{P_{22}^{eur}(v)}{P_{22}^{eur}}\right]^{-\lambda} \frac{P_2^{eur}C_2}{P_{22}^{eur}}
\end{aligned}
\tag{1.7}
$$

where $Y_i(v)$ is the total output of the firm producing brand *v* and located in country *i*. It consists of the goods sold in the United States, $Y_{1i}(v)$, and the goods sold in Europe, $Y_{2i}(v)$. An important feature of (1.7) is that the demand is determined by the consumer (retail) prices, denoted by *P*. The wholesale prices charged by the firms, that we denote by *Q*, do have an indirect impact on (1.7) as they affect the retail prices. But pattern of consumption is affected by the exchange rate only if there is some pass-through to retail prices. The presence of pass-through to wholesale prices is not sufficient for this to occur.

We assume that firms use a linear production function through which one hour of labor yields one unit of output. Denoting the profits of a firm producing brand *v* in region *i* by $\Pi_i(v)$, we write:

$$
\begin{aligned}
\Pi_1(v) &= [Q_{11}^{dol}(v) - W_1]Y_{11}(v) + [Q_{21}^{dol}(v) - W_1]Y_{21}(v) \\
\Pi_2(v) &= [Q_{12}^{eur}(v) - W_2]Y_{12}(v) + [Q_{22}^{eur}(v) - W_2]Y_{22}(v)
\end{aligned}
\tag{1.8}
$$

where $Q_{ij}^{k}(v)$ is the wholesale price, expressed in the region *k* currency, charged by firm *v*, located in region *j*, for its goods shipped to the retailer in region *i*. Total profits are the sum of profits from the United States market and profits from the European market. Note that profits are separable across markets, so that if the firm can set different prices in different markets, its choice for the price charge in the United States is unaffected by conditions in Europe.

1.3.3. The currency of price setting

Prices must be set prior to the realization of shocks. We consider that firms always set the wholesales prices in their own currency, for sales to both the domestic and foreign retailers. By contrast, retailers can set the retail prices either in the consumers currency, in which case they bear the exchange rate risk, or in the currency used by the firm, in which case the exchange rate risk is passed through to the consumers.[8] Because of the complexities of dealing with multiple menu costs, we do not attempt to directly model the optimal choice of currency of price setting for retail firms. The intuition developed in the introduction, and the excerpt from the European Central Bank bulletin strongly suggests however, that the euro will lead European marketers to stabilize the prices of imported goods in euro's. Therefore, we investigate the impact of the euro in the post-adjustment phase, in which a substantial degree of pricing of U.S.-manufactured goods in Europe has switched from dollar-denomination to euro-denomination. More specifically, pre-euro, the European retailer sets the retail prices of imported goods in dollar terms, but once the euro is introduced retail prices are set in euro. Therefore, the effect of the euro is to reduce the sensitivity of European consumer prices to fluctuations in the exchange rate. The euro does not affect the pricing of goods sold in the US, where imported retail goods are set in dollar terms, before and after the euro.[9]

Our distinction between firms and retailers allows us to separate the invoicing of exports from the sensitivity of consumer prices to exchange rate fluctuations. Therefore,

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[8] Such a distinction is irrelevant for domestic sales, as the consumers and the firm use the same currency.

consumer prices can be stabilized in local currency, even though exporters invoice their goods in their own domestic currency[10]. Table 1 summarizes the currency in which prices are set, as well as the degree of exchange rate pass-through.

Table 1: Currency of Pricing			
Wholesale prices (*Q*), before and after the euro			
Region of production	Region of consumption	Currency	Pass-through to retailer
United States Europe	Europe United States	US dollar European cur.	Complete Complete
Retail prices (*P*), before the euro			
Region of production	Region of consumption	Currency	Pass-through to consumer
United States Europe	Europe United States	US dollar US dollar	***Complete*** Zero
Retail prices (*P*), after the euro			
Region of production	Region of consumption	Currency	Pass-through to consumer
United States Europe	Europe United States	Euro US dollar	***Zero*** Zero

As retailers behave competitively, their expected discounted profits are zero. The retail prices, conditional on the wholesale prices, are then obtained from the zero profit

[9] For evidence on this, see Engel and Rogers (1996).
[10] Our set-up is therefore consistent with the observation of Obstfeld and Rogoff (1999) that the terms of trade is negatively correlated with the exchange rate. While there is no exchange rate pass-through on consumer prices when retailers set them in the local currency, prices paid by the retailers for the imported goods react to fluctuations of the exchange rate as wholesale prices are set in the producers currency. Therefore the wholesale terms of trade is negatively correlated with the exchange rate.

condition. The objective of the firms is to maximize their expected discounted profits. Retailers and firms are owned by the domestic residents,[11] implying that the expected profits are evaluated using the households' contingent nominal interest rate.

Before the euro

The US retailer chooses prices in US dollars for the brands she sells. The price for domestic brand v is written as $P_{11}^{dol}(v)$, and the price for imported brand v is $P_{12}^{dol}(v)$. As shown in the Appendix, the expected profits on each brand are zero, which leads to the following retail prices:

$$P_{11t}^{dol}(v) = Q_{11t}^{dol}(v) \qquad P_{12t}^{dol}(v) = Q_{12t}^{eur}(v)\frac{E_{t-1}S_{12t}C_{1t}^{1-\rho}}{E_{t-1}C_{1t}^{1-\rho}}$$

The domestic retail price is identical to the wholesale price, and the retail price for an imported brand is the wholesale price corrected by the expected exchange rate, adjusted for the marginal utility of income.

The European retailer chooses a price in US dollars for imported brands, $P_{21t}^{dol}(v)$, that is converted to European currency to obtain the consumer price. She also chooses a price in European currency, $P_{22t}^{eur}(v)$, for European brands. The Appendix shows that the retail prices are simply equal to the wholesale prices:

$$P_{21t}^{dol}(v) = Q_{21t}^{dol}(v) \qquad P_{22t}^{eur}(v) = Q_{22t}^{eur}(v)$$

We now turn to the optimization problem of the producing firms themselves. A US firm chooses two different wholesale prices, both denominated in US dollars. One, $Q_{11}^{dol}(v)$, is charged to the domestic retailer, and the other, $Q_{21}^{dol}(v)$, is charged to the European retailer. The firm chooses the wholesale prices by taking into account their impact on retail prices and

[11] This is done without loss of generality: the assumption of complete markets, reflected in the optimal risk sharing condition (1.4), implies that the firms' optimal choices are unaffected by the country of residence of their owners.

the demand by consumers. As shown in the Appendix, the resulting retail prices are written as (all firms being identical, the v index can be omitted):

(1.9)
$$P_{11t}^{dol} = \frac{\lambda}{\lambda - 1} \frac{E_{t-1}[W_{1t} C_{1t}^{1-\rho}]}{E_{t-1} C_{1t}^{1-\rho}}$$

(1.10)
$$P_{21t}^{dol} = \frac{\lambda}{\lambda - 1} \frac{E_{t-1}[W_{1t} C_{2t}^{1-\rho}]}{E_{t-1} C_{2t}^{1-\rho}}$$

Equations (1.9) and (1.10) indicate that in general the firm will not set prices at their certainty equivalent level ($\lambda(\lambda-1)^{-1} E_{t-1} W_{1t}$). Focusing on (1.9), the covariance between the US wage and $C_{1t}^{1-\rho}$ affects the price. Intuitively, the firm maximizes the expected value of nominal profits, weighted by the consumer's marginal utility of money. In general, the firm chooses a price which represents the best trade-off between the states in which it would want to set a high price ex post against those states in which it would want a low price ex post. The term $C_{1t}^{1-\rho}$ captures the total demand facing the firm, evaluated at the consumer's marginal utility of money. If the covariance between W_{1t} and $C_{1t}^{1-\rho}$ is negative, the marginal cost tends to be low in states when the firm's demand evaluated at the marginal utility of money is high. But these are the states about which the firm's owner cares most. In such states, the firm would set a low price ex-post if it could. Prices being pre-set, the firm sets a price that is below the certainty equivalent value, so as to more closely approximate the ex post profit maximizing pricing policy for the states it cares most about. The same intuition can be used to explain the pricing equation (1.10).

A European firm chooses two different wholesale prices in European currency: $Q_{22t}^{eur}(v)$, charged to the European retailer, and $Q_{12t}^{eur}(v)$, charged to the US retailer. The optimization leads to the following retail prices:

(1.11)
$$P_{12t}^{dol} = \frac{\lambda}{\lambda - 1} \frac{E_{t-1}[S_{12t} W_{2t} C_{1t}^{1-\rho}]}{E_{t-1} C_{1t}^{1-\rho}}$$

(1.12)
$$P_{22t}^{eur} = \frac{\lambda}{\lambda - 1} \frac{E_{t-1}[W_{2t} C_{2t}^{1-\rho}]}{E_{t-1} C_{2t}^{1-\rho}}$$

A similar intuition can be given for the pricing equations (1.11)-(1.12) as was given for equation (1.9). All firms being identical within a region, per capita employment (output) in the United States and Europe can be written from (1.7) as:

$$\begin{aligned} L_{1t} &= Y_{1t} = n\frac{P_{1t}^{dol} C_{1t}}{P_{11t}^{dol}} + (1-n)\frac{S_{12t} P_{2t}^{eur} C_{2t}}{P_{21t}^{dol}} \\ L_{2t} &= Y_{2t} = n\frac{P_{1t}^{dol} C_{1t}}{P_{12t}^{dol}} + (1-n)\frac{P_{2t}^{eur} C_{2t}}{P_{22t}^{eur}} \end{aligned} \tag{1.13}$$

After the euro

The introduction of the euro does not affect the prices chosen by the US retailer. Similarly, the European retail prices for domestic goods are determined using the same rule as before. The only change occurs for the European retail prices of US goods, which are now set in euro instead of US dollars. The zero profit condition leads to the following retail price:

$$P_{21t}^{eur}(v) = Q_{21t}^{dol}(v)\frac{E_{t-1} S_{12t}^{-1} C_{2t}^{1-\rho}}{E_{t-1} C_{2t}^{1-\rho}}$$

Turning to the producing firms, the optimization problem of a European producer is unchanged, and the resulting retail prices for European goods in the US and Europe remain determined by (1.11) and (1.12). Similarly, the retail price of US goods in the US is still given by (1.9). The change of the pricing rule for imports by the European retailer affects the optimal export wholesale price charged by the US firm, $Q_{21t}^{dol}(v)$. The Appendix shows that the optimization by the US firms results in the following expression for the imports retail price in Europe:

$$P_{21t}^{eur} = \frac{\lambda}{\lambda - 1}\frac{E_{t-1}[S_{12t}^{-1} W_{1t} C_{2t}^{1-\rho}]}{E_{t-1} C_{2t}^{1-\rho}} \tag{1.14}$$

European employment is given by (1.13), whereas US employment becomes:

$$L_{1t} = Y_{1t} = n\frac{P_{1t}^{dol} C_{1t}}{P_{11t}^{dol}} + (1-n)\frac{P_{2t}^{eur} C_{2t}}{P_{21t}^{eur}} \tag{1.15}$$

2. The impact of the euro on consumption and employment

2.1. Monetary shocks and consumption determination

We assume that monetary shocks are the only source of volatility in the model, and the money supply follows a random walk (with drift), so that for each region *i* we have

$$E_t\left(M_{it}\big/M_{it+1}\right)=\mu_i \,.$$

In addition, we assume that M_{it} follows an independent, log-normal distribution, for each *i*.[12] Letting lower-case letters be logs, this implies that:

$$m_{it+1}=m_{it}+v_{it+1}$$

where v_{it} has mean $-\ln\mu_i+0.5\sigma_{v_i}^2$ and variance $\sigma_{v_i}^2$. In order to focus on the impact of the euro solely through currency of pricing, we consider that the growth rate and volatility of money shocks is unaffected by the euro, and is identical in the US and Europe: so that $\mu_1=\mu_2=\mu$, and $\sigma_{v_1}^2=\sigma_{v_2}^2=\sigma_v^2$. In the pre-euro situation, the exchange rate pegging between European countries implies that money supplies are equalized across countries. As money supplies are log normal, all variables in our models follow a log normal distribution. Throughout the paper, lower case letters denote logs ($z=\ln Z$) and the variances / covariances across log variables are denoted by: $\sigma_{zy}=E[zy]-E[z]E[y]$.

Under these assumptions, it is easy to verify from the money demand equations, (1.5) that the nominal discount factor $E_t d_{it+1}$, is constant in each region and equal to $\beta\mu$ [13]. This means that consumption in each country is a function only of the real money supply:

$$C_{it}^{\rho}=\frac{1-\mu\beta}{\chi}\frac{M_{it}}{P_{it}^{i}} \tag{2.1}$$

[12] None of the main results depend on the fact that monetary shocks are independent across countries under flexible exchange rates. This assumption merely simplifies the exposition.

Using (1.4) it is then immediate to show that

(2.2)
$$S_{12t} = \frac{M_{1t}}{M_{2t}}$$

Before the introduction of the euro, US consumer prices are entirely predetermined. By contrast, European consumer prices are affected by monetary shocks through the exchange rate pass-through on imports from the US. Putting (2.1) and (2.2) together, we obtain:

(2.3)
$$C_{1t} = \left(\frac{1-\mu\beta}{\chi} \frac{M_{1t}}{(P^1_{11t})^n (P^1_{12t})^{1-n}} \right)^{\frac{1}{\rho}} \propto (M_{1t})^{\frac{1}{\rho}}$$

(2.4)
$$C_{2t} = \left(\frac{1-\mu\beta}{\chi} \frac{M^n_{1t} M^{1-n}_{2t}}{(P^1_{21t})^n (P^2_{22t})^{1-n}} \right)^{\frac{1}{\rho}} \propto (M^n_{1t} M^{1-n}_{2t})^{\frac{1}{\rho}}$$

where $\propto$ denotes a relation of proportionality. US consumption is entirely insulated from European money shocks, because the retail prices for imports from Europe are set in dollars. But European consumption responds to US money shocks through exchange rate adjustment.

After the introduction of the euro, US consumption is still determined by (2.3), whereas European consumption is insulated from US money shocks:

(2.5)
$$C_{2t} = \left(\frac{1-\mu\beta}{\chi} \frac{M_{2t}}{P^n_{21t} P^{1-n}_{22t}} \right)^{\frac{1}{\rho}} \propto (M_{2t})^{\frac{1}{\rho}}$$

2.2. Consumption volatility

The major results of the analysis are presented in Table 2, and detailed in the Appendix. We start with the variance of log consumption in the US and Europe. Before the introduction of the euro, European consumption must be less volatile than US consumption. This reflects the cushioning role of the exchange rate pass-through on real variables. A monetary expansion in Europe increases the nominal balances of European consumers. But it

[13] Although money supply shocks do affect consumption, they do so in a way that leaves the term $E_t[C^{\rho}_{it} P^i_{it}][C^{\rho}_{it+1} P^i_{it+1}]^{-1}$ unaffected. Thus, the nominal interest rate is not affected by random walk money shocks, given the specification of preferences used.

also leads to a depreciation of the European currency, which partially reduces the purchasing power of European consumers through imported inflation. This effect disappears with the introduction of the euro, as retail prices for imports from the US are now set in euro so there is no exchange rate pass-through to consumers. Table 2 shows that the introduction of the euro increases the volatility of European consumption, while leaving US consumption volatility unchanged.

On this measure alone, it would seem that the introduction of the euro would make Europeans worse off, while having no implications for US welfare. But welfare cannot be measured only by consumption variance. This is because the stochastic properties of exchange rate regimes also has implications for the expected values of consumption and output, as discussed in Devereux and Engel (1998). In order to do a full welfare analysis, we must therefore compute the expected values of consumption and employment.

2.3. Expected consumption

Before the euro

We can use the pricing equations (1.9) and (1.10), the risk-sharing relationship (1.4), the labor supply equation (1.6) and the definitions of the price index (1.3) to write the two equations which implicitly determine $E_{t-1}C_{1t}$ and $E_{t-1}C_{2t}$ (see the Appendix for the detailed derivation):

(2.6) $$1 = \frac{\lambda\eta}{\lambda - 1}\frac{E_{t-1}C_{1t}}{E_{t-1}C_{1t}^{1-\rho}}$$

and

(2.7) $$1 = \frac{\lambda\eta}{\lambda - 1}\left(\frac{E_{t-1}[S_{12t}^{1-n}C_{2t}]}{E_{t-1}C_{2t}^{1-\rho}}\right)^{n}\left(\frac{E_{t-1}[S_{12t}^{-n}C_{2t}]}{E_{t-1}C_{2t}^{1-\rho}}\right)^{1-n}$$

These equations can be solved by utilizing the fact that since the money supply follows a log normal distribution, then so will consumption.

Table 2 shows that in both regions an increase in consumption volatility increases expected consumption if $\rho > 1$. To highlight the intuition behind this result, we point out that from labor supply (1.6) the nominal wage in the United States is proportional to C_{1t}^{ρ}. Then, from (1.9), we see that if $\rho > 1$, the marginal cost is negatively correlated with the firms marginal utility-discounted demand $C_{1t}^{1-\rho}$, and firms set their prices below the certainty equivalent values. Since consumption is proportional to real balances, low prices result in higher consumption.

Expected consumption in Europe however is *negatively* related to exchange rate volatility. For both US and European producers, exchange rate volatility increases the variance of marginal cost, given C_{2t}. This induces them to raise their prices charged for sales in Europe relative to those in the US ($P_{11t}^{dol} < P_{21t}^{dol}$), thereby reducing expected European consumption. The presence of this additional channel in Europe therefore implies that expected consumption is lower in Europe than in the United States before the euro, as shown in Table 2.

After the euro

After the introduction of the euro, the European retail price for imports from the US is given by (1.14) instead of (1.10). The expected US consumption is still determined by (2.6). As shown in the Appendix, European expected consumption is determined by:

(2.8)
$$1 = \frac{\lambda\eta}{\lambda - 1} \frac{E_{t-1}C_{2t}}{E_{t-1}C_{2t}^{1-\rho}}$$

which replaces (2.7). Table 2 shows that expected consumption is not affected in the United States. By contrast, the effect of exchange rate volatility on European expected consumption disappears, as US exporters now set their prices in euro. The removal of the direct impact of exchange rate volatility reinforces the effect of the higher European consumption volatility, and the introduction of the euro boosts expected consumption in Europe.

2.4. Expected employment

Expected employment can be computed by combining (1.13) and (1.15) with our results for expected consumption. The Appendix establishes that expected employment is the same for the United States and Europe, and is given by the following equation, both before and after the introduction of the euro:

$$E_{t-1}L_{1t} = E_{t-1}L_{2t} = \frac{\lambda - 1}{\lambda\eta}[nE_{t-1}C_{1t}^{1-\rho} + (1-n)E_{t-1}C_{2t}^{1-\rho}] \tag{2.9}$$

Table 2 shows that the introduction of the euro *reduces* expected employment, in both countries. Expected employment in each region is just the sum of US and European household's consumption of that region's good. Expected employment falls because expected European consumption of both good 1 and 2 (which is proportional to $E_{t-1}C_{2t}^{1-\rho}$) falls.

At first glance this seems paradoxical; expected composite consumption in Europe rises, but expected consumption of each element in the composite falls. But it important to remember that composite consumption is not a linear function of the consumption of each region's good. We can derive the following relation between the aggregate consumption index and the consumptions of each type of good:

$$E_{t-1}C_{2t} = \frac{1}{n^n(1-n)^{1-n}}\left(E_{t-1}C_{21t}\right)^n\left(E_{t-1}C_{22t}\right)^{1-n}\exp\left[-\frac{n(1-n)}{2}Var(c_{21t}/c_{22t})\right]$$

Before the introduction of the euro, exchange rate fluctuations affect the relative price of domestic and imported consumption, since $Var(c_{21t}/c_{22t}) = \sigma_s^2$. This depresses expected composite consumption. The introduction of the euro eliminates this effect. While the expected consumption of each good falls, this is more than offset by the removal of the effects of exchange rate volatility (which increases the volatility of consumption of domestic and imported goods), so that expected composite consumption rises.

Figure 1 illustrates the point, with domestic and imported consumption on the horizontal and vertical axis, respectively. Indifference curves connect all possible pairs of domestic and imported consumption giving the same overall consumption basket. Figure 1 presents two such curves, $C = C^A$ and $C = C^B$, with C^B giving higher utility than C^A. The figure contrasts two cases. In the first case, exchange rate volatility is large, and the economy can be either at point A or at point B, the aggregate consumption basket being equal to C^A at either point. The expected consumption of domestic and imported goods is given by $C^{dom}(C^A)$ and $C^{imp}(C^A)$ respectively. The second case is characterized by a lower exchange rate volatility, and the economy can be at point C or at point D. At either point, the aggregate consumption basket C^B is larger than in the previous case. But the expected consumption of each good, $C^{dom}(C^B)$ and $C^{imp}(C^B)$, is smaller.

3. The welfare effects of the euro

We now examine the impact on welfare. Expected utility depends upon consumption, real money balances, and labor supply. But following recent literature (e.g. Corsetti and Pesenti, 1998), we focus on the expected utility of consumption and labor supply alone, abstracting from the role of real balances. The Appendix shows that the expected utility for the US and Europe is given by:

(3.1) $$E_{t-1}U_{1t} = \Psi_1 \frac{1}{1-\rho} E_{t-1}C_{1t}^{1-\rho} - \frac{\lambda - 1}{\lambda}(1-n)E_{t-1}C_{2t}^{1-\rho}$$

(3.2) $$E_{t-1}U_{2t} = \Psi_2 \frac{1}{1-\rho} E_{t-1}C_{2t}^{1-\rho} - \frac{\lambda - 1}{\lambda} nE_{t-1}C_{1t}^{1-\rho}$$

where $\Psi_1 = \dfrac{\lambda + n(\lambda - 1)(\rho - 1)}{\lambda} > 0$,and $\Psi_2 = \dfrac{\lambda + (1-n)(\lambda - 1)(\rho - 1)}{\lambda} > 0$.

How does the introduction of the euro affect expected utility? To see the effects, we use the following decomposition, due to the properties of the log-normal distribution

(3.3) $$E_{t-1}C_{it}^{1-\rho} = (E_{t-1}C_{it})^{1-\rho} \exp\left[\frac{\rho(\rho-1)}{2}\sigma_{c_i}^2\right]$$

For the US, the introduction of the euro affects neither expected consumption nor consumption volatility, and $E_{t-1}C_{1t}^{1-\rho}$ is unchanged. The effect of the euro on $E_{t-1}C_{2t}^{1-\rho}$ is more complex. The increase in $E_{t-1}C_{2t}$ tends to lower $E_{t-1}C_{2t}^{1-\rho}$, as $\rho > 1$, whereas the higher consumption volatility goes the other way. Table 2 shows that the former effect is stronger and $E_{t-1}C_{2t}^{1-\rho}$ is reduced by the introduction of the euro.

It follows from (3.2), that the introduction of the euro increases European utility. Since $E_{t-1}C_{2t}^{1-\rho}$ falls, the expected utility of consumption rises, and by the same token, the fall in expected employment also raises expected utility. Thus Europeans must gain. How about expected utility in the US? While expected consumption and consumption variance in the US is unchanged, the fall in expected employment must also raise expected utility in the US. Thus, the introduction of the euro raises welfare in both Europe and the US!

Our model therefore shows that the introduction of the euro is not a zero-sum game in which any European gain would be mirrored by a loss for the United States. Instead, both regions benefit. Therefore, paradoxically, the role of the US dollar as the world currency is actually *detrimental* for US welfare, when the alternative is a world where consumer prices are stabilized in local currencies.

4. The law of one price for US exports

In the pre-euro environment, US firms were free to choose different wholesale prices for their sales to the domestic and foreign retailers. This assumption might be questioned. For example anti-dumping laws could make it difficult for US firms to set different prices in a given currency. We could alternatively assume that US firms must set the same US dollar wholesale price for both retailers ($Q_{11t}^{dol}(v) = Q_{21t}^{dol}(v)$). The Appendix presents the analysis under this alternative setup, and the results are summarized in Table 3. The results regarding consumption volatility are unchanged. Compared to the baseline model, the pre-euro expected consumption is lower in the United States and higher in Europe. The introduction of the euro will then increase expected consumption in both regions. It also reduces effort in both regions. Interestingly, the welfare impact is the same in Europe and the US, as $E_{t-1}C_{1t}^{1-\rho} = E_{t-1}C_{2t}^{1-\rho}$ both before and after the euro, and it is lowered by the introduction of the euro. Then, from (3.1) and (3.2), we can again show that both regions benefit, hence the main message of the paper remains unaltered.

5. Exchange rate flexibility in pre-euro Europe

We have so far assumed that European countries pegged their exchange rates vis a vis one another in the lead-up to the launching of the euro. This is a fairly accurate description of the reality, but it interesting to ask how the situation would differ if intra-European exchange rates were flexible before the euro. As in the previous section, we would envisage that there are conflicting effects. On the one hand, exchange rate volatility stabilizes domestic consumption when imported goods are priced in the foreign currency. But on the other hand, exchange rate volatility depresses expected consumption.

To explore these separate effects, we can analyze a version of our model where the world consists of three countries: the United States, of size n, Germany, of size n_2 and France, of size $n_3=1-n-n_2$. The analysis is outlined in the Appendix, and the results are presented in Table 4. The introduction of the euro now has two effects. In addition of the effect through pricing of goods that we have analyzed so far, the euro brings a fixed exchange rate regime at the intra-European level.

The intra-European exchange rate regime has no effect on the volatility and expected level of US consumption. Table 4 shows that expected employment is higher in the pre-euro era, relative to the baseline model of Table 2. The positive welfare impact of the euro on US residents is then larger when the intra-European exchange rate is initially flexible.

For Europe, the situation is more complex. Assuming that the intra-European exchange rate fluctuations are passed-through to consumer prices before the euro,[14] Table 4 shows that the flexible intra-European exchange rate reduces expected consumption in Europe in the pre-euro era. As this is only partially offset by the lower volatility of consumption, a change towards a fixed exchange rate is beneficial for European residents. Thus, $E_{t-1}C_{1t}^{1-\rho}$ is unaffected by the introduction of the euro, whereas $E_{t-1}C_{2t}^{1-\rho}$ is reduced, the later effect being stronger than in the baseline model. From (3.1) and (3.2) we see that the benefits of the introduction of the euro are *actually stronger* when the intra-European exchange rate is initially floating. Intuitively, the benefits from the introduction of the euro *per se* are reinforced by the benefits from pegging the intra-European exchange rate.

6. Alternative assumptions regarding the currency of pricing

So far we have assumed that the euro would alter the pricing behavior of the European retailer, inducing her to set imported retail prices in euro. Perhaps however the influence of the euro will lead the US retailer, instead of her European counterpart, to adjust her pricing practices. What would be the situation if the US retailer sets the retail prices for imports from Europe in euro, thereby passing the exchange rate fluctuations through to US consumers?

In this alternative scenario, the results are in fact very different. The derivations proceed as before, save for the fact that US consumption is now exposed to exchange rate risk. The analysis is detailed in the Appendix and the results are presented in Table 5. As consumer prices are effected by the exchange rate in both countries, the introduction of the euro reduces consumption volatility in the United States and leaves it unchanged in Europe. The expected consumption level is determined by (2.7) for Europe and by a similar relation

[14] As the situation is symmetric across European countries, firms end up choosing the same price, in their currency, for exports and domestic sales.

for the United States. The Appendix shows that the PPP holds, and consumption is always equalized across the two regions. Now, as shown in Table 5, the introduction of the euro does not affect expected consumption in Europe, but reduces it in the United States. Expected employment is higher as $E_{t-1}C_{2t}^{1-\rho}$ is unchanged and $E_{t-1}C_{1t}^{1-\rho}$ increases. (3.1) and (3.2) then lead us to conclude that the introduction of the euro has a detrimental welfare effect, *both for Europe and the United States*. It is especially detrimental to US residents, as the reduction of expected consumption is added to the cost of higher effort.

Therefore, if the post-euro world is characterized by complete exchange rate pass-through to consumer prices, the introduction of the euro has an adverse effect worldwide. In such a case, the United States indeed does benefit from the dominant role of the dollar in the pre-euro era.

7. A numerical illustration

We now illustrate our findings by computing the magnitude of the effects on consumption, output and welfare. In order to focus on the role of price setting, we reasonably assume that the United States and Europe have the same size (*n=0.5*). We set the standard deviation of money shocks to 3.5% ($\sigma_v = 0.035$, $\sigma_v^2 = 0.001225$), and compute the effects for various values of $\rho > 1$, which is the empirically relevant range. For brevity, we focus on the baseline case where the euro induces US firms to set their prices for European consumption in euro instead of US dollars.

Figure 2 presents the percentage change in expected consumption brought by the introduction of the euro. Expected consumption isn't affected in the United States and is increased in Europe. If $\rho = 2$, the euro boosts expected consumption by 0.02% in Europe. Figure 3 illustrates the reduction in expected employment, which is identical in both regions. If $\rho = 2$, the introduction of the euro reduces expected employment by 0.004%.

Figure 4 presents the welfare gain. To facilitate the interpretation of the results, we express the gain as a percentage of the gain that would result from removing monetary volatility entirely ($\sigma_v^2 = 0$). We can see that the gain is quite sizable: if $\rho = 2$, the introduction of the euro brings a gain equal to 27.9 % of the gain from completely removing monetary variability for Europe. The corresponding figure for the United States is 10.2 %.

Another perspective on the welfare gain from the euro is to compute the reduction in money volatility that would bring the same welfare gain, without the euro, as the gain brought by the euro, for a given volatility. We can show that if $\rho = 2$, the benefit from the introduction of the euro for Europe is equivalent to a 15 % reduction in the standard deviation of monetary shock worldwide. The corresponding figure for the United States is a 5 % reduction of the standard deviation.

8. Conclusions

This paper has shown that the introduction of the euro could have important positive and normative effects for both Europe and the rest of the world. In the case where the euro causes a change in the retail pricing of U.S. imports in Europe, our central conjecture, the advent of the euro causes a rise in the expected value of consumption in both the US and Europe, and a rise in welfare. This result holds whether the pre-euro situation was one of fixed exchange rates or floating exchange rates, within the European economies.

There are substantial additional implications of the euro that could be explored within the same type of model. Clearly, a substantial change in the currency of pricing may have important business cycle consequences. Betts and Devereux (1999) show how changes in price setting can alter international macroeconomic transmission in substantial ways. The main point that we wish to make in this paper is that there may be important and previously unforseen consequences of the European single currency, when we take account of the potential endogeneity of the currency of price setting in a world of sticky prices.

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Table 2 : Main results

	Before the euro	After the euro
Consumption volatility		
United States	$\sigma_{c_1}^2 = \frac{1}{\rho^2}\sigma_v^2$	$\sigma_{c_1}^2 = \frac{1}{\rho^2}\sigma_v^2$
Europe	$\sigma_{c_2}^2 = \frac{n^2 + (1-n)^2}{\rho^2}\sigma_v^2$	$\sigma_{c_2}^2 = \frac{1}{\rho^2}\sigma_v^2$
Expected consumption		
United States	$E_{t-1}C_{1t} = \Phi \exp\left[\frac{\rho-1}{2}\sigma_{c_1}^2\right] = \Phi \exp\left[\frac{\rho-1}{2\rho^2}\sigma_v^2\right]$	$E_{t-1}C_{1t} = \Phi \exp\left[\frac{\rho-1}{2}\sigma_{c_1}^2\right] = \Phi \exp\left[\frac{\rho-1}{2\rho^2}\sigma_v^2\right]$
Europe	$E_{t-1}C_{2t} = \Phi \exp\left[\frac{\rho-1}{2}\sigma_{c_2}^2 - \frac{n(1-n)}{2\rho}\sigma_{s_{12}}^2\right]$ $= \Phi \exp\left[\left(\frac{\rho-1}{\rho^2}\left(\frac{1}{2} - n(1-n)\right) - \frac{n(1-n)}{\rho}\right)\sigma_v^2\right]$	$E_{t-1}C_{2t} = \Phi \exp\left[\frac{\rho-1}{2}\sigma_{c_1}^2\right] = \Phi \exp\left[\frac{\rho-1}{2\rho^2}\sigma_v^2\right]$
$\Phi = \left(\frac{\lambda\eta}{\lambda-1}\right)^{-1/\rho}$		

Table 2 (contd.)		
	Before the euro	After the euro
Employment United States And Europe	$E_{t-1}L_t = \Phi \exp\left[\frac{\rho-1}{2\rho^2}\sigma_v^2\right] \times \left\{n+(1-n)\exp\left[\frac{n(1-n)(1-\rho)^2}{\rho^2}\sigma_v^2\right]\right\}$	$E_{t-1}L_t = \Phi \exp\left[\frac{\rho-1}{2\rho^2}\sigma_v^2\right]$
Expected 'power' consumption United States	$E_{t-1}C_{1t}^{1-\rho} = \Phi^{1-\rho} \exp\left[\frac{\rho-1}{2\rho^2}\sigma_v^2\right]$	$E_{t-1}C_{1t}^{1-\rho} = \Phi^{1-\rho} \exp\left[\frac{\rho-1}{2\rho^2}\sigma_v^2\right]$
Europe	$E_{t-1}C_{2t}^{1-\rho} = \Phi^{1-\rho} \exp\left[\left(\frac{\rho-1}{2\rho^2}+\frac{n(1-n)(1-\rho)^2}{\rho^2}\right)\sigma_v^2\right]$	$E_{t-1}C_{2t}^{1-\rho} = \Phi^{1-\rho} \exp\left[\frac{\rho-1}{2\rho^2}\sigma_v^2\right]$

Table 3 : Pre-euro situation under the constraint $Q_{11t}^{dol}(v) = Q_{21t}^{dol}(v)$	
Expected Consumption	
United States	$E_{t-1}C_{1t} = \Phi \exp\left[\frac{\rho-1}{\rho^2}\left(\frac{1}{2} - n(1-n)^2\right)\sigma_v^2\right]$
Europe	$E_{t-1}C_{2t} = \Phi \exp\left[\left(\frac{\rho-1}{\rho^2}\left(\frac{1}{2} - n(1-n)^2\right) - \frac{n(1-n)}{\rho}\right)\sigma_v^2\right]$
Employment	
United States and Europe	$E_{t-1}L_t = \Phi \exp\left[\left(\frac{\rho-1}{2\rho^2} + \frac{(\rho-1)^2}{\rho^2}n(1-n)^2\right)\sigma_v^2\right]$
Expected power consumption	
United States	$E_{t-1}C_{1t}^{1-\rho} = \Phi^{1-\rho} \exp\left[\left(\frac{\rho-1}{2\rho^2} + \frac{(\rho-1)^2}{\rho^2}n(1-n)^2\right)\sigma_v^2\right]$
Europe	$E_{t-1}C_{2t}^{1-\rho} = \Phi^{1-\rho} \exp\left[\left(\frac{\rho-1}{2\rho^2} + \frac{(\rho-1)^2}{\rho^2}n(1-n)^2\right)\sigma_v^2\right]$

Table 4 : Pre-euro situation under a flexible intra-European exchange rate	
Expected Consumption	
United States	$E_{t-1}C_{1t} = \Phi \exp\left[\frac{\rho-1}{2\rho^2}\sigma_v^2\right]$
Europe	$E_{t-1}C_{2t} = \Phi \exp\left[\left(\frac{\rho-1}{\rho^2}\left(\frac{1}{2}-n(1-n)\right)-\frac{n(1-n)}{\rho}-\frac{(\rho-1)n_2n_3}{\rho^2}-\frac{n_2n_3}{\rho}\right)\sigma_v^2\right]$
Employment	
United States and Europe	$E_{t-1}L_t = \Phi \exp\left[\frac{\rho-1}{2\rho^2}\sigma_v^2\right]\left\{n+(1-n)\exp\left[\left(\frac{n(1-n)(1-\rho)^2}{\rho^2}+\frac{(1-\rho)^2n_2n_3}{\rho^2}\right)\sigma_v^2\right]\right\}$
Expected power consumption	
United States	$E_{t-1}C_{1t}^{1-\rho} = \Phi^{1-\rho}\exp\left[\frac{\rho-1}{2\rho^2}\sigma_v^2\right]$
Europe	$E_{t-1}C_{2t}^{1-\rho} = \Phi^{1-\rho}\exp\left[\left(\frac{\rho-1}{2\rho^2}+\frac{n(1-n)(1-\rho)^2}{\rho^2}+\frac{(1-\rho)^2n_2n_3}{\rho^2}\right)\sigma_v^2\right]$

Table 5 : Post-euro situation under pricing in the producer currency	
Expected Consumption United States and Europe	$E_{t-1}C_{1t} = \Phi \exp\left[\left(\frac{\rho-1}{\rho^2}\left(\frac{1}{2}-n(1-n)\right)-\frac{n(1-n)}{\rho}\right)\sigma_v^2\right]$
Employment United States and Europe	$E_{t-1}L_t = \Phi \exp\left[\left(\frac{\rho-1}{2\rho^2}+\frac{(\rho-1)^2}{\rho^2}n(1-n)\right)\sigma_v^2\right]$
Expected power consumption United States and Europe	$E_{t-1}C_{1t}^{1-\rho} = \Phi^{1-\rho} \exp\left[\left(\frac{\rho-1}{2\rho^2}+\frac{(\rho-1)^2}{\rho^2}n(1-n)\right)\sigma_v^2\right]$

Figure 1
Consumption Aggregate

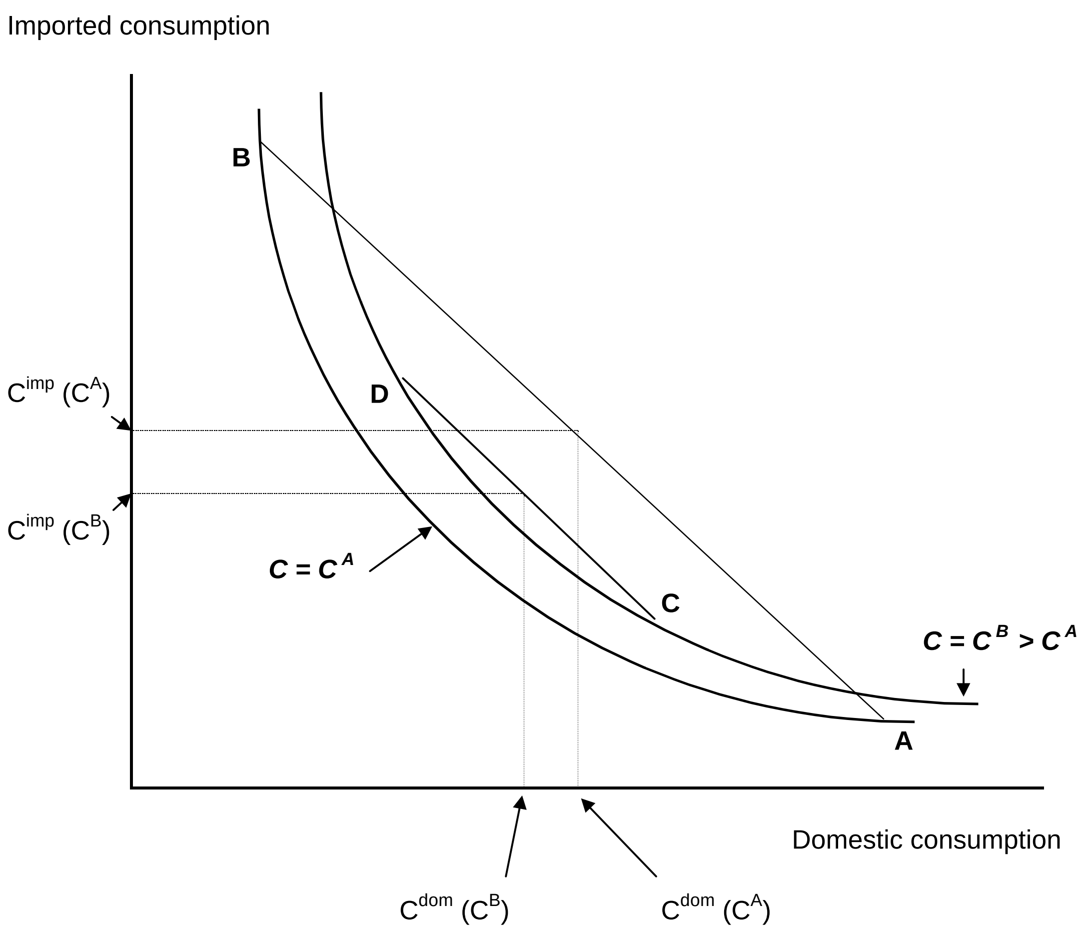
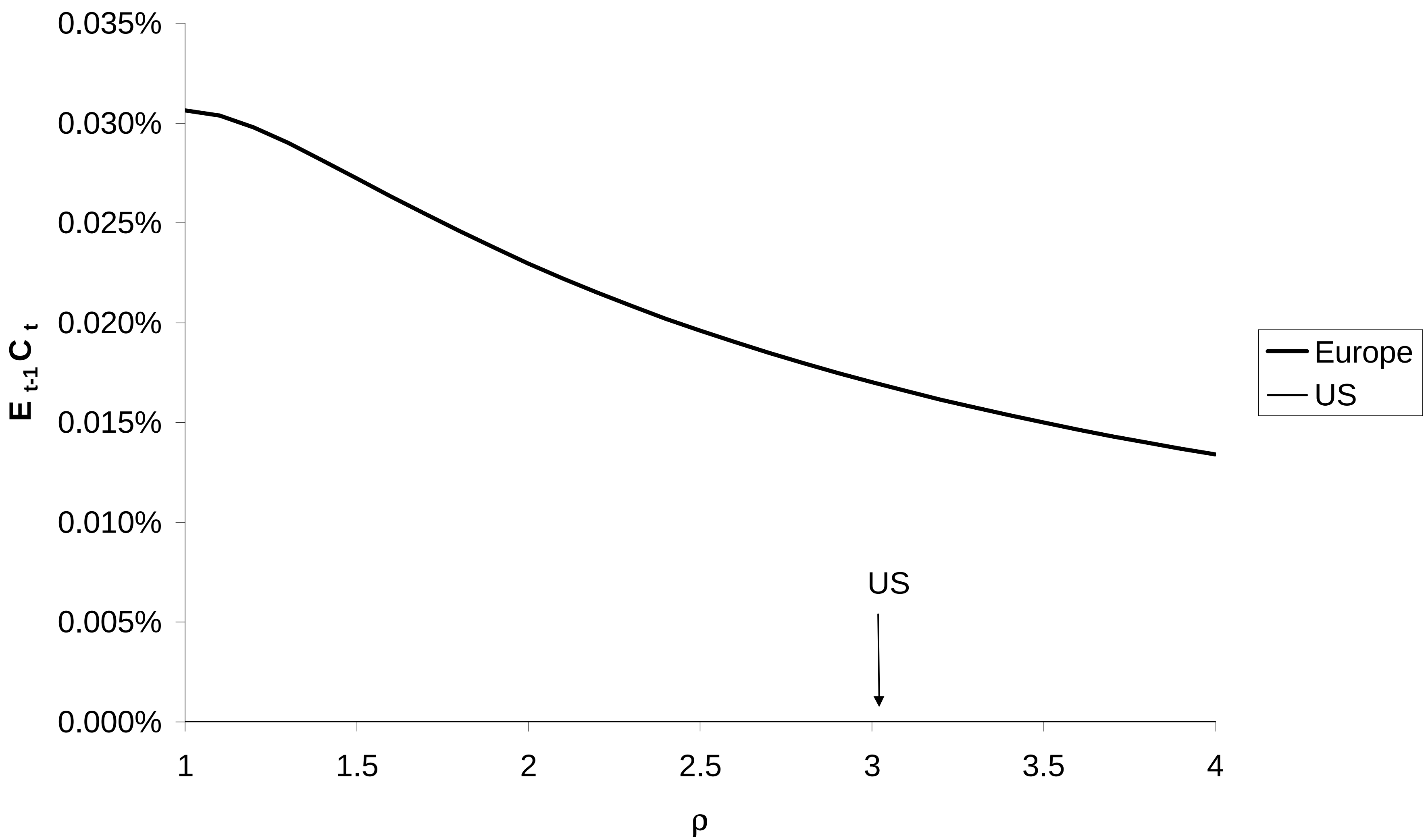


Figure 2: Percentage change in expected consumption



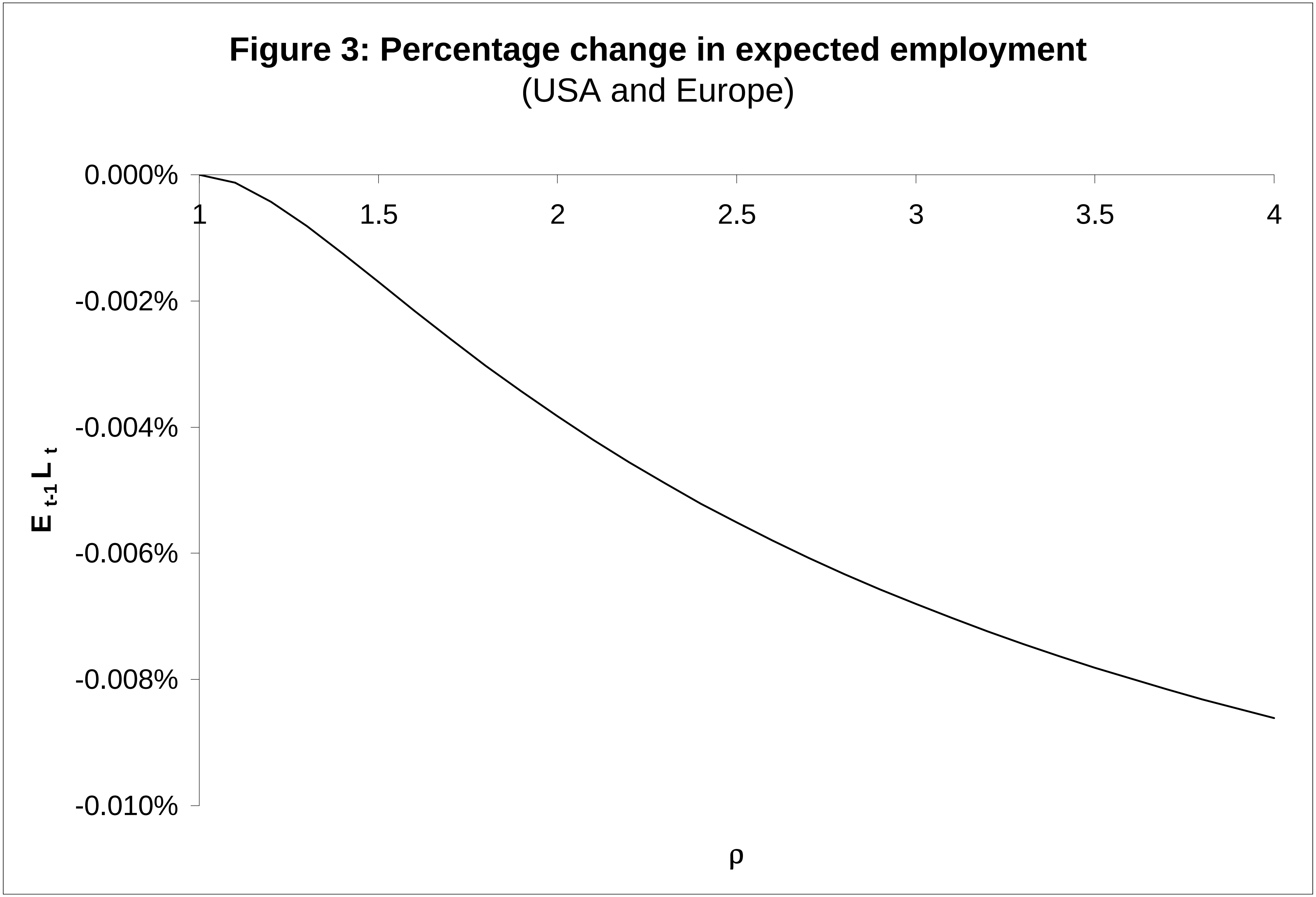
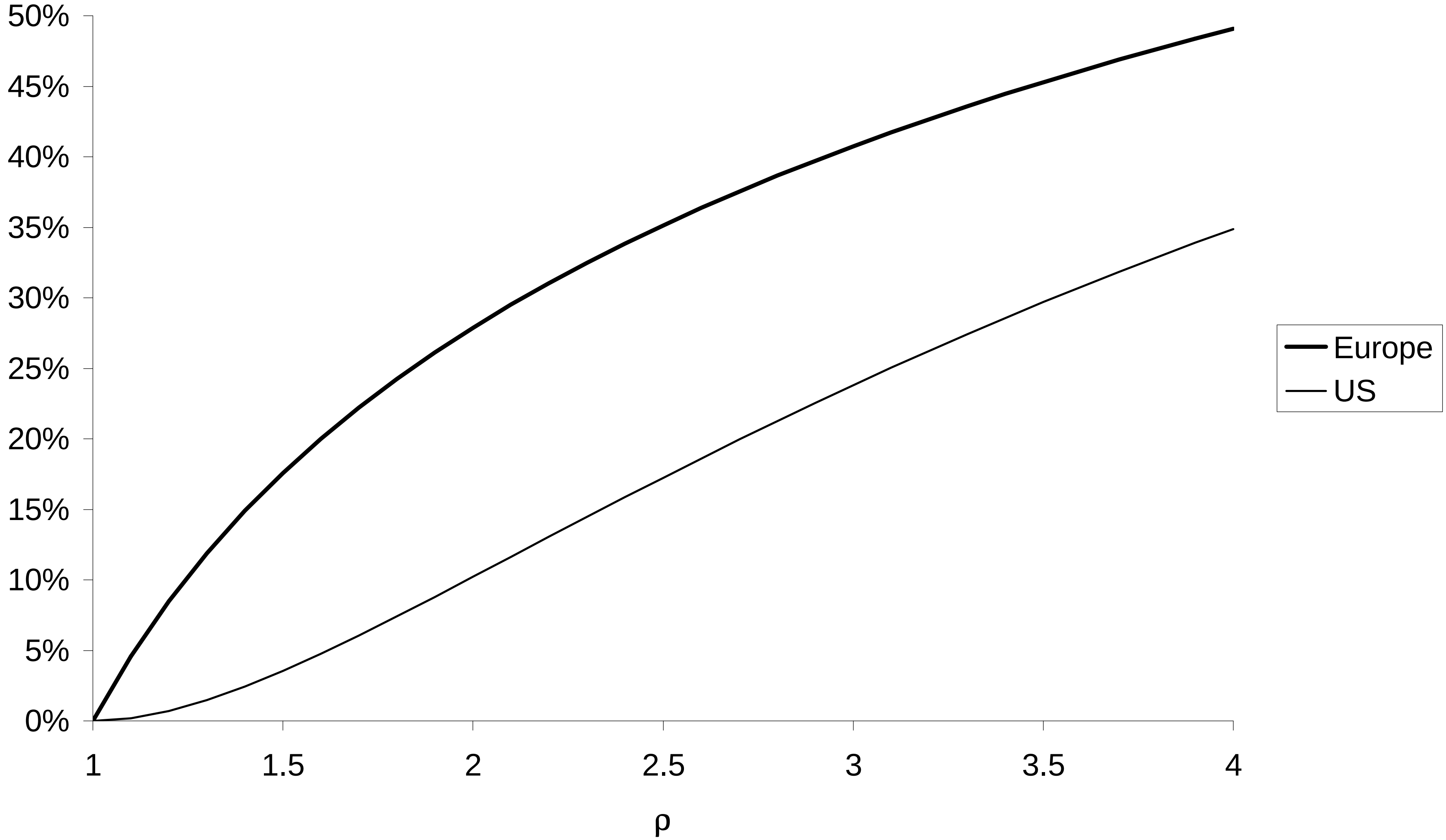


Figure 3: Percentage change in expected employment
(USA and Europe)
0.000%
-0.002%
-0.004%
-0.006%
-0.008%
-0.010%
1
1.5
2
2.5
3
3.5
4
E t-1 L t
ρ

Figure 4: Welfare gain (% of gain from removing volatility)



Appendix to M. B. Devereux, C. Engel, and C. Tille:

"Exchange Rate Pass-through and the Effects of the Euro"

A. Retailers' price setting

Before the euro

The representative US retailer chooses prices in US dollar for domestic brands, $P_{11t}^{dol}(v)$, and imported brands, $P_{12t}^{dol}(v)$. The goods are purchased from the manufacturers at a unit cost of $Q_{11t}^{dol}(v)$ US dollar for a domestic brand, and $Q_{12t}^{eur}(v)$ units of European currency for a European brand. The retailer incurs no additional extra cost. Using (1.2) the expected profit, using the representative consumer discount factor, are written as:

$$nE_{t-1}d_{1t}\left\{\begin{array}{l}\int_0^n \left[P_{11t}^{dol}(v)-Q_{11t}^{dol}(v)\right]\left[\frac{P_{11t}^{dol}(v)}{P_{11t}^{dol}}\right]^{-\lambda}\frac{P_{1t}^{dol}C_{1t}}{P_{11t}^{dol}}dv \\ +\int_n^1 \left[P_{12t}^{dol}(v)-S_{12t}Q_{12t}^{eur}(v)\right]\left[\frac{P_{12t}^{dol}(v)}{P_{12t}^{dol}}\right]^{-\lambda}\frac{P_{1t}^{dol}C_{1t}}{P_{12t}^{dol}}dv\end{array}\right\}$$

where $d_{1t}=[\beta C_{1t}^{-\rho}P_{1t-1}^{dol}][C_{1t-1}^{-\rho}P_{1t}^{dol}]^{-1}$. The retail market being competitive, the above expected profits are equal to zero. This implies that the expected profits on each brand are zero. If not, another retailer would enter the market and focus solely on the brand where she could make a positive profit. The zero expected profit condition on each brand implies that:

$$\text{(A.1)} \qquad P_{11t}^{dol}(v)=Q_{11t}^{dol}(v) \qquad P_{12t}^{dol}(v)=Q_{12t}^{eur}(v)\frac{E_{t-1}S_{12t}C_{1t}^{1-\rho}}{E_{t-1}C_{1t}^{1-\rho}}$$

The retail price of a domestic brand is equal to its wholesale price, and the retail price of an imported brand is equal to the wholesale price in foreign currency, times the expected exchange rate adjusted for the marginal utility of income.

The representative European retailer sells domestic brands, for which she chooses a retail price in European currency, $P_{22t}^{eur}(v)$, and pays a wholesale price in European currency, $Q_{22t}^{eur}(v)$. She also sells imported brands, for which she pays a wholesale price in US dollar, $Q_{21t}^{dol}(v)$. As explained in the text, she sets the retail price in US dollar, $P_{21t}^{dol}(v)$, and passes the exchange rate fluctuations to the consumer. The discounted expected profits are:

$$(1-n)E_{t-1}d_{2t}\left\{\begin{array}{l}\int_0^n S_{12t}^{-1}\left[P_{21t}^{dol}(v)-Q_{21t}^{dol}(v)\right]\left[\frac{S_{12t}^{-1}P_{21t}^{dol}(v)}{S_{12t}^{-1}P_{21t}^{dol}}\right]^{-\lambda}\frac{P_{2t}^{eur}C_{2t}}{S_{12t}^{-1}P_{21t}^{dol}}dv\\ +\int_n^1\left[P_{22t}^{eur}(v)-Q_{22t}^{eur}(v)\right]\left[\frac{P_{22t}^{eur}(v)}{P_{22t}^{eur}}\right]^{-\lambda}\frac{P_{2t}^{eur}C_{2t}}{P_{22t}^{eur}}dv\end{array}\right\}$$

where $d_{2t}=[\beta C_{2t}^{-\rho}P_{2t-1}^{eur}][C_{2t-1}^{-\rho}P_{2t}^{eur}]^{-1}$. The expected zero profit condition for each brand implies that the retailer simply passes the wholesale price through to consumers:

$$P_{21t}^{dol}(v)=Q_{21t}^{dol}(v) \qquad P_{22t}^{eur}(v)=Q_{22t}^{eur}(v) \tag{A.2}$$

After the euro

The situation of the representative US retailer isn't changed, and her prices are given by (A.1). The European retailer now sets the retail price of imported brands in euro, $P_{21t}^{eur}(v)$. The expected profits are then:

$$(1-n)E_{t-1}d_{2t}\left\{\begin{array}{l}\int_0^n\left[P_{21t}^{eur}(v)-S_{12t}^{-1}Q_{21t}^{dol}(v)\right]\left[\frac{P_{21t}^{eur}(v)}{P_{21t}^{eur}}\right]^{-\lambda}\frac{P_{2t}^{eur}C_{2t}}{P_{21t}^{eur}}dv\\ +\int_n^1\left[P_{22t}^{eur}(v)-Q_{22t}^{eur}(v)\right]\left[\frac{P_{22t}^{eur}(v)}{P_{22t}^{eur}}\right]^{-\lambda}\frac{P_{2t}^{eur}C_{2t}}{P_{22t}^{eur}}dv\end{array}\right\}$$

The retail prices are then computed as:

$$P_{21t}^{eur}(v)=Q_{21t}^{dol}(v)\frac{E_{t-1}S_{12t}^{-1}C_{2t}^{1-\rho}}{E_{t-1}C_{2t}^{1-\rho}} \qquad P_{22t}^{eur}(v)=Q_{22t}^{eur}(v) \tag{A.3}$$

B. Firms' price setting

Before the euro

A US firm chooses two wholesale prices in US dollar: $Q_{11t}^{dol}(v)$ for sales to domestic retailers and $Q_{21t}^{dol}(v)$ for exports. Using (1.7), (1.8), (A.1) and (A.2), the objective of the firm is to maximize:

$$
\begin{aligned}
& nE_{t-1}d_{1t}\left[Q_{11t}^{dol}(v) - W_{1t}\right]\left[\frac{Q_{11t}^{dol}(v)}{P_{11t}^{dol}}\right]^{-\lambda}\frac{P_{1t}^{dol}C_{1t}}{P_{11t}^{dol}} \\
& +(1-n)E_{t-1}d_{1t}\left[Q_{21t}^{dol}(v) - W_{1t}\right]\left[\frac{S_{12t}^{-1}Q_{21t}^{dol}(v)}{S_{12t}^{-1}P_{21t}^{dol}}\right]^{-\lambda}\frac{P_{2t}^{eur}C_{2t}}{S_{12t}^{-1}P_{21t}^{dol}}
\end{aligned}
$$

Recalling that $Q_{11t}^{dol}(v)$, $Q_{21t}^{dol}(v)$ and the variables for time *t*-1 are not affected by time *t* shocks, the first order condition with respect to $Q_{11t}^{dol}(v)$ is written as:

(B.1) $$Q_{11t}^{dol}(v) = P_{11t}^{dol} = \frac{\lambda}{\lambda-1}\frac{E_{t-1}[W_{1t}C_{1t}^{1-\rho}]}{E_{t-1}C_{1t}^{1-\rho}}$$

which corresponds to equation (1.9). Turning to $Q_{21t}^{dol}(v)$, we recall that the situation is identical across US firms ($Q_{21t}^{dol}(v) = P_{21t}^{dol}(v) = P_{21t}^{dol}$) and write the first order condition as:

$$Q_{21t}^{dol}(v) = \frac{\lambda}{\lambda-1}\frac{E_{t-1}[W_{1t}C_{1t}^{-\rho}(P_{1t}^{dol})^{-1}P_{2t}^{eur}C_{2t}S_{12t}]}{E_{t-1}[C_{1t}^{-\rho}(P_{1t}^{dol})^{-1}P_{2t}^{eur}C_{2t}S_{12t}]}$$

Using the optimal risk sharing condition (1.4) we obtain equation (1.10):

(B.2) $$Q_{21t}^{dol}(v) = P_{21t}^{dol} = \frac{\lambda}{\lambda-1}\frac{E_{t-1}[W_{1t}C_{2t}^{1-\rho}]}{E_{t-1}C_{2t}^{1-\rho}}$$

A European firm chooses two wholesale prices in European currency, one for exports, $Q_{12t}^{eur}(v)$, and one for sales to domestic retailers, $Q_{22t}^{eur}(v)$. Using (A.1) and (A.2), Its objective is to maximize:

$$nE_{t-1}d_{2t}\left[Q_{12t}^{eur}-W_{2t}\right]\left[\frac{1}{P_{12t}^{dol}}Q_{12t}^{eur}(v)\frac{E_{t-1}S_{12t}C_{1t}^{1-\rho}}{E_{t-1}C_{1t}^{1-\rho}}\right]^{-\lambda}\frac{P_{1t}^{dol}C_{1t}}{P_{12t}^{dol}}$$
$$+(1-n)E_{t-1}d_{2t}\left[Q_{22t}^{eur}(v)-W_{2t}\right]\left[\frac{Q_{22t}^{eur}(v)}{P_{22t}^{eur}}\right]^{-\lambda}\frac{P_{2t}^{eur}C_{2t}}{P_{22t}^{eur}}$$

Recalling that in equilibrium all firms make the same choice, the first order condition with respect to $Q_{12t}^{eur}(v)$ is written as:

$$Q_{12t}^{eur}(v)=\frac{\lambda}{\lambda-1}\frac{E_{t-1}[W_{2t}C_{2t}^{-\rho}(P_{2t}^{eur})^{-1}P_{1t}^{dol}C_{1t}]}{E_{t-1}[C_{2t}^{-\rho}(P_{2t}^{eur})^{-1}P_{1t}^{dol}C_{1t}]}$$

Combining this result with the optimal risk sharing condition (1.4), we write:

$$Q_{12t}^{eur}(v)=\frac{\lambda}{\lambda-1}\frac{E_{t-1}[S_{12t}W_{2t}C_{1t}^{1-\rho}]}{E_{t-1}[S_{12t}C_{1t}^{1-\rho}]}$$

Using (A.1) we obtain equation (1.11):

(B.3) $$P_{12t}^{dol}(v)=P_{12t}^{dol}=\frac{\lambda}{\lambda-1}\frac{E_{t-1}[S_{12t}W_{2t}C_{1t}^{1-\rho}]}{E_{t-1}C_{1t}^{1-\rho}}$$

From the first order condition with respect to $Q_{22t}^{eur}(v)$ and (A.2), we obtain equation (1.12):

(B.4) $$Q_{22t}^{eur}(v)=P_{22t}^{eur}=\frac{\lambda}{\lambda-1}\frac{E_{t-1}[W_{2t}C_{2t}^{1-\rho}]}{E_{t-1}C_{2t}^{1-\rho}}$$

After the euro

The introduction of the euro does not change the situation of European firms, and (B.3) and (B.4) remain valid. A US firm however faces a different situation, as the

European retailers to whom its goods are sent now set the retail prices in Euro. The wholesale price for domestic sales is still given by (B.1), whereas the wholesale price for exports is now given by:

$$Q_{21t}^{dol}(v) = \frac{\lambda}{\lambda - 1} \frac{E_{t-1}[S_{12t}^{-1} W_{1t} C_{2t}^{1-\rho}]}{E_{t-1}[S_{12t}^{-1} C_{2t}^{1-\rho}]}$$

Combining this result with (A.3) leads to equation (1.14):

$$\text{(B.5)} \qquad P_{21t}^{eur}(v) = P_{21t}^{eur} = \frac{\lambda}{\lambda - 1} \frac{E_{t-1}[S_{12t}^{-1} W_{1t} C_{2t}^{1-\rho}]}{E_{t-1} C_{2t}^{1-\rho}}$$

C. Expected consumption

Before the euro

To derive equation (2.6), we use the labor supply relation (1.6) to write $W_{1t} = \eta P_{1t}^{dol} C_{1t}^{\rho}$, and $W_{2t} = \eta P_{2t}^{eur} C_{2t}^{\rho} = \eta S_{12t}^{-1} P_{1t}^{dol} C_{1t}^{\rho}$. Combining with (B.1) and (B.3), we derive:

$$P_{11t}^{dol} = P_{12t}^{dol} = P_{1t}^{dol} \frac{\lambda \eta}{\lambda - 1} \frac{E_{t-1} C_{1t}}{E_{t-1} C_{1t}^{1-\rho}}$$

Since $P_{1t}^{dol} = (P_{11t}^{dol})^n (P_{12t}^{dol})^{1-n}$, we obtain equation (2.6):

$$\text{(C.1)} \qquad 1 = \frac{\lambda \eta}{\lambda - 1} \frac{E_{t-1} C_{1t}}{E_{t-1} C_{1t}^{1-\rho}}$$

To get equation (2.7), we rewrite equation (B.2) recalling that $W_{1t} = \eta P_{1t}^{dol} C_{1t}^{\rho}$ $= \eta S_{12t} P_{2t}^{eur} C_{2t}^{\rho}$ and $P_{2t}^{eur} = S_{12t}^{-n} (P_{21t}^{dol})^n (P_{22t}^{eur})^{1-n}$

$$P_{21t}^{dol} = (P_{21t}^{dol})^n (P_{22t}^{eur})^{1-n} \frac{\lambda \eta}{\lambda - 1} \frac{E_{t-1}[S_{12t}^{1-n} C_{2t}]}{E_{t-1} C_{2t}^{1-\rho}}$$

Similarly, we use $W_{2t} = \eta P_{2t}^{eur} C_{2t}^{\rho}$ to write (B.4) as:

$$P_{22t}^{eur} = (P_{21t}^{dol})^n (P_{22t}^{eur})^{1-n} \frac{\lambda\eta}{\lambda - 1} \frac{E_{t-1}[S_{12t}^{-n} C_{2t}]}{E_{t-1} C_{2t}^{1-\rho}}$$

Combining the last two results leads to (2.7):

(C.2)
$$1 = \frac{\lambda\eta}{\lambda - 1} \left(\frac{E_{t-1}[S_{12t}^{1-n} C_{2t}]}{E_{t-1} C_{2t}^{1-\rho}} \right)^n \left(\frac{E_{t-1}[S_{12t}^{-n} C_{2t}]}{E_{t-1} C_{2t}^{1-\rho}} \right)^{1-n}$$

(2.6) and (2.7) can be linearized to derive the expected consumption. We recall the property of the log-normal distribution:

$$x = \ln(X) \to N(\mu, \sigma^2) \Rightarrow E[X^a] = \exp[a\mu + \tfrac{1}{2} a^2 \sigma^2]$$

(2.6) can then be written as:

$$E_{t-1} c_{1t} = -\frac{1}{\rho} \ln\left(\frac{\lambda\eta}{\lambda - 1} \right) + \frac{\rho - 2}{2} \sigma_{c_1}^2$$

Recalling that $\sigma_{c_1}^2 = \rho^{-2} \sigma_v^2$ from (2.3), we derive:

$$E_{t-1} C_{1t} = \exp\left[E_{t-1} c_{1t} + \frac{1}{2} \sigma_{c_1}^2 \right] = \Phi \exp\left[\frac{\rho - 1}{2\rho^2} \sigma_v^2 \right]$$

where $\Phi = [(\lambda\eta)/(\lambda - 1)]^{-1/\rho}$. Following similar steps, (2.7) can be rewritten after some algebra as:

$$E_{t-1} c_{2t} = -\frac{1}{\rho} \ln\left(\frac{\lambda\eta}{\lambda - 1} \right) + \frac{\rho - 2}{2} \sigma_{c_2}^2 - \frac{n(1-n)}{2\rho} \sigma_{s_{12}}^2$$

From (2.2) and (2.4), we know that $\sigma_{c_2}^2 = (n^2 + (1-n)^2) \rho^{-2} \sigma_v^2$ and $\sigma_{s_{12}} = 2\sigma_v^2$, and write:

$$\begin{aligned} E_{t-1} C_{2t} &= \exp\left[E_{t-1} c_{2t} + \frac{1}{2} \sigma_{c_2}^2 \right] \\ &= \Phi \exp\left[\left(\frac{\rho - 1}{\rho^2} \left(\frac{1}{2} - n(1-n) \right) - \frac{n(1-n)}{\rho} \right) \sigma_v^2 \right] \end{aligned}$$

After the euro

Expected US consumption can be obtained from (B.1) and (B.3) which remain valid after the introduction of the euro. Following the same steps as above, we show that the euro has no effect on expected US consumption:

$$E_{t-1}C_{1t} = \Phi \exp\left[\frac{\rho-1}{2\rho^2}\sigma_v^2\right]$$

Turning to European consumption, we use the labor supply (1.6) to write $W_{2t} = \eta P_{2t}^{eur} C_{2t}^{\rho}$ and $W_{1t} = \eta P_{1t}^{dol} C_{1t}^{\rho} = \eta S_{12t} P_{2t}^{eur} C_{2t}^{\rho}$. We can rearrange (B.4) and (B.5) to obtain:

$$P_{21t}^{eur} = P_{22t}^{eur} = \frac{\lambda\eta}{\lambda-1}\frac{E_{t-1}[P_{2t}^{eur}C_{2t}]}{E_{t-1}C_{2t}^{1-\rho}}$$

European consumer prices being preset, we use (1.3) to derive (2.8):

$$1 = \frac{\lambda\eta}{\lambda-1}\frac{E_{t-1}C_{2t}}{E_{t-1}C_{2t}^{1-\rho}} \qquad \text{(C.3)}$$

which is similar to (C.1). Following similar steps as for the US, we derive:

$$E_{t-1}c_{2t} = -\frac{1}{\rho}\ln\left(\frac{\lambda\eta}{\lambda-1}\right) + \frac{\rho-2}{2}\sigma_{c_2}^2$$

Recalling that $\sigma_{c_2}^2 = \rho^{-2}\sigma_v^2$ from (2.5), we obtain:

$$E_{t-1}C_{2t} = \exp\left[E_{t-1}c_{2t} + \frac{1}{2}\sigma_{c_2}^2\right] = \Phi \exp\left[\frac{\rho-1}{2\rho^2}\sigma_v^2\right]$$

D. Expected employment

Before the euro

We derive the expected employment levels by combining (1.13) with our solutions for retail prices (1.9)-(1.12), the labor supply (1.6) and the optimal risk sharing condition (1.4). Expected employment in the United States is computed as:

$$\begin{aligned} E_{t-1}L_{1t} &= n\frac{P_{1t}^{dol}E_{t-1}C_{1t}}{P_{11t}^{dol}} + (1-n)\frac{E_{t-1}S_{12t}P_{2t}^{eur}C_{2t}}{P_{21t}^{dol}} \\ &= \frac{\lambda-1}{\lambda\eta}E_{t-1}[nC_{1t}^{1-\rho} + (1-n)C_{2t}^{1-\rho}] \end{aligned}$$

Turning to expected European employment, we write:

$$\begin{aligned} E_{t-1}L_{2t} &= n\frac{P_{1t}^{dol}E_{t-1}C_{1t}}{P_{12t}^{dol}} + (1-n)\frac{E_{t-2}P_{2t}^{eur}C_{2t}}{P_{22t}^{eur}} \\ &= \frac{\lambda-1}{\lambda\eta}E_{t-1}[nC_{1t}^{1-\rho} + (1-n)C_{2t}^{1-\rho}] \end{aligned}$$

After the euro

We undertake similar steps, replacing (1.10) by (1.14) and using (1.15) for US employment. European employment is computed as above, whereas US employment is given by:

$$\begin{aligned} E_{t-1}L_{1t} &= n\frac{P_{1t}^{dol}E_{t-1}C_{1t}}{P_{11t}^{dol}} + (1-n)\frac{E_{t-1}P_{2t}^{eur}C_{2t}}{P_{21t}^{eur}} \\ &= \frac{\lambda-1}{\lambda\eta}E_{t-1}[nC_{1t}^{1-\rho} + (1-n)C_{2t}^{1-\rho}] \end{aligned}$$

Expected employment is always the same across regions, and is always given by the same formula. Of course, the value of the terms in the formula is not the same before and after the euro.

E. Welfare

In our setup, the real effects of monetary shocks occur entirely in the short run. From (1.1) and (2.9), we write the expected per capita welfare in country *i* as (omitting the real balances):

$$E_{t-1}U_{it} = \frac{1}{1-\rho}E_{t-1}C_{it}^{1-\rho} - \eta E_{t-1}L_{it}$$
$$= \frac{1}{1-\rho}E_{t-1}C_{it}^{1-\rho} - \frac{\lambda-1}{\lambda}E_{t-1}[nC_{1t}^{1-\rho} + (1-n)C_{2t}^{1-\rho}]$$

Simple algebra leads to equations (31.)-(3.2).

F. The law of one price for US exports

This Appendix derives a version of the model where US firms are constrained to set the same US dollar wholesale price for domestic sales and exports before the introduction of the euro ($Q_{21t}^{dol}(v) = Q_{11t}^{dol}(v)$). (2.3) and (2.4) remain valid, and the pre-euro consumption volatility is still given by Table 2. The post-euro setup is identical as before, and the pre-euro analysis of European firm is unchanged.

Price setting

The situation of the retailers is unchanged, and they set their prices as in Appendix A. A US firm chooses a unique US dollar wholesale price, $Q_{11t}^{dol}(v)$, charged to all retailers. Using (A.1) and (A.2), its objective is written as:

$$E_{t-1}d_{1t}(Q_{11t}^{dol}(v)-W_{1t})\left[\frac{Q_{11t}^{dol}(v)}{P_{11t}^{dol}}\right]^{-\lambda}\left[n\frac{P_{1t}^{dol}C_{1t}}{P_{11t}^{dol}}+(1-n)\frac{S_{12t}P_{2t}^{eur}C_{2t}}{P_{11t}^{dol}}\right]$$

The first order condition can be written as:

$$Q_{11t}^{dol}(v)=P_{11t}^{dol}=\frac{\lambda}{\lambda-1}\frac{E_{t-1}W_{1t}C_{1t}^{\ -\rho}(P_{1t}^{dol})^{-1}[nP_{1t}^{dol}C_{1t}+(1-n)S_{12t}P_{2t}^{eur}C_{2t}]}{E_{t-1}C_{1t}^{\ -\rho}(P_{1t}^{dol})^{-1}[nP_{1t}^{dol}C_{1t}+(1-n)S_{12t}P_{2t}^{eur}C_{2t}]}$$

Using the optimal risk sharing condition (1.4) we write:

(F.1) $$Q_{11t}^{dol}(v)=P_{11t}^{dol}=\frac{\lambda}{\lambda-1}\frac{E_{t-1}W_{1t}[nC_{1t}^{1-\rho}+(1-n)C_{2t}^{1-\rho}]}{E_{t-1}[nC_{1t}^{1-\rho}+(1-n)C_{2t}^{1-\rho}]}$$

Expected consumption

We use the labor supply in the United States (1.6) to write $W_{1t}=\eta P_{1t}^{dol}C_{1t}^{\rho}$, and combine it with (F.1) to get:

$$P_{11t}^{dol}=P_{1t}^{dol}\frac{\lambda\eta}{\lambda-1}\frac{E_{t-1}[nC_{1t}+(1-n)C_{2t}^{1-\rho}C_{1t}^{\rho}]}{E_{t-1}[nC_{1t}^{1-\rho}+(1-n)C_{2t}^{1-\rho}]}$$

From Appendix C, we know that $P_{12t}^{dol}=P_{1t}^{dol}(\lambda\eta)(\lambda-1)^{-1}(E_{t-1}C_{1t})(E_{t-1}C_{1t}^{1-\rho})^{-1}$. Recalling that $P_{1t}^{dol}=(P_{11t}^{dol})^{n}(P_{12t}^{dol})^{1-n}$, we obtain:

(F.2) $$1=\frac{\lambda\eta}{\lambda-1}\left(\frac{E_{t-1}[nC_{1t}+(1-n)C_{2t}^{1-\rho}C_{1t}^{\rho}]}{E_{t-1}[nC_{1t}^{1-\rho}+(1-n)C_{2t}^{1-\rho}]}\right)^{n}\left(\frac{E_{t-1}C_{1t}}{E_{t-1}C_{1t}^{1-\rho}}\right)^{1-n}$$

which determines US consumption. To obtain the corresponding equation for European consumption, we start by combining (F.1) with the labor supply ($W_{1t} = \eta P_{1t}^{dol} C_{1t}^{\rho}$ $= \eta S_{12t} P_{2t}^{eur} C_{2t}^{\rho}$) and the definition of the European CPI ($P_{2t}^{eur} = S_{12t}^{-n} (P_{11t}^{dol})^n (P_{22t}^{eur})^{1-n}$) to get:

$$P_{11t}^{dol} = (P_{11t}^{dol})^n (P_{22t}^{eur})^{1-n} \frac{\lambda\eta}{\lambda - 1} \frac{E_{t-1}[(nC_{1t}^{1-\rho} C_{2t}^{\rho} + (1-n)C_{2t}) S_{12t}^{1-n}]}{E_{t-1}(nC_{1t}^{1-\rho} + (1-n)C_{2t}^{1-\rho})}$$

From Appendix C we know that $P_{22t}^{eur} = (\lambda\eta)(\lambda-1)^{-1}(E_{t-1}[P_{2t}^{eur} C_{2t}])(E_{t-1}C_{2t}^{1-\rho})^{-1}$. Combining this with the previous result, we derive:

$$\text{(F.3)} \qquad 1 = \frac{\lambda\eta}{\lambda - 1} \left(\frac{E_{t-1}[(nC_{1t}^{1-\rho} C_{2t}^{\rho} + (1-n)C_{2t}) S_{12t}^{1-n}]}{E_{t-1}[nC_{1t}^{1-\rho} + (1-n)C_{2t}^{1-\rho}]} \right)^n \left(\frac{E_{t-1}[C_{2t} S_{12t}^{-n}]}{E_{t-1} C_{2t}^{1-\rho}} \right)^{1-n}$$

(F.2) and (F.3) are non-linear in logs, but can be approximated as a first order expansion around a steady state with zero volatility. The numerator of the first term in (F.2) can be approximated as:

$$\begin{aligned}
&\ln\{E_{t-1}[nC_{1t} + (1-n)C_{2t}^{1-\rho} C_{1t}^{\rho}]\} \\
&= \ln\{n \exp[E_{t-1}c_{1t} + \tfrac{1}{2}\sigma_{c_1}^2] \\
&\qquad + (1-n)\exp[\rho E_{t-1}c_{1t} + (1-\rho)E_{t-1}c_{2t} + \tfrac{1}{2}\rho^2\sigma_{c_1}^2 + \tfrac{1}{2}(1-\rho)^2\sigma_{c_2}^2 + \rho(1-\rho)\sigma_{c_1c_2}]\} \\
&\cong (n + (1-n)\rho)E_{t-1}c_{1t} + (1-n)(1-\rho)E_{t-1}c_{2t} + \tfrac{1}{2}(n + (1-n)\rho^2)\sigma_{c_1}^2 \\
&\quad + \tfrac{1}{2}(1-n)(1-\rho)^2\sigma_{c_2}^2 + \rho(1-n)(1-\rho)\sigma_{c_1c_2}
\end{aligned}$$

Similarly, the denominator can be approximated as:

$$\begin{aligned}
&\ln\{E_{t-1}[nC_{1t}^{1-\rho} + (1-n)C_{2t}^{1-\rho}]\} \\
&= \ln\{n\exp[(1-\rho)E_{t-1}c_{1t} + \tfrac{1}{2}(1-\rho)^2\sigma_{c_1}^2] + (1-n)\exp[(1-\rho)E_{t-1}c_{2t} + \tfrac{1}{2}(1-\rho)^2\sigma_{c_2}^2]\} \\
&\cong n(1-\rho)E_{t-1}c_{1t} + (1-n)(1-\rho)E_{t-1}c_{2t} + \tfrac{1}{2}n(1-\rho)^2\sigma_{c_1}^2 + \tfrac{1}{2}(1-n)(1-\rho)^2\sigma_{c_2}^2
\end{aligned}$$

The terms in (F.2) can then be written as:

$$\ln\left(\frac{E_{t-1}[nC_{1t}+(1-n)C_{2t}^{1-\rho}C_{1t}^{\rho}]}{E_{t-1}[nC_{1t}^{1-\rho}+(1-n)C_{2t}^{1-\rho}]}\right)^{n}$$
$$\cong n\left\{\rho E_{t-1}c_{1t}+(1-n)\rho(1-\rho)\sigma_{c_1c_2}+\tfrac{1}{2}(n+(1-n)\rho^2-n(1-\rho)^2)\sigma_{c_1}^2\right\}$$
$$\ln\left(\frac{E_{t-1}C_{1t}}{E_{t-1}C_{1t}^{1-\rho}}\right)^{1-n}=(1-n)\left\{\rho E_{t-1}c_{1t}+\tfrac{1}{2}(1-(1-\rho)^2)\sigma_{c_1}^2\right\}$$

We can then take a log approximation of (F.2) as:

$$0=\ln\left(\frac{\lambda\eta}{\lambda-1}\right)+\rho E_{t-1}c_{1t}+n(1-n)\rho(1-\rho)\sigma_{c_1c_2}+\tfrac{1}{2}\rho[2-\rho-2n(1-n)(1-\rho)]\sigma_{c_1}^2$$

which we solve as:

$$E_{t-1}C_{1t}=\Phi\exp\left[\frac{\rho-1}{2}\sigma_{c_1}^2-(\rho-1)n(1-n)(\sigma_{c_1}^2-\sigma_{c_1c_2})\right]$$

where $\Phi=[(\lambda\eta)/(\lambda-1)]^{-1/\rho}$.

The numerator of the first component of (F.3) can be approximated as follows:

$$\begin{aligned}&\ln\{E_{t-1}[(nC_{1t}^{1-\rho}C_{2t}^{\rho}+(1-n)C_{2t})S_{12t}^{1-n}]\}\\ &\cong(1-n)E_{t1}s_{12t}+n(1-\rho)E_{t-1}c_{1t}+(n\rho+(1-n))E_{t-1}c_{2t}\\ &\quad+\tfrac{1}{2}(1-n)^2\sigma_{s_{12}}^2+\tfrac{1}{2}n(1-\rho)^2\sigma_{c_1}^2+\tfrac{1}{2}(n\rho^2+(1-n))\sigma_{c_2}^2\\ &\quad+n\rho(1-\rho)\sigma_{c_1c_2}+n(1-n)(1-\rho)\sigma_{s_{12}c_1}+(1-n)(n\rho+(1-n))\sigma_{s_{12}c_2}\end{aligned}$$

We can then write the two elements of (F.3) as:

$$\ln\left(\frac{E_{t-1}[(nC_{1t}^{1-\rho}C_{2t}^{\rho}+(1-n)C_{2t})S_{12t}^{1-n}]}{E_{t-1}[nC_{1t}^{1-\rho}+(1-n)C_{2t}^{1-\rho}]}\right)^{n}$$
$$\cong n\left\{\begin{aligned}&(1-n)E_{t1}s_{12t}+\rho E_{t-1}c_{2t}+\tfrac{1}{2}(1-n)^2\sigma_{s_{12}}^2+\tfrac{1}{2}(n\rho^2+(1-n)-(1-n)(1-\rho)^2)\sigma_{c_2}^2\\ &+n\rho(1-\rho)\sigma_{c_1c_2}+n(1-n)(1-\rho)\sigma_{s_{12}c_1}+(1-n)(n\rho+(1-n))\sigma_{s_{12}c_2}\end{aligned}\right\}$$
$$\ln\left(\frac{E_{t-1}[C_{2t}S_{12t}^{-n}]}{E_{t-1}C_{2t}^{1-\rho}}\right)^{1-n}=(1-n)\left\{\begin{aligned}&\rho E_{t-1}c_{2t}-nE_{t1}s_{12t}+\tfrac{1}{2}n^2\sigma_{s_{12}}^2+\tfrac{1}{2}(1-(1-\rho)^2)\sigma_{c_2}^2\\ &-n\sigma_{s_{12}c_2}\end{aligned}\right\}$$

which allows us to take a log linear approximation of (F.3) as:

$$0 = \ln\left(\frac{\lambda\eta}{\lambda-1}\right) + \rho E_{t-1}c_{2t} + \tfrac{1}{2}n(1-n)\sigma_{s_{12}}^2 + \tfrac{1}{2}\rho(2-\rho)\sigma_{c_2}^2$$
$$-n^2(1-n)(1-\rho)(\sigma_{s_{12}c_2} - \sigma_{s_{12}c_1}) + n^2\rho(\rho-1)(\sigma_{c_2}^2 - \sigma_{c_1c_2})$$

Which we solve to obtain:

$$E_{t-1}C_{2t} = \Phi \exp\begin{bmatrix} \frac{\rho-1}{2}\sigma_{c_2}^2 - (\rho-1)n^2(\sigma_{c_2}^2 - \sigma_{c_1c_2}) \\ -\frac{n(1-n)}{2\rho}\sigma_{s_{12}}^2 \quad + \frac{n^2(1-n)(1-\rho)}{\rho}(\sigma_{s_{12}c_2} - \sigma_{s_{12}c_1}) \end{bmatrix}$$

Expected employment

Expected US employment can be computed as:

$$\begin{aligned} E_{t-1}L_{1t} &= n\frac{P_{1t}^{dol}E_{t-1}C_{1t}}{P_{11t}^{dol}} + (1-n)\frac{E_{t-1}S_{12t}P_{2t}^{eur}C_{2t}}{P_{11t}^{dol}} \\ &= \frac{\lambda-1}{\lambda\eta}E_{t-1}[nC_{1t}^{1-\rho} + (1-n)C_{2t}^{1-\rho}]\frac{nE_{t-1}C_{1t} + (1-n)E_{t-1}C_{1t}^{\rho}C_{2t}^{1-\rho}}{E_{t-1}[nC_{1t} + (1-n)C_{1t}^{\rho}C_{2t}^{1-\rho}]} \\ &= \frac{\lambda-1}{\lambda\eta}E_{t-1}[nC_{1t}^{1-\rho} + (1-n)C_{2t}^{1-\rho}] \end{aligned}$$

which is of the same form as in (2.9) in the baseline model. Table 3 presents the values of expected consumption, employment, and ‘power’ consumption under the alternative setup.

G. Exchange rate flexibility in pre-euro Europe

In this extension, we assume that before the introduction of the euro, the exchange rate between the French franc and the Deutsche Mark floats. The post-euro situation is unchanged from the baseline model. We assume that European retailers entirely pass the exchange rate fluctuations through to consumers. The retail prices in Germany and France are therefore equal to the wholesales prices charged by the producer, times the relevant exchange rate. The household problem is similar as the one presented in section 1.1, with the consumption basket now defined as:

$$C_i(x) = \frac{1}{n^n n_2^{n_2} n_3^{n_3}} \left(C_{i1}(x)\right)^n \left(C_{i2}(x)\right)^{n_2} \left(C_{i3}(x)\right)^{n_3}$$

The analysis of the model is similar to the one presented in the main text. Assuming $\mu_i = \mu \, \forall i$ for simplicity, we can show that $S_{1it} = M_{1t} M_{it}^{-1}$ for $i = 2$, 3. Consumption in the United States is still given by (2.3). As there is complete exchange rate pass-through at the intra-European level, consumption in France and Germany is proportional to the worldwide nominal balances:

(G.1) $$C_{2t} \text{ and } C_{3t} \propto (M_{1t}^{n} M_{2t}^{n_2} M_{3t}^{n_3})^{\frac{1}{\rho}}$$

From (G.1), we can compute the consumption volatility. It is equal to its value in Table 2 for the United States, and its value in Europe is:

(G.2) $$\sigma_{c_2}^2 = \sigma_{c_3}^2 = \sigma_{c_2 c_3} = \frac{n^2 + n_2^2 + n_3^2}{\rho^2} \sigma_v^2$$

Price setting

We now turn to the optimal price setting for each firm. A US firm sets its wholesale prices in US dollar, without any constraint of their being equalized across markets. Retailers in US and Europe then simply pass the wholesale prices through to retail prices, up to the exchange rate ($P_{11t}^{dol}(v) = Q_{11t}^{dol}(v)$, $P_{21t}^{DM}(v) = S_{12t}^{-1} Q_{21t}^{dol}(v)$, $P_{31t}^{FF}(v) = S_{13t}^{-1} Q_{31t}^{dol}(v)$). A US firm maximizes:

$$
\begin{aligned}
& nE_{t-1} d_{1t} \left[Q_{11t}^{dol}(v) - W_{1t} \right] \left[\frac{P_{11t}^{1}(v)}{P_{11t}^{dol}} \right]^{-\lambda} \frac{P_{1t}^{dol} C_{1t}}{P_{11t}^{dol}} \\
& + n_2 E_{t-1} d_{1t} \left[Q_{21t}^{dol}(v) - W_{1t} \right] \left[\frac{S_{12t}^{-1} Q_{21t}^{dol}(v)}{P_{21t}^{DM}} \right]^{-\lambda} \frac{P_{2t}^{DM} C_{2t}}{P_{21t}^{DM}} \\
& + n_3 E_{t-1} d_{1t} \left[Q_{31t}^{dol}(v) - W_{1t} \right] \left[\frac{S_{13t}^{-1} Q_{31t}^{dol}(v)}{P_{31t}^{FF}} \right]^{-\lambda} \frac{P_{3t}^{FF} C_{3t}}{P_{31t}^{FF}}
\end{aligned}
$$

After some algebra, the optimal prices can be written as:

$$
\begin{aligned}
P_{11t}^{dol} &= Q_{11t}^{dol}(v) = \frac{\lambda \eta}{\lambda - 1} \frac{E_{t-1}[P_{1t}^{dol} C_{1t}]}{E_{t-1} C_{1t}^{1-\rho}} \\
P_{21t}^{dol} &= Q_{21t}^{dol}(v) = \frac{\lambda \eta}{\lambda - 1} \frac{E_{t-1}[P_{1t}^{dol} C_{1t}^{\rho} C_{2t}^{1-\rho}]}{E_{t-1} C_{2t}^{1-\rho}} \\
P_{31t}^{dol} &= Q_{31t}^{dol}(v) = \frac{\lambda \eta}{\lambda - 1} \frac{E_{t-1}[P_{1t}^{dol} C_{1t}^{\rho} C_{3t}^{1-\rho}]}{E_{t-1} C_{3t}^{1-\rho}}
\end{aligned}
$$

A German firm sets three wholesale prices in DM: one for its sales to the US, $Q_{12t}^{DM}(v)$, one for its sales in Germany, $Q_{22t}^{DM}(v)$, and one for its sales to France, $Q_{32t}^{DM}(v)$. The retail price in the US is similar to (A.2):

$$
P_{12t}^{dol}(v) = Q_{12t}^{DM}(v) \frac{E_{t-1}[S_{12t} C_{1t}^{1-\rho}]}{E_{t-1} C_{1t}^{1-\rho}}
$$

The German firm maximizes:

$$nE_{t-1}d_{2t}\left[Q_{12t}^{DM}(v)-W_{2t}\right]\left[\frac{1}{P_{12t}^{dol}}Q_{12t}^{DM}(v)\frac{E_{t-1}[S_{12t}C_{1t}^{1-\rho}]}{E_{t-1}C_{1t}^{1-\rho}}\right]^{-\lambda}\frac{P_{1t}^{dol}C_{1t}}{P_{12t}^{dol}}$$
$$+n_2E_{t-1}d_{2t}\left[Q_{22t}^{DM}(v)-W_{2t}\right]\left[\frac{Q_{22t}^{DM}(v)}{P_{22t}^{DM}}\right]^{-\lambda}\frac{P_{2t}^{DM}C_{2t}}{P_{22t}^{DM}}$$
$$+n_3E_{t-1}d_{2t}\left[Q_{32t}^{DM}(v)-W_{2t}\right]\left[\frac{S_{12t}S_{13t}^{-1}Q_{32t}^{DM}(v)}{P_{32t}^{FF}}\right]^{-\lambda}\frac{P_{3t}^{FF}C_{3t}}{P_{32t}^{FF}}$$

The optimal prices can be written as:

$$P_{12t}^{dol}=\frac{\lambda\eta}{\lambda-1}\frac{E_{t-1}[P_{1t}^{dol}C_{1t}]}{E_{t-1}C_{1t}^{1-\rho}}$$
$$P_{22t}^{DM}=Q_{22t}^{DM}(v)=\frac{\lambda\eta}{\lambda-1}\frac{E_{t-1}[P_{2t}^{DM}C_{2t}]}{E_{t-1}C_{2t}^{1-\rho}}$$
$$P_{32t}^{DM}=Q_{32t}^{DM}(v)=\frac{\lambda\eta}{\lambda-1}\frac{E_{t-1}[S_{13t}S_{12t}^{-1}P_{3t}^{FF}C_{3t}]}{E_{t-1}C_{3t}^{1-\rho}}$$

A French firm faces a similar situation, and maximizes:

$$nE_{t-1}d_{3t}\left[Q_{13t}^{FF}(v)-W_{3t}\right]\left[\frac{1}{P_{13t}^{dol}}Q_{13t}^{FF}(v)\frac{E_{t-1}[S_{13t}C_{1t}^{1-\rho}]}{E_{t-1}C_{1t}^{1-\rho}}\right]^{-\lambda}\frac{P_{1t}^{dol}C_{1t}}{P_{13t}^{dol}}$$
$$+n_2E_{t-1}d_{3t}\left[Q_{23t}^{FF}(v)-W_{3t}\right]\left[\frac{S_{13t}S_{12t}^{-1}Q_{23t}^{FF}(v)}{P_{23t}^{DM}}\right]^{-\lambda}\frac{P_{2t}^{DM}C_{2t}}{P_{23t}^{DM}}$$
$$+n_3E_{t-1}d_{3t}\left[Q_{33t}^{FF}(v)-W_{3t}\right]\left[\frac{Q_{33t}^{FF}(v)}{P_{33t}^{FF}}\right]^{-\lambda}\frac{P_{3t}^{FF}C_{3t}}{P_{33t}^{FF}}$$

The optimal prices can be computed as:

$$P_{13t}^{dol}=Q_{13t}^{FF}(v)\frac{E_{t-1}[S_{13t}C_{1t}^{1-\rho}]}{E_{t-1}C_{1t}^{1-\rho}}=\frac{\lambda\eta}{\lambda-1}\frac{E_{t-1}[P_{1t}^{dol}C_{1t}]}{E_{t-1}C_{1t}^{1-\rho}}$$
$$P_{23t}^{FF}=Q_{23t}^{FF}(v)=\frac{\lambda\eta}{\lambda-1}\frac{[E_{t-1}S_{12t}S_{13t}^{-1}P_{2t}^{DM}C_{2t}]}{E_{t-1}C_{2t}^{1-\rho}}$$
$$P_{33t}^{FF}=Q_{33t}^{FF}(v)=\frac{\lambda\eta}{\lambda-1}\frac{E_{t-1}[P_{3t}^{FF}C_{3t}]}{E_{t-1}C_{3t}^{1-\rho}}$$

Expected consumption

From the solutions for P_{11t}^{dol}, P_{12t}^{dol} and P_{13t}^{dol} we can establish that US expected consumption is still given by (2.6). As US actual consumption is still determined by (2.3), its variance is identical as in the baseline model. It is then straightforward to show that the pre-euro expected US consumption is given by Table 2, and is therefore unaffected by the intra-European exchange rate regime.

Turning to Germany, we can write:

$$P_{21t}^{dol} = (P_{21t}^{dol})^{n} (P_{22t}^{DM})^{n_2} (P_{23t}^{FF})^{n_3} \frac{\lambda\eta}{\lambda-1} \frac{E_{t-1}[S_{12t}^{n_2} S_{13t}^{n_3} C_{2t}]}{E_{t-1}C_{2t}^{1-\rho}}$$

$$P_{22t}^{DM} = (P_{21t}^{dol})^{n} (P_{22t}^{DM})^{n_2} (P_{23t}^{FF})^{n_3} \frac{\lambda\eta}{\lambda-1} \frac{E_{t-1}[S_{12t}^{-(1-n_2)} S_{13t}^{n_3} C_{2t}]}{E_{t-1}C_{2t}^{1-\rho}}$$

$$P_{23t}^{FF} = (P_{21t}^{dol})^{n} (P_{22t}^{DM})^{n_2} (P_{23t}^{FF})^{n_3} \frac{\lambda\eta}{\lambda-1} \frac{E_{t-1}[S_{12t}^{n_2} S_{13t}^{-(1-n_3)} C_{2t}]}{E_{t-1}C_{2t}^{1-\rho}}$$

which implies:

$$E_{t-1}C_{2t}^{1-\rho} = \frac{\lambda\eta}{\lambda-1} \left(E_{t-1}S_{12t}^{n_2} S_{13t}^{n_3} C_{2t}\right)^{n} \left(E_{t-1}S_{12t}^{-(1-n_2)} S_{13t}^{n_3} C_{2t}\right)^{n_2} \left(E_{t-1}S_{12t}^{n_2} S_{13t}^{-(1-n_3)} C_{2t}\right)^{n_3}$$

We can solve this equation as:

(G.3)
$$E_{t-1}c_{2t} = -\frac{1}{\rho}\ln\left(\frac{\lambda\eta}{\lambda-1}\right) + \frac{\rho-2}{2}\sigma_{c_2}^2 - \frac{n_2(1-n_2)}{2\rho}\sigma_{s_{12}}^2 - \frac{n_3(1-n_3)}{2\rho}\sigma_{s_{13}}^2 + \frac{n_2 n_3}{\rho}\sigma_{s_{12}s_{13}}$$

Turning to France, we can show that:

$$P_{31t}^{dol} = (P_{31t}^{dol})^{n} (P_{32t}^{DM})^{n_2} (P_{33t}^{FF})^{n_3} \frac{\lambda\eta}{\lambda-1} \frac{E_{t-1}[S_{13t}^{n_3} S_{12t}^{n_2} C_{3t}]}{E_{t-1}C_{3t}^{1-\rho}}$$

$$P_{32t}^{DM} = (P_{31t}^{dol})^{n} (P_{32t}^{DM})^{n_2} (P_{33t}^{FF})^{n_3} \frac{\lambda\eta}{\lambda-1} \frac{E_{t-1}[S_{13t}^{n_3} S_{12t}^{-(1-n_2)} C_{3t}]}{E_{t-1}C_{3t}^{1-\rho}}$$

$$P_{33t}^{FF} = (P_{31t}^{dol})^{n} (P_{32t}^{DM})^{n_2} (P_{33t}^{FF})^{n_3} \frac{\lambda\eta}{\lambda-1} \frac{E_{t-1}[S_{13t}^{-(1-n_3)} S_{12t}^{n_2} C_{3t}]}{E_{t-1}C_{3t}^{1-\rho}}$$

which implies:

$$E_{t-1}C_{3t}^{1-\rho} = \frac{\lambda\eta}{\lambda-1}\left(E_{t-1}S_{13t}^{n_3}S_{12t}^{n_2}C_{3t}\right)^{n}\left(E_{t-1}S_{13t}^{n_3}S_{12t}^{-(1-n_2)}C_{3t}\right)^{n_2}\left(E_{t-1}S_{13t}^{-(1-n_3)}S_{12t}^{n_2}C_{3t}\right)^{n_3}$$

We can solve this to obtain:

$$\text{(G.4)} \qquad E_{t-1}c_{3t} = -\frac{1}{\rho}\ln\left(\frac{\lambda\eta}{\lambda-1}\right)+\frac{\rho-2}{2}\sigma_{c_3}^2-\frac{n_2(1-n_2)}{2\rho}\sigma_{s_{12}}^2-\frac{n_3(1-n_3)}{2\rho}\sigma_{s_{13}}^2 + \frac{n_2 n_3}{\rho}\sigma_{s_{12}s_{13}}$$

From (G.2)-(G.3)-(G.4), expected consumption is the same in Germany and in France, as is consumption volatility. From the optimal prices we then conclude that the law of one price holds at the intra-European level, i.e. the French Franc price is the same for sales in France and exports to Germany. This implies that PPP holds at the intra-European level, and (1.4) implies that consumption is always the same in France and Germany.

In addition, we can show that expected employment in France and Germany is given by (2.9). Table 4 presents the values of expected consumption, employment, and 'power' consumption under the alternative setup.

H. Alternative assumptions regarding the currency of pricing

The baseline analysis assumes that the introduction of the euro leads to a change of pricing behavior for European importers, making the European retail prices less sensitive to fluctuations in the exchange rate. However, it could be the case that European importers do not change their pricing practice but US importers adjust theirs and pass exchange rate fluctuations through to consumers. Under this alternative, consumer prices in the United States can change due to the exchange rate fluctuations US and European consumption levels are then proportional to worldwide money supply:

(H.1) $$C_{1t} \text{ and } C_{2t} \propto (M_{1t}^{n} M_{2t}^{1-n})^{\frac{1}{\rho}}$$

This implies that consumption volatility is the same in both regions:

(H.2) $$\sigma_{c_1}^2 = \sigma_{c_2}^2 = \frac{n^2 + (1-n)^2}{\rho^2} \sigma_v^2$$

Optimal prices

Retailers set the retail prices to be equal to the wholesale prices, adjusted by the exchange rate. The situation for a US producer is unchanged by the euro, and the optimal prices are given by:

$$P_{11t}^{dol} = Q_{11t}^{dol}(v) = \frac{\lambda\eta}{\lambda - 1} \frac{E_{t-1} P_{1t}^{dol} C_{1t}}{E_{t-1} C_{1t}^{1-\rho}}$$
$$P_{21t}^{dol} = Q_{21t}^{dol}(v) = \frac{\lambda\eta}{\lambda - 1} \frac{E_{t-1} S_{12t} P_{2t}^{eur} C_{2t}}{E_{t-1} C_{2t}^{1-\rho}}$$

A European firm maximizes:

$$nE_{t-1} d_{2t} \left[Q_{12t}^{eur}(v) - W_{2t} \right] \left[\frac{S_{12t} Q_{12t}^{eur}(v)}{P_{12t}^{dol}} \right]^{-\lambda} \frac{P_{1t}^{dol} C_{1t}}{P_{12t}^{dol}}$$
$$+ (1-n) E_{t-1} d_{2t} \left[P_{22t}^{eur}(v) - W_{2t} \right] \left[\frac{Q_{22t}^{eur}(v)}{P_{22t}^{eur}} \right]^{-\lambda} \frac{P_{2t}^{eur} C_{2t}}{P_{22t}^{eur}}$$

After some algebra, the optimal prices are written as:

$$P_{12t}^{eur} = Q_{12t}^{eur}(v) = \frac{\lambda\eta}{\lambda - 1} \frac{E_{t-1} S_{12t}^{-1} P_{1t}^{dol} C_{1t}}{E_{t-1} C_{1t}^{1-\rho}}$$
$$P_{22t}^{eur} = Q_{22t}^{eur}(v) = \frac{\lambda\eta}{\lambda - 1} \frac{E_{t-1} P_{2t}^{eur} C_{2t}}{E_{t-1} C_{2t}^{1-\rho}}$$

Expected consumption

From the optimal prices, we can write:

$$P_{11t}^{dol} = (P_{11t}^{dol})^n (P_{12t}^{eur})^{1-n} \frac{\lambda\eta}{\lambda-1} \frac{E_{t-1}[S_{12t}^{1-n} C_{1t}]}{E_{t-1} C_{1t}^{1-\rho}}$$
$$P_{12t}^{eur} = (P_{11t}^{dol})^n (P_{12t}^{eur})^{1-n} \frac{\lambda\eta}{\lambda-1} \frac{E_{t-1}[S_{12t}^{-n} C_{1t}]}{E_{t-1} C_{1t}^{1-\rho}}$$

which implies:

$$1 = \frac{\lambda\eta}{\lambda-1}\left(\frac{E_{t-1} S_{12t}^{1-n} C_{1t}}{E_{t-1} C_{1t}^{1-\rho}}\right)^n \left(\frac{E_{t-1} S_{12t}^{-n} C_{1t}}{E_{t-1} C_{1t}^{1-\rho}}\right)^{1-n}$$

Taking logs, we obtain:

(H.3) $$E_{t-1} c_{1t} = -\frac{1}{\rho}\ln\left(\frac{\lambda\eta}{\lambda-1}\right) + \frac{\rho-2}{2}\sigma_{c_1}^2 - \frac{n(1-n)}{2\rho}\sigma_{s_{12}}^2$$

Turning to European consumption, (2.7) remains valid and we write:

(H.4) $$E_{t-1} c_{2t} = -\frac{1}{\rho}\ln\left(\frac{\lambda\eta}{\lambda-1}\right) + \frac{\rho-2}{2}\sigma_{c_2}^2 - \frac{n(1-n)}{2\rho}\sigma_{s_{12}}^2$$

From (H.2)-(H.3)-(H.4), we see that expected consumption is the same in the US and Europe. This implies that the law of one price holds, as the US dollar price set by a US firm is the same for domestic sales and exports. We can show that expected employment is the same in both regions and is given by (2.9). Table 5 presents the values of expected consumption, employment, and 'power' consumption under the alternative setup.