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Journal of Monetary Economics 51 (2004) 691–712

Journal of MONETARY ECONOMICS

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Endogenous pricing to market and financing costs ☆

Joshua Aizenman[a,b,*]

[a] *Department of Economics, University of California, Santa Cruz, Santa Cruz, CA 95064, USA*
[b] *NBER, Cambridge, MA 02138, USA*

Received 20 August 2001; received in revised form 30 May 2003; accepted 12 August 2003

Abstract

This paper explains why relative PPP should hold more tightly in emerging markets, and why pricing to market would be observed more frequently in the OECD countries. It studies the endogenous determination of pricing to market, in a real option model with time-dependent transportation costs, where the future terms of trade are random. Allowing time-dependent transportation costs adds a dimension of investment to the pre-buying of imports, implying that financial considerations determine the frequency of pricing to market, and the deviations from relative PPP. If the expected discounted cost of last minute delivery is higher than pre-buying, one exercises the option of spot market imports if the realized terms of trade are favorable enough. Pricing to market is observed in countries characterized by low terms of trade volatility and low financing costs. In these circumstances, imports are pre-bought, and the spot market for imports is inactive. In countries where the financing costs and the terms of trade volatility are high, few imports are pre-bought, the price of imports is determined by the realized real exchange rate, and a version of relative PPP holds. With an intermediate level of terms of trade volatility and of financing costs, a mixed regime is observed. If the realized real exchange rate is weak, pricing to market would prevail, increasing consumers' welfare by shielding them from the adverse purchasing power consequences of weak terms of trade. If the realized real exchange rate is favorable enough, more imports are purchased in the spot market, and the relative PPP would hold. Higher financing costs increase the cost of pre-

☆ Useful comments by George Akerlof, Andrew Bernard, Sebastian Edwards, Dan Friedman, Mauri Obstfeld, Nancy Marion, David Romer, Carlos Vegh and the participants in seminars at Berkeley, Dartmouth, UCLA, UCSC and the University of Washington are gratefully acknowledged. I am also indebted to an anonymous referee for insightful comments dealing with the empirical implications of the model. Any errors are mine.

*Corresponding author. Department of Economics and the NBER, University of California, Santa Cruz, Social Science 1, 1156 High Street, Santa Cruz, CA 95064; USA. Tel.: +1-831-459-4791; fax: +1-831-459-5900.

E-mail address: jaizen@ucsc.edu (J. Aizenman).

0304-3932/$ - see front matter
doi:10.1016/j.jmoneco.2003.08.013

buying imports, reducing thereby the frequency of pricing to market, increasing the expected relative price of imports, reducing the expected deviations from relative PPP, and reducing welfare.

JEL classification: F15; F36; F41

Keywords: Pricing to market; Trade credits; Time-dependent transportation costs; Volatility; Relative PPP

1. Introduction and summary

The puzzling lack of a tighter association between goods' prices and the exchange rate is one of the intriguing observations in International Economics. Following Krugman (1987), pricing in domestic currency and pricing to market (PTM) have provided an interpretation to this puzzle.[1] A direct implication of the PTM hypothesis is the low pass-through from the exchange rate to prices, and the resultant failure of the relative PPP to hold in the short and intermediate-runs. While the empirical literature confirmed these predictions, it also detected a systematic heterogeneity of the patterns of PTM across various goods.[2] Recent studies also find that the relative PPP holds better in emerging markets.[3] An important unresolved question concerns the conditions under which PTM is endogenously chosen by the producers, and when should we expect the relative PPP to hold more tightly. Addressing these questions is crucial for a better understanding of issues like the welfare implications of exchange rate volatility, the incidence of protective policies, and the welfare ranking of fixed versus flexible exchange rate regimes.

The purpose of this paper is to provide a framework where the degree of pricing to market is endogenously determined, as part of the problem of balancing the benefits of pre-set prices with the costs of managing the delivery system needed to support rigid prices. This paper is motivated by the inherent trade-off between price and quantity adjustments, where pricing in local currency requires that quantities should be plentiful to fulfill the demand at the pre-set price. Hence, pricing in local currency and pricing to market may involve complex issues of delivery management. In such a system, the degree of local currency pricing is impacted by the financial costs of

[1] See Obstfeld and Rogoff (1996, Chapters 9, 10) for an overview of the low association between goods' prices and the exchange rate, and Obstfeld and Rogoff (2000) for a recent overview of puzzles in International Economics (including the pricing puzzle), highlighting the relevance of transportation costs. See Goldberg and Knetter (1997) for a comprehensive review of the empirical literature that followed Krugman's study.

[2] See Isard (1977), Wei and Parsley (1996) and Engel (1999) for empirical studies of (deviations from) the law of one price. See Marston (1990) and Knetter (1993) for studies of pricing to market, and Rogoff (1996) for an overview of the PPP puzzle.

[3] See Hausmann et al. (1999). Calvo and Reinhart (2000) find that the average pass through from exchange rate changes to prices is about four times as large for emerging markets as for developed countries. Cheung and Lai (2000) report that the persistence in PPP deviations is lower for developing countries.

timely delivery of goods, as well as by the transportation costs associated with timely re-supply of inventories.[4]

The paper departs from the previous pricing to market literature by allowing time-dependent transportation costs.[5] The presumption is that the cost of delivering a good ordered ahead of time is lower than the cost of a last minute delivery, as pre-buying would allow to find the cheapest means of transportation, even if it would require more time to deliver [see Carlton (1979) for a pioneering analysis on costly delivery lags].[6] We model the implications of time-dependent transportation costs on the pricing and the delivery of imports in a 2 period, 2 goods model, where the second period terms of trade are random. Allowing time-dependent transportation costs adds a dimension of investment to the pre-buying of imports. With uncertain future terms of trade, spot market imports resembles an option—one exercises the option of last minute imports if the realized terms of trade are favorable enough.

The above suggests a simple way of modeling endogenously the switch from pricing to market to a flexible price environment. Assuming that the expected discounted cost of last minute delivery is higher than pre-buying, it follows that in countries where the terms of trade volatility is small, most imports are pre-bought, and the spot market for imports is inactive. In these circumstances the prices of importables are delinked from the realized terms of trade, as is the case in the pricing to market (PTM) regime. Greater volatility induces more frequent realizations of relatively high and low values of the real exchange rate. For terms of trade volatility high enough, it would make sense to scale down the pre-buying, in order to exploit the "good tail" of the real exchange rate distribution, where spot market imports are cheaper. In these circumstances, we will observe a mixed regime—if the realized real exchange rate is favorable enough, imports are purchased in the spot market, the price of imports is determined by the realized real exchange rate, and a version of relative PPP holds. Otherwise, the pricing to market will prevail. As is the case with options, the value of the option of spot market imports increases with the volatility, implying that the frequency of pricing to market tends to be lower in more volatile economies.[7]

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[4] These issues were sidestepped by most of the literature by assuming instant delivery of traded goods.

[5] See Hummels (2000) for a careful assessment of the patterns of transportation costs. Hummels finds that Ocean freight rates have increased while air freight rates have declined rapidly. The share of US imports going by airfreight rose from zero to 30% between 1950 and 1998. The estimated cost of an extra days travel is around 0.3% of the value of shipped (0.5% for the manufacturing sector). These findings suggest that for a growing number of goods, alternative means of delivery offer a trade off between the speed and the cost of delivery.

[6] An example of these considerations is the pricing of heating oil to consumers, where the "pre-buy protection plan" allows consumers to purchase forward the desired amount of heating oil at a pre-set price that is expected to be lower than the future spot market price for last minute delivery. Each spring customers in New England are advised—"Before the weather turns colder, protect and insulate your wallet from the inevitable rising costs of home heating oil. This program (the pre-buy) allows you to lock into fuel oil prices while they are low, and pay that one low fixed price for your entire year's usage, no matter how high the prices may soar."

[7] Our model is an application of the real option framework. See Dixit and Pindyck (1994) for a comprehensive overview of real options and investment.

Another implication of time-dependent transportation costs is that financial considerations determine the frequency of pricing to market, and the deviations from relative PPP. Specifically, higher financing costs would increase the cost of pre-buying, encouraging spot market imports, reducing the frequency of pricing to market, increasing the tendency of relative PPP to hold, and increasing the expected price of imports. The net effect is welfare reducing as the PTM shields consumers from the adverse purchasing power effects of weak terms of trade. This result is of special relevance for emerging markets, where limited financial depth and costly credit encourage spot market trade, and discourage pre-buying. It suggests two channels explaining why relative PPP may hold better for emerging markets—first the volatility, and second the financing costs. Both imply less frequent pricing to markets, and greater association between the exchange rate, the prices of imports, and the volume of trade. While the two channels reinforce each other in reducing the incidence of PTM, they have different welfare implications. Our discussion shows that, for a given real interest rate, higher terms of trade volatility tend to increase welfare. Higher financing costs are always welfare reducing, and are associated with lower imports.[8]

The implications of pricing to market on the desirable exchange rate flexibility have been studied by comparing the behavior of the nominal exchange rate and prices in regimes with polar pricing rules for imports. In the first, import prices are set in producer's currency, as has been the traditional assumption in the Mundell–Fleming open economy macro models. In the second system, import prices are set in consumer's currency, in line with the pricing to market literature.[9] These studies pointed out that the welfare ranking of fix versus flexible exchange rate regimes and the dynamics of output and consumption hinge on the pricing rule. For example, Devereux and Engel (1998) report that "When prices are set in producer's currency, as in the traditional framework, we find that there is a trade-off between floating and fixed exchange rates. Exchange rate adjustment under floating rates allows for a lower variance of consumption, but exchange rate volatility itself leads to a lower average level of consumption. When prices are set in consumer's currency, floating exchange rates always dominate fixed exchange rates." Our findings imply that the pre-setting prices in consumer's currency would not characterize emerging markets, and would be observed more frequently in the OECD countries. This finding, combined with the Devereux and Engel (1998) results, may provide another explanation for the "fear to float" by emerging market economies.

Section 2 describes the model, and characterizes the impact of a higher discount rate and higher terms of trade volatility for the case of linear inter-temporal preferences. Section 3 investigates the welfare consequences of higher financing costs. Section 4 concludes. The appendix extends the model to risk averse agents.

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[8] These effects are potentially large, and provide an interpretation for the potential use of cutting trade credit as a means of inducing borrowers to service their debt.

[9] See Devereux and Engel (1998) and Betts and Devereux (2000).

2. The model

Assume a small economy producing a domestic traded good, and consuming both domestic and foreign goods (denoted by x and y, respectively). Imports are associated with transportation costs that depend on the delivery lag. We focus on the simplest version of the model—a two period endowment model, where the supply of the domestic good in period i is $\bar{x}_i (i = 1, 2)$. The domestic and the foreign markets are geographically separated. Imports of the foreign goods are subject to time-dependent transportation costs, assumed to be higher for last minute delivery.[10] Consider the case where the consumer's utility H is the discounted value of temporal utilities $v_i (i = 1, 2)$[11]

$$H = v_1 + \frac{v_2}{1+\rho} \quad \text{where } v_i = \begin{cases} v_1 = x_1 & \text{for } i = 1 \\ v_2 = x_2 + \dfrac{\theta}{\beta}[Y_2]^{\beta} & \text{for } i = 2 \end{cases}, \quad 0<\beta<1, \ 0<\theta. \tag{1}$$

For simplicity of presentation, we assume that imports are consumed only in the second period. We normalize the first period prices of the domestic good to 1. Consumers can pre-buy imports in the first period for a scheduled delivery in the second period. The "pre-buying" price of y_2 is $1 + t$ units of x_1 (t stands for the transportation costs, where the implicit cost of y_2, net of transportation and financing, is normalized to 1). Consumers may postpone buying y to the second period, relying on the spot market. The spot market price of y_2 is random

$$(1 + \tilde{t})(1 + \delta), \tag{2}$$

where $\tilde{t}$ is the transportation cost for spot "last minute" deliveries, and δ is a random shock determining the second period international relative price of the imported good. We denote by $f(\delta)$ the corresponding p.d.f. of the "external terms of trade," defined in the interval $\underset{\sim}{\delta} \leqslant \delta \leqslant \bar{\delta}$, where $-1 < \underset{\sim}{\delta}$. The time line and the possible trade patterns are summarized in Fig. 1.

We denote by y_2^p the pre-buying of imports contracted for second period delivery, and by y_2^s the spot market imports. The opportunity costs of imports y_2^p; y_2^s in terms of exports sold in period 1 and 2 are denoted by x_1^p; x_2^s, respectively, where

$$\begin{aligned} x_1^p &= y_2^p (1 + t), \\ x_2^s &= y_2^s (1 + \tilde{t})(1 + \delta). \end{aligned} \tag{3}$$

[10] Pre-buying may be cheaper also if production costs are lower when producers have more lead time [see Carlton (1979) for further discussion of this possibility]. The logic of our analysis applies also to the case where production costs are time-dependent. See Aizenman (1984) for an analysis of deviations from PPP due to costly arbitrage [due to lump sum and time-independent transportation costs] in a one good world.

[11] With utility (1) the demand for imports is likely to be independent from income, simplifying the analytical discussion. It can be shown that the main results of the paper are applicable to other utilities, though the analytical discussion is more involved.

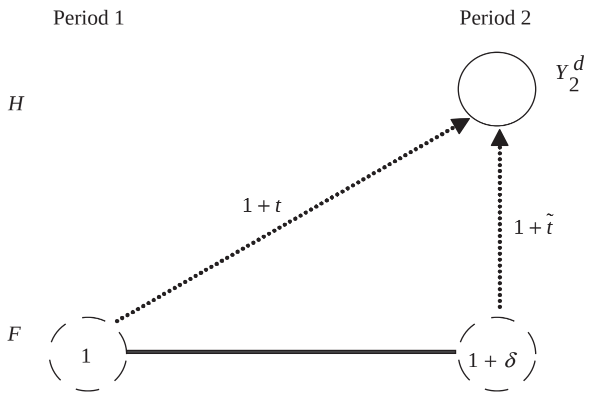


Fig. 1. Pre-buying and last minute transpiration costs. The lower row corresponds to the foreign country (denoted by F), the upper row to the home country (denoted by H). The numbers in the lower circles are the cost of purchasing the foreign good in the foreign country in period 1 and 2, measured in terms of good x. The second period demand for the foreign good is $y_2^{\rm d}$. The numbers attached to the arrows are one plus the Ad Valorem transportation cost. The diagonal arrow corresponds to the slower delivery of pre-bought imports, which is assumed to take one period (e.g., ocean shipment). The vertical arrow corresponds to the fast delivery (e.g., air shipment).

The consumption of x and y are characterized by

$$x_1 = \bar{x}_1 - x_1^{\rm p} - s,$$
$$x_2 = \bar{x}_2 + s(1 + r^*) - x_2^{\rm s}, \quad y_2 = \frac{x_1^{\rm p}}{1+t} + \frac{x_2^{\rm s}}{(1+\tilde{t})(1+\delta)}, \tag{4}$$

where s is the first period saving, yielding a real interest rate r^* (defined in terms of the domestic good). To avoid a corner solution stemming from the linearity of the intertemporal utility we assume first that $\rho = r^*$. The drawback of using the linear intertemporal utility is that it does not allow us to investigate fully the effects of changing the financing cost on the optimal patterns of pre-buying. We will address these issues in the appendix, where we illustrate how to extend the analysis to allow for risk averse consumers.[12] The consumer problem is to determine the optimal pair $\langle x_2^{\rm s}; x_1^{\rm p} \rangle$. We solve it backwards—first we find the optimal spot market trade in the second period. Next, applying this solution we construct the expected utility in the first period. Finally, we find the pre-buying that maximizes this expected utility.

The consumer determines the second period consumption plan by finding the spot market imports that would maximize

$$\underset{x_2^{\rm s},}{\rm MAX}\left[\bar{x}_2 + (1+r^*)s - x_2^{\rm s} + \frac{\theta}{\beta}\left[\frac{x_2^{\rm s}}{(1+\tilde{t})(1+\delta)} + \frac{x_1^{\rm p}}{1+t}\right]^{\beta}\right] \quad \text{S.T.} \quad x_2^{\rm s} \geqslant 0. \tag{5}$$

[12] Note that our consumer is risk neutral in the sense that the marginal utility of consuming the numeraire good x is constant. Diminishing marginal utility applies, however, to the imported good, y. Hence, ceteris paribus, the consumer would prefer less volatile consumption of y.

The solution of which implies that the consumer will buy y_2 in the spot market only if the realized terms of trade are favorable enough, $\delta < \delta^*$, where

$$\delta^* = \left(\frac{1+t}{x_1^{\mathrm{p}}}\right)^{1-\beta} \frac{\theta}{1+\tilde{t}} - 1 \tag{6}$$

and the optimal second period spot market exports (used to finance spot market imports) are

$$x_2^{\mathrm{s}} = \begin{cases} \left[\left(\dfrac{\theta}{(1+\tilde{t})(1+\delta)}\right)^{1/(1-\beta)} - \dfrac{x_1^{\mathrm{p}}}{1+t}\right] & \\ \times(1+\tilde{t})(1+\delta) & \text{if} \quad \delta < \delta^*, \\ 0 & \text{if} \quad \delta \geqslant \delta^*. \end{cases} \tag{7}$$

The resultant second period utility is

$$v_2 = \begin{cases} \tilde{v}_2(\delta) = \bar{x}_2 + s(1+r^*) + \dfrac{x_1^{\mathrm{p}}(1+\tilde{t})(1+\delta)}{1+t} & \\ \qquad + \left(\dfrac{1}{\beta} - 1\right)\left(\dfrac{\theta^{1/\beta}}{(1+\tilde{t})(1+\delta)}\right)^{\beta/(1-\beta)} & \text{if} \quad \delta < \delta^*, \\ \tilde{v}_2(\delta^*) = \bar{x}_2 + s(1+r^*) + \dfrac{\theta}{\beta}\left[\dfrac{x_1^{\mathrm{p}}}{1+t}\right]^{\beta} & \text{if} \quad \delta \geqslant \delta^*. \end{cases} \tag{8}$$

It is easy to confirm that for $\delta^* > \delta$, $\tilde{v}_2(\delta^*) < \tilde{v}_2(\delta)$. The first period utility is

$$v_1 = \bar{x}_1 - s - x_1^{\mathrm{p}}. \tag{9}$$

The consumer's expected utility is

$$\mathrm{E}(U) = v_1 + \frac{1}{1+\rho}\left[\tilde{v}_2(\delta^*) + \int_{\underline{\delta}}^{\delta^*} \{\tilde{v}_2(\delta) - \tilde{v}_2(\delta^*)\} f(\delta)\,\mathrm{d}\delta\right]. \tag{10}$$

Eq. (10) implies that the consumer will exercise the option of spot market imports in the second period only if the terms of trade were favorable enough—if $\delta^* > \delta$. Otherwise (when $\delta^* \leqslant \delta$), the second period supply of imports is determined by the pre-buying of y. In these circumstances the prices of imports are delinked from the realized terms of trade, as is the case in the pricing to market (PTM) regime.

Eqs. (6)–(7) indicate that the choice of the optimal pre-buying determines also the range where PTM applies, occurring with probability $F(\delta^*) = \int_{\delta^*}^{\bar{\delta}} f(\delta)\,\mathrm{d}\delta$. It implies that increasing the pre-buying of imports reduces the range where the option of spot market imports would be exercised, increasing the frequency of PTM. This suggests that the optimal pre-buying of imports tends to be lower the greater the value of the flexibility associated with the option of using the spot market is, as will be when the terms of trade volatility go up. Pre-buying implies also implicit saving, hence the opportunity cost of pre-buying increases with the discount rate. This suggests that a higher discount rate would reduce the pre-buying, thereby increasing the range where the option of imports via the spot market is exercised.

We verify these claims by studying the first-order condition determining the optimal pre-buying, obtained by solving $\mathrm{Max}_{x_1^{\mathrm{p}}}\,[\mathrm{E}(U)]$,

$$-1+\frac{1}{1+\rho}\left[\int_{\underline{\delta}}^{\delta^*}\frac{\partial\tilde{v}_2(\delta)}{\partial x_1^{\mathrm{p}}}f(\delta)\,\mathrm{d}\delta+\int_{\delta^*}^{\bar{\delta}}\frac{\partial\tilde{v}_2(\delta^*)}{\partial x_1^{\mathrm{p}}}f(\delta)\,\mathrm{d}\delta\right]=0. \tag{11}$$

Applying (6), (8) and (11) we infer that

$$-1+\frac{1}{1+\rho}\left[\int_{\underline{\delta}}^{\delta^*}\frac{(1+\tilde{t})(1+\delta)}{1+t}f(\delta)\,\mathrm{d}\delta+\int_{\delta^*}^{\bar{\delta}}\frac{\theta}{1+t}\left[\frac{x_1^{\mathrm{p}}}{1+t}\right]^{\beta-1}f(\delta)\,\mathrm{d}\delta\right]=0. \tag{12}$$

The expected net gain from pre-buying is the discounted expected marginal utility induced by pre-buying minus the opportunity cost of pre-buying. Optimality requires this gain to be zero at the margin. Applying (6) to (12), we can rewrite the first-order condition as

$$-1+c\left[\int_{\underline{\delta}}^{\delta^*}(1+\delta)f(\delta)\,\mathrm{d}\delta+\int_{\delta^*}^{\bar{\delta}}(1+\delta^*)f(\delta)\,\mathrm{d}\delta\right]=0$$

$$\text{where } c=\frac{1+\tilde{t}}{(1+\rho)(1+t)}. \tag{12$'$}$$

The term c is the expected relative intertemporal cost of the spot market to pre-buying imports. Henceforth, we will assume that $c>1$, as will be the case if last minute delivery is relatively costly. The equilibrium relative price in the second period is determined by the ratio of the marginal utilities of the two goods

$$\frac{p_{y,2}}{p_{x,2}}=\frac{\mathrm{d}v_2/\mathrm{d}y_2}{\mathrm{d}v_2/\mathrm{d}x_2}=\theta[y_2]^{\beta-1}. \tag{13}$$

Applying (5)–(7) it follows that

$$\frac{p_{y,2}}{p_{x,2}}=(1+\tilde{t})\min[1+\delta^*;1+\delta]=\begin{cases}(1+\tilde{t})(1+\delta) & \text{if} \quad \delta<\delta^*,\\ (1+\tilde{t})(1+\delta^*) & \text{if} \quad \delta\geqslant\delta^*.\end{cases} \tag{14}$$

Hence, if the realized terms of trade are favorable enough ($\delta<\delta^*$), the spot market for imports is active. In these circumstances, the price of imports is determined by the realized real exchange rate, $(1+\tilde{t})(1+\delta)$, and the relative PPP holds (adjusted for transportation costs). We refer to this regime as the flexible price regime, and denote it by FL. If the realized terms of trade are weak ($\delta>\delta^*$), no spot market trade will take place, and the PTM regime will prevail,

$$\left.\frac{p_{y,2}}{p_{x,2}}\right|_{\mathrm{PTM}}=(1+\tilde{t})(1+\delta^*)=\theta(y_2^{\mathrm{p}})^{\beta-1}. \tag{15}$$

Hence, optimal pre-buying of imports shields the consumer from the "bad tail" of the terms of trade distribution. Applying (14), the expected pass-through between the real exchange rate and the domestic price of importables is

$$\int_{\underline{\delta}}^{\bar{\delta}}\frac{\mathrm{d}[p_{y,2}/p_{x,2}]}{\mathrm{d}\delta}f(\delta)\,\mathrm{d}\delta=(1+\tilde{t})(1-F). \tag{16}$$

Hence, explaining the factors determining the probability of pricing to market would account also for the association between the real exchange rate and imports prices.

Applying (12′) and (14) we infer a simple interpretation of the first-order condition corresponding to optimal trade. With optimal pre-buying, the discounted expected relative price of imports in the second period equals the first period cost of pre-buying

$$\int_{\underline{\delta}}^{\bar{\delta}} \frac{p_{y,2}}{p_{x,2}} f(\delta)\,\mathrm{d}\delta = (1+t)(1+\rho). \tag{17}$$

Further insight can be gained with the help of Fig. 2. Curve ABC is the demand for imports *in the absence* of pre-buying, as a function of the realized terms of trade [i.e., the relative price of imports purchased in the spot market, $(1+\tilde{t})(1+\delta)$]. Curve A′B′C′ traces the realized terms of trade as a function of the terms of trade shock. Imports pre-buying of Y_2^{p}, corresponding to δ^*, would shield the consumer from the "bad tail" of terms of trade realizations, truncating the effective demand to DBC. If the realized spot market price of imports is above $(1+\tilde{t})(1+\delta^*)$, pricing to market would prevail, at the level corresponding to point D. If the realized spot price is below $(1+\tilde{t})(1+\delta^*)$, like at point E, the spot market will be active. Spot market imports would increase the available supply by Y_2^{s}, so that the demand for imports at the spot price E would be met. The effect of pre-buying is to truncate the price distribution to curve D′B′C′. Eq. (17) implies that the optimal level of pre-buying is determined by the "brake-even" condition: the expected price along the truncated price distribution should cover the cost of pre-buying. Hence, the pricing to market level exceeds the cost of pre-buying, $(1+t)(1+\rho)$, by a premium. This premium, on average, covers the losses induced in states of nature where the realized terms of trade are below the pre-buying costs.

Proposition 1 summarizes the resulting pricing system.

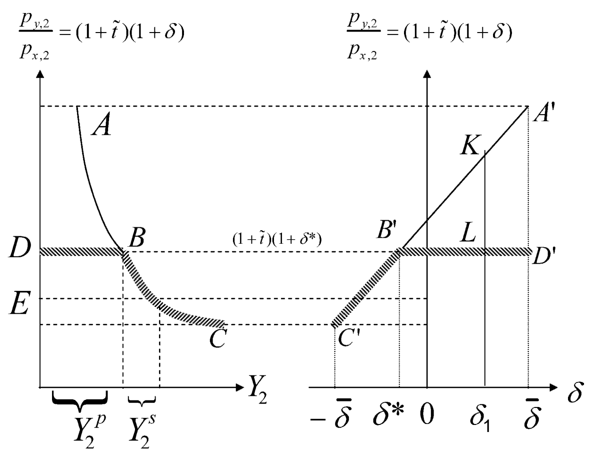


Fig. 2. (A)—imports demand, (B)—terms of trade shocks.

Proposition 1. a. *Higher discount rate, higher pre-buying transportation cost, and lower transportation cost of imports purchased in the spot market reduce the first period pre-buying. This in turn implies that the frequency of PTM drops and the frequency of flexible prices (FL regime) increase.*

b. *Low volatility economies are characterized by PTM. Spot market imports would be observed if the volatility of the terms of trade exceeds a threshold. Above that threshold, higher volatility will reduce the frequency of PTM, increasing spot market imports.*[13]

Proof. Proposition 1a follows from (12′), observing that a lower c would reduce the valuation of the expected gain from pre-buying, reducing the optimal pre-buying of imports (recall that $c = (1+\tilde{t})/(1+\rho)(1+t))$. Note that the definition of F, (12′) and (6) imply that $\mathrm{sgn}(\mathrm{d}F/\mathrm{d}c) = -\mathrm{sgn}(\mathrm{d}\delta^*/\mathrm{d}c)$; $\mathrm{d}x_1^{\mathrm{p}}/\mathrm{d}\delta^* < 0$. We denote the LHS of (12′) by L

$$L = -1 + c\left[\int_{\underline{\delta}}^{\delta^*} (1+\delta)f(\delta)\,\mathrm{d}\delta + \int_{\delta^*}^{\bar{\delta}} (1+\delta^*)f(\delta)\,\mathrm{d}\delta\right].$$

The first-order condition determining δ^* is $L = 0$. Hence $\mathrm{d}\delta^*/\mathrm{d}c = -(\partial L/\partial c)(\partial L/\partial \delta^*)$. Note that $\partial L/\partial \delta^* = F > 0$, consequently, $\mathrm{sgn}[\mathrm{d}F/\mathrm{d}c] = \mathrm{sgn}[\partial L/\partial c] = \mathrm{sgn}[1/c] > 0$, and $\mathrm{d}\delta^*/\mathrm{d}c < 0$.

Applying the last result to (6) imply $\mathrm{d}x_1^{\mathrm{p}}/\mathrm{d}c > 0$.

The intuition for result 1b is that in the absence of any volatility, $c > 1$ implies that pre-buying is cheaper, hence the PTM regime will prevail. Greater volatility induces more frequent realizations of relatively high and low real exchange rates. For volatility high enough, it would make sense to scale down the pre-buying, in order to exploit the "good tail" of the real exchange distribution, where spot market imports are cheaper.

We illustrate the impact of higher volatility by considering a uniform distribution of the terms of trade shock, where $-\underline{\delta} = \bar{\delta}$.[14] In these circumstances the first order condition determining the frequency of PTM, (12′), can be reduced to[15]

$$F = \min\left[1, \sqrt{\frac{c-1}{c\bar{\delta}}}\right]. \tag{18}$$

This condition implies that the spot market imports will be exercised (and hence $F < 1$) only if the volatility is high enough, so that $\bar{\delta} > (c-1)/c \cong \tilde{t} - (t+\rho)$.

[13] A relevant concern is Jensen's inequality—how would our results be affected if the increase in volatility preserves the mean of $1/(1+\delta)$, instead of preserving the mean of $1+\delta$. It can be verified that the key results of the paper hold for both cases.

[14] Similar results apply if the terms of trade follow a truncated normal distribution, or if the log of the terms of trade follows the normal distribution.

[15] Note that for a uniform distribution, $f(\delta) = 1/2\bar{\delta}$; $F = (\bar{\delta} - \delta^*)/2\bar{\delta}$, and Eq. (12′) has form $1 = [0.5\{(1+\delta^*)^2 - (1-\bar{\delta})^2\} + (1+\delta^*)(\bar{\delta} - \delta^*)]c/2\bar{\delta}$. Collecting terms, the last equation is equivalent to $1 = [4\bar{\delta} - (\bar{\delta} - \delta^*)^2]c/(4\bar{\delta})$. This in turn is equivalent to $1 = [1 - (F)^2\bar{\delta}]c$, the solution of which provides Eq. (18).

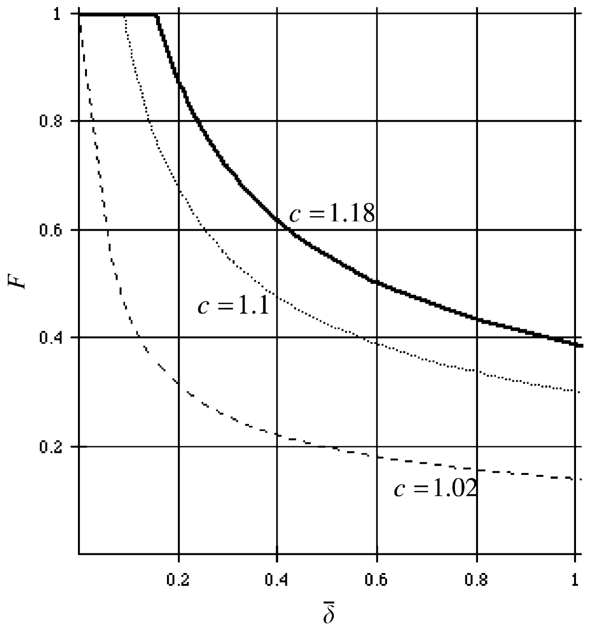


Fig. 3. Volatility and PTM incidence. The figure traces the dependency of F (the probability of PTM) on the volatility, for a uniform distribution, where $f(\delta) = 1/(2\bar{\delta})$, and $c = 1.02, 1.1, 1.18$.

Applying (18) we infer that

$$\frac{dF}{d\bar{\delta}} < 0. \tag{19}$$

Fig. 3 depicts the dependency of the frequency of PTM on the terms of trade volatility, for different levels of c. Above the threshold $(c-1)/c$, a higher term of trade volatility reduces the frequency of the PTM regime. Lower c shifts the curve leftwards and downwards.[16]

We turn now to assess the expected deviations from PPP, adjusted for transportation costs. The actual relative price of imports is provided by (14). The spot market relative price of imports is $p_{y,2}/p_{x,2}|_{\text{spot}} = (1+\tilde{t})(1+\delta)$. A measure of the deviation from the relative PPP is the percentage gap between the relative price

[16] These results are a direct application of options pricing logic. Note that the second period income associated with pre-importing the good is $\min[(1+\tilde{t})(1+\delta), (1+\tilde{t})(1+\delta^*] = (1+\tilde{t})(1+\delta) - \max[(1+\tilde{t})(1+\delta) - (1+\tilde{t})(1+\delta^*), 0]$. The importing dealer's expected gross income is equivalent to the income of an agent importing via the spot market $[(1+\tilde{t})(1+\delta)]$, who sells a call option on that income stream, $(-\max[(1+\tilde{t})(1+\delta) - (1+\tilde{t})(1+\delta^*), 0])$. With equilibrium pre-buying, the dealer's expected gross income equals the cost, $(1+t)(1+\rho)$. Higher terms of trade volatility increases the expected value of the call option and reduces the dealer expected income, reducing thereby pre-imports and incidence of pricing to market.

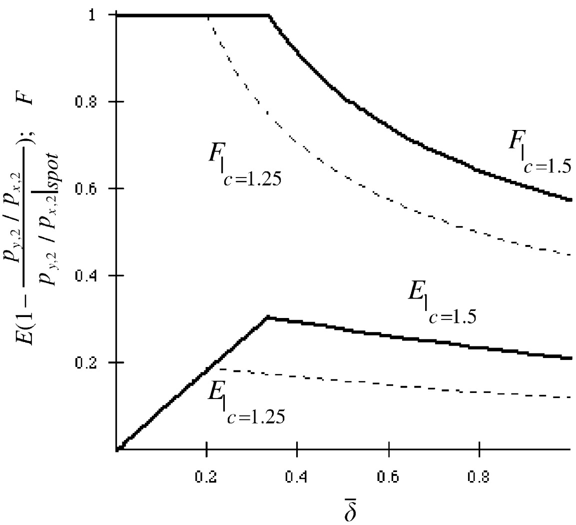


Fig. 4. The expected deviations from PPP, the probability of PTM, and terms of trade volatility. Curves F and E report the probability of PTM and the expected deviations from PPP, respectively. The bold curves correspond to $c = 1.5$. The dashed curves correspond to $c = 1.25$.

for spot market imports and the relative price observed in the domestic market,

$$1 - \frac{p_{y,2}/p_{x,2}}{p_{y,2}/p_{x,2}|_{\text{spot}}}. \tag{20}$$

Applying (14), if follows that

$$\mathrm{E}\left(1 - \frac{p_{y,2}/p_{x,2}}{p_{y,2}/p_{x,2}|_{\text{spot}}}\right) = \int_{\delta^*}^{\bar{\delta}} \frac{\delta - \delta^*}{1 + \delta} f(\delta)\, \mathrm{d}\delta > 0. \tag{21}$$

Hence, the expected deviations from PPP is proportional to the expected gap between the spot market relative price of imports and the PTM relative price, evaluated along the "bad tail" of the terms of trade distribution. In terms of Fig. 2B, for realized terms of trade $\delta_1; \delta_1 > \delta^*$, the deviation from PPP is the vertical distance KL. Fig. 4 reports the expected deviations from PPP and the probability of pricing to market as a function of terms of trade volatility, for the case of a uniform distribution, where $f(\delta) = 1/(2\bar{\delta})$. Note that the association is non-linear.

3. Financing costs, volatility and welfare

The empirical literature suggests that import prices are more responsive to the exchange rate in emerging markets. Our discussion in the previous section suggests two independent channels explaining this finding—volatility and financing costs. The purpose of this section is to investigate the welfare cost of these channels, and to identify which of the two has a greater impact on the overall welfare of a country.

One way to address these issues with linear, risk neutral preferences is to assume that the interest rate exceeds the discount factor, and all pre-buying is financed by credit, as would be the case if $\bar{x}_1 = 0$, and $r^* > \rho$. This is a special example of the model studied in Section 1, corresponding to $s = -x_1^{\mathrm{p}};\quad v_1 = 0$. The first-order condition determining the optimal level of pre-buying in these circumstances is[17]

$$-1 + c^* \left[\int_{\underline{\delta}}^{\delta^*} (1+\delta) f(\delta)\, \mathrm{d}\delta + \int_{\delta^*}^{\bar{\delta}} (1+\delta^*) f(\delta)\, \mathrm{d}\delta \right] = 0, \tag{22}$$

where

$$c^* = \frac{1+\tilde{t}}{(1+r^*)(1+t)}. \tag{23}$$

We assume that the interest rate and the terms of trade volatility are not too high, resulting in an internal equilibrium where some pre-buying takes place, and $0 < F < 1$. Proposition 2 summarizes the resulting pricing system.

Proposition 2. (a) *Higher financing costs increase the expected price of imports, reducing the expected deviations from relative PPP, and reducing welfare.*

(b) *For a given real interest rate, higher terms of trade volatility increases welfare.*

Proof. (a) Recalling that optimal pre-buying is determined by $\partial \mathrm{E}(U)/\partial x_1^{\mathrm{p}} = 0$, the envelope theorem implies that the welfare effect of the higher interest rate is

$$\frac{\mathrm{dE}(U)}{\mathrm{d}r^*} = \frac{\partial \mathrm{E}(U)}{\partial r^*} + \frac{\partial \mathrm{E}(U) \mathrm{d}x_1^{\mathrm{p}}}{\partial x_1^{\mathrm{p}}\ \mathrm{d}r^*} = -\frac{x_1^{\mathrm{p}}}{1+\rho}. \tag{24}$$

Recalling (14) and (20), the expected relative price of imports is

$$\begin{aligned} \mathrm{E}\left(\frac{p_{y,2}}{p_{x,2}}\right) &= (1+\tilde{t}) \left[\int_{\underline{\delta}}^{\delta^*} (1+\delta) f(\delta)\, \mathrm{d}\delta + \int_{\delta^*}^{\bar{\delta}} (1+\delta^*) f(\delta)\, \mathrm{d}\delta \right] \\ &= (1+r^*)(1+t). \end{aligned} \tag{25}$$

Consequently, we infer that

$$\frac{\partial \mathrm{E}\left(\dfrac{p_{y,2}}{p_{x,2}}\right)}{\partial r^*} = 1 + t > 0. \tag{26}$$

Hence, higher financing costs increase the expected relative price of imports by the transportation cost of spot market imports.

[17] This condition is obtained from (10), noting that with $r^* > \rho,\ v_1 = 0$, and

$$\tilde{v}_2(\delta^*) = \bar{x}_2 - x_1^{\mathrm{p}}(1+r^*) + \frac{\theta}{\beta}\left[\frac{x_1^{\mathrm{p}}}{1+t}\right]^{\beta},$$

$$\tilde{v}_2(\delta) = \bar{x}_2 - x_1^{\mathrm{p}}(1+r^*) + \frac{x_1^{\mathrm{p}}(1+\tilde{t})(1+\delta)}{1+t} + \left(\frac{1}{\beta} - 1\right)\theta^{1/(1-\beta)}\left(\frac{1}{(1+\tilde{t})(1+\delta)}\right)^{\beta/(1-\beta)}.$$

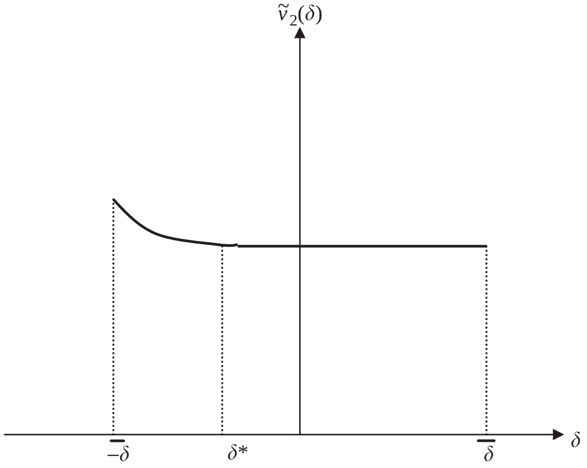


Fig. 5. Volatility and welfare.

We turn now to assess the impact of higher interest rate on the expected deviations from PPP, adjusted for transportation costs. Applying (21) and (22), it follows that higher financing costs imply that

$$\frac{\partial}{\partial r^*}\left[\mathrm{E}\left(1-\frac{p_{y,2}/p_{x,2}}{p_{y,2}/p_{x,2}|_{\mathrm{spot}}}\right)\right] = -\int_{\delta^*}^{\bar{\delta}} \frac{1}{1+\delta} f(\delta)\,\mathrm{d}\delta \frac{\partial \delta^*}{\partial r^*} < 0. \tag{27}$$

Recalling that higher financing costs reduce the pre-buying ($\partial\delta^*/\partial r^* > 0$), it follows that it also reduces the expected deviations from PPP.

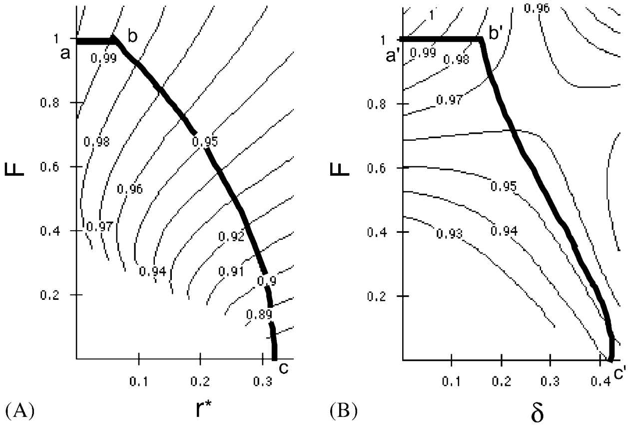
(b) This result follows from the observation that $\tilde{v}_2(\delta)$ is a convex function of δ for $\delta^* > \delta$, and a linear function for $\delta^* < \delta$ [see Fig. 5].[18] Hence, a mean preserving increase in the volatility of terms of trade increases the expected second period utility.

We illustrate the quantitative nature of these results with the help of a simulation. The bold curve in Fig. 6A traces the dependency of the probability of the PTM regime on the interest rate. The contours trace the welfare relative to the benchmark at point a, where $r^* = 0$ and $F = 1$. Note that increasing the interest rate from zero to about 0.3 eliminates the pre-buying, and induces a welfare drop of about 12%. This welfare drop is due to the elimination of gains from the pre-buying—gains attributed to the ability to protect the purchasing power against weak future terms of trade. This welfare drop is associated with a large drop in average imports. Volatility by itself, however, enhances welfare, as is shown in Proposition 2.

[18] Note that

$$[\tilde{v}_2(\delta)]''_\delta = \frac{2-\beta}{1-\beta}\frac{\theta^{1/(1-\beta)}}{(1+\delta)^2}\left(\frac{1}{(1+\tilde{\imath})(1+\delta)}\right)^{\beta/(1-\beta)} > 0$$

for $\delta^* > \delta$, and $[\tilde{v}_2(\delta)]''_\delta = 0$ for $\delta^* < \delta$.



(A) (B)

Fig. 6. Financing costs, volatility and welfare. The figures trace the probability of PTM (F) for a uniform distribution, where $f(\delta) = 1/(2\bar{\delta})$; $\theta = 0.5$; $\beta = 0.5$; $t = 0.1$; $\bar{x}_2 = 1$; $\tilde{t} = 0.4$; $\rho = 0$. The bold line traces the dependency of F on the interest rate (A) and volatility (B), respectively. (A) assumes $\bar{\delta} = 0.2$. (B) assumes that the interest rate increases with volatility, $r = 0.75\bar{\delta}$. The contours trace the welfare relative to the benchmark at point a and a′ in A and B, respectively. (A) Interest rate and PTM, (B) volatility, interest rate and PTM.

While we treated the interest rate and the volatility as independent in Fig. 6A, the two are likely to be positively correlated. First, if the domestic capital market in emerging markets is segmented from the global market, one expects credit to be financed by risk averse agents who would demand a higher interest rate to compensate for the higher volatility. Second, the literature on costly state verification pointed out that volatility tends to be associated with higher financial costs (see Townsend, 1979). Hence, one expects that higher terms of trade volatility will increase the cost of credit. Applying this association, one may trace the combined effects of the volatility and the interest rate channels. In these circumstances, one expects that the net welfare effect of volatility will be negative—the higher cost of credit will terminate PTM, eliminating any welfare gains from higher volatility. We illustrate this in Fig. 6B, which assumes a linear association between terms of trade volatility and financing costs. The bold line outlines the dependency of the probability of the PTM regime on the volatility. The contours trace the welfare, relative to the benchmark at point a', where $F = 1$.

4. Discussion and concluding remarks

We end the paper with a discussion on several empirical implications of the model, and possible extensions and limitations of the paper.

This paper studied the patterns of the pricing to market of consumption goods. One can extend its logic to deal with the pricing and delivery of inputs used as intermediate parts and components. Such an extension should recognize that the limited substitutability of intermediate inputs may limit the use of last minute imports. Relying on spot market shipments of components may be too costly or too risky when one deals with complex production lines in developing countries. Instead, one expects greater reliance on orderly shipments that are planned well ahead of time, and on the active management of inventories. These patterns may be associated with more frequent violations of PPP, as well as higher financial costs. An interesting hypothesis is that countries that have greater ex-ante terms of trade volatility and well functioning airports and custom systems exhibit a higher elasticity of import quantities with respect to price shocks. In contrast, countries where these systems are more costly and inefficient, opt to use larger inventories.[19]

The model suggests a way of defining the period for measuring deviations from PPP, linking it to delivery lags determined by the available transportation modes [ocean, air shipping, train, etc.]. One should adjust these times to delays in clearing the ports and customs in the various countries. These delays may be also associated with significant time and resource costs, and may differ widely among destinations. Some of the costly delays in ports are also associated with corruption, implemented by literary hold ups.[20] An interesting hypothesis would be the degree to which emerging markets exhibit higher terms of trade volatility at frequencies determined by these delivery lags. While scarcity of data may inhibit empirical work along this line, our discussion suggests that greater attention should be paid to the implications of these time and procedural delays.[21]

Other testable hypotheses include the possibility of asymmetric patterns on deviations from PPP, and the impact of faster means of transportation on the observed deviations from PPP. Specifically, when spot market imports are relatively

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[19] A partial conformation of these observation is reported by Guasch and Spiller (1999). They report the very large disadvantage of Latin American economies vis-á-vis the US with respect to inventories: on average these countries hold twice as much raw material and finished products as the US. According to the authors, higher transaction costs explain a relevant part of these inventories discrepancies: Latin American countries faced with uncertain demand, longer delays, and larger costs for small frequent shipments, choose to maintain larger inventory reserves. Considering the cost of capital is normally higher in Latin America than in the US, the authors point out that these high inventory levels translate into considerable costs and ultimately in lower competitiveness and diminished growth. See Hewitt and Gillson (2003) for more discussion of the challenges associated with shipping to developing countries.

[20] In a Mozambican survey of traders Biggs et al. (1999) find that 45% of those surveyed had been solicited to pay or had paid a fee not otherwise required by law or regulation. Most paid between $4 and $40, but 9% paid between $40 and $400. For Thailand, according to results of a survey on 1024 individuals, 74.4% of respondents answered that they had paid bribes in order to facilitate customs clearance.

[21] This concern was the focus of Nicholas Stern's remarks in New Delhi, November 28, 2002: "Recent World Bank investment climate surveys in India and other countries have highlighted areas where improvements could yield large benefits. For example, clearing customs in India takes three times longer than in high-income countries. In China the longest delay experienced by firms in the past year averaged just 12 days, while in India the average longest delay was 21 days. Port congestion and delays mean that transportation costs are much higher in India. The cost of shipping a container of goods from India to the United States is 35 percent higher than shipping from China and 20 percent higher than shipping from Thailand." [see http://lnweb18.worldbank.org/SAR/sa.nsf/Countries/India/554EEBE742277DBA85256C7F002D0F6C?OpenDocument].

cheap, there will be more last minute buying, and PPP holds better. In contrast, when spot market imports are relatively expensive there will be less last minute buying, and we will see larger deviations from PPP. This suggests that a symmetric distribution of the spot market prices is associated with asymmetric deviations from PPP. Another hypothesis suggests that the introduction of new means of transportation may impact profoundly the patterns of deviations from PPP. Famine due to distribution problems may be viewed as the most extreme example of deviations from PPP. One expects that the introduction of the railway system in India and other developing countries had a profound impact on the incidence of famines, allowing faster and cheaper delivery of food to affected areas, reducing thereby the deviations from PPP across various localities.[22]

Another challenge for the empirical implementation of our model is the presence of alternative channels explaining differential PTM patterns among countries. Specifically, the composition of trade matters—firms with market power are pricing differential goods, having the option of PTM, whereas firms trading commodities deal with homogenous products, where PPP would tend to hold more closely. As the weight of differential products is greater for the OECD countries than for developing countries, one expects less PTM in developing countries. This discussion also suggests it would be useful to extend the model in order to deal with market power and strategic behavior. For example, one may consider the case where consumers are risk averse, and where risk neutral middlemen dealers deliver imports. It can be verified that, as long as there is no collusion among dealers preventing last-minute imports, the key results of the paper continue to hold—the equilibrium pricing to market insures against the worst realizations of the real exchange rate. Competition among dealers would imply that import prices would decline below the PTM level when the realized real exchange rate is favorable. Our model can be readily extended to allow for monopolistic competition among various varieties of imports. In this extended model, the pre-buying is determined at a level where the discounted expected price of the imported good equals the first period cost of pre-buying, adjusted for the monopolistic competitive mark-up.

In order to gain tractability, this paper used a simple model, ignoring important considerations that determine the patterns of PTM. A shortcoming of this strategy is that the paper does not explain the high persistence of the deviations from PPP observed in the data. Attempts to reconcile this gap should recognize factors like the collusive behavior among dealers, non-traded inputs, time-dependent production costs, and staggering of prices.[23] An implication of our model is that, ceteris-paribus, emerging markets would rely more on air-delivery than the OECD countries. This conclusion, however, ignores the possibility that airfreight may be more expensive in emerging markets due to their underdeveloped modern infrastructure. The above suggests that empirical studies of the patterns of PTM across countries would benefit by controlling for the cost of various means of transportation, the composition of imports, and the competitiveness of the network of dealers. The logic of our

[22] I am indebted to George Akerlof for suggesting this example.

[23] See Bergin and Feenstra (2001) for analysis of PTM with staggered contracts.

discussion would apply to developing countries only in circumstances where the menu of transportation modes includes several alternatives. Hence, one expects it to have greater relevance for emerging markets, than for the poorest countries. It also suggests that having access to cheaper trade credit adds to the advantages of multinationals operating in developing countries.

Our discussion was simplified considerably by assuming a unique source of uncertainty—stochastic terms of trade, leading to a random supply price of imported goods. This assumption was motivated by the large relative price shocks induced by volatile real and nominal exchange rates. Assuming a stable demand function implied that the demand at the pre-set price matched the pre-buying of imports. Consequently, the switch to spot market imports was induced by the supply side, due to favorable realization of the terms of trade. A useful extension would add the possibility of stochastic demand. A proper treatment of such an extension should model active management of inventories. In these circumstances, the realized demand at the pre-set price would occasionally fall short of the pre-buying. The equilibrium resolution of this incipient "excess supply" would absorb part (sometimes all) of the gap by inventory accumulation. One presumes that even in this extended model Proposition 2 will continue to hold—higher costs of credit and higher interest rates would increase the cost of carrying the inventories forward, reducing the inventory adjustment, and increasing the tendency to observe price adjustment.

Our paper suggests that in the circumstances facing emerging markets, pricing to market would be observed less frequently than in the OECD countries. Hence, in evaluating the choice of exchange rate regimes for emerging markets, assuming relative PPP is likely to describe better the economic environment. This in turn suggests a bias towards lower flexibility of the exchange rate in emerging markets. As Devereux and Engel (1998) showed, pricing to market biases the choice in favor of a flexible exchange rate by the resultant delinking of domestic prices from the exchange rate, a bias that would not hold for emerging markets where the pricing to market is not a viable option.

Appendix A

The paper assumed risk neutral agents, with intertemporal linear preferences. While these assumptions simplified the analysis, the linear model has a limited ability to account for the impact of a higher interest rate. This appendix illustrates how to extend our analysis to the case of risk averse consumers. Specifically, suppose that with the exception of preferences, all the assumptions of the paper hold. The consumers maximize the expected value of

$$H = U(v_1) + \frac{1}{1+\rho}U(v_2) \quad \text{where} \quad U(v) = \begin{cases} \dfrac{[v]^{1-\phi}}{1-\phi} & \text{for } \phi \neq 1 \\ \ln v & \text{for } \phi = 1 \end{cases} \tag{A.1}$$

Hence, the consumer's expected utility is

$$\mathrm{E}(H) = U(v_1) + \frac{1}{1+\rho}\left[U[\tilde{v}_2(\delta^*)] + \int_{\underline{\delta}}^{\delta^*} \{U[\tilde{v}_2(\delta)] - U[\tilde{v}_2(\delta^*)]\} f(\delta)\,\mathrm{d}\delta\right]. \quad \text{(A.2)}$$

The consumer's problem is to determine the optimal triplet $\langle x_2^{\mathrm{s}}; x_1^{\mathrm{p}}; s \rangle$. We solve it backwards—first, we find the optimal spot market trade in the second period (x_2^{s}). Next, applying this solution we construct the expected utility in the first period. Finally, we find the pre-buying and the saving ($x_1^{\mathrm{p}}; s$) that maximizes this expected utility. Note that the first part of the solution (optimal (x_2^{s})) is identical to the one in Section 2, because it deals with the patterns of consumption in the second period, after the uncertainty of the terms of trade has been resolved. Hence, Eqs. (5)–(9) continue to hold. Applying these conditions to (A.2), we infer that the first-order conditions determining the optimal saving and the optimal pre-buying are

$$\text{a.} \quad -U'(v_1) + \frac{1+r^*}{1+\rho}\left[\int_{\underline{\delta}}^{\delta^*} U[\tilde{v}_2(\delta)] f(\delta)\,\mathrm{d}\delta + U'[\tilde{v}_2(\delta^*)]\int_{\delta^*}^{\bar{\delta}} f(\delta)\,\mathrm{d}\delta\right] = 0,$$

$$\text{b.} \quad -U'(v_1) + \frac{1+\tilde{t}}{(1+\rho)(1+t)}\left[\int_{\underline{\delta}}^{\delta^*} (1+\delta) U[\tilde{v}_2(\delta)] f(\delta)\,\mathrm{d}\delta + U'[\tilde{v}_2(\delta^*)](1+\delta^*)\int_{\delta^*}^{\bar{\delta}} f(\delta)\,\mathrm{d}\delta\right] = 0, \quad \text{(A.3)}$$

where $U' = \partial U/\partial x$ is the marginal utility of x (the domestic good). There are two ways to transfer purchasing power from the first to the second period—saving and pre-buying. The first-order conditions in (A.3) imply that intertemporal arbitrage exhausts the utility gain from intertemporal trade. Optimal saving is reached when the first period marginal utility of x equals the interest rate times the expected marginal utility of the second period consumption, discounted by the subjective rate of time preference (see (A.3a)). Similarly, optimal pre-buying equates the marginal utility of the first period consumption of x(= the opportunity cost of x in the first period) to the discounted expected marginal utility induced by pre-buying $1/(1+t)$ units of second period y (see (A.3b)).

The impact of higher financing costs are summarized in the following proposition.

Proposition A.1. *Higher interest rate reduces the first period pre-buying for small savings. This in turn implies that the frequency of PTM goes down.*

Proof. A higher interest rate would increase the relative price of pre-buying. This would lead to a substitution away from pre-buying to spot market delivery, reducing the incidence of pricing to market. The assumption that the net saving is small implies that the induced income effect due to the interest rate change is small, and hence the substitution effect would dominate.

We illustrate it for the case where $\phi = 1$ (hence $U(v) = \ln v$). Similar methodology applies for the case where $\phi \neq 1$. The first-order conditions can be rewritten as

$$\text{a.}\quad -\frac{1}{v_1}+\frac{1+r^*}{1+\rho}\left[\int_{\underline{\delta}}^{\delta^*}\frac{1}{\tilde{v}_2(\delta)}f(\delta)\,\mathrm{d}\delta+\frac{1}{\tilde{v}_2(\delta^*)}\int_{\delta^*}^{\bar{\delta}}f(\delta)\,\mathrm{d}\delta\right]=0,$$

$$\text{b.}\quad -\frac{1}{v_1}+\frac{1+\tilde{t}}{(1+\rho)(1+t)}\left[\int_{\underline{\delta}}^{\delta^*}\frac{1+\delta}{\tilde{v}_2(\delta)}f(\delta)\,\mathrm{d}\delta+\frac{1+\delta^*}{\tilde{v}_2(\delta^*)}\int_{\delta^*}^{\bar{\delta}}f(\delta)\,\mathrm{d}\delta\right]=0. \quad (A.4)$$

We denote these first-order conditions by

$$\text{a.}\quad L_1=0$$
$$\text{b.}\quad L_2=0 \quad (A.5)$$

Using Eqs. (8), (9), and (A.1) we infer that the impact of changing the interest rate on saving and pre-buying is summarized by

$$\begin{pmatrix}\dfrac{\partial L_1}{\partial s} & \dfrac{\partial L_1}{\partial x_1^{\mathrm{p}}}\\ \dfrac{\partial L_2}{\partial s} & \dfrac{\partial L_2}{\partial x_1^{\mathrm{p}}}\end{pmatrix}\begin{bmatrix}\mathrm{d}s\\ \mathrm{d}x_1^{\mathrm{p}}\end{bmatrix}=-\mathrm{d}r^*\begin{bmatrix}\dfrac{\partial L_1}{\partial r^*}\\ \dfrac{\partial L_2}{\partial r^*}\end{bmatrix}, \quad (A.6)$$

where

$$\frac{\partial L_2}{\partial x_1^{\mathrm{p}}}=-\frac{1}{(v_1)^2}-\frac{1+\tilde{t}}{(1+\rho)(1+t)}\left[\int_{\underline{\delta}}^{\delta^*}\frac{(1+\tilde{t})(1+\delta)^2}{1+t}\frac{f(\delta)}{[\tilde{v}_2(\delta)]^2}\mathrm{d}\delta\right.$$
$$\left.+\frac{1+\delta^*}{[\tilde{v}_2(\delta^*)]^2}\frac{\theta}{1+t}\left[\frac{x_1^{\mathrm{p}}}{1+t}\right]^{\beta-1}\int_{\delta^*}^{\bar{\delta}}f(\delta)\,\mathrm{d}\delta\right]<0,$$

$$\frac{\partial L_1}{\partial r^*}=\frac{1}{v_1(1+r^*)}-s\frac{1+r^*}{1+\rho}\left[\int_{\underline{\delta}}^{\delta^*}\frac{f(\delta)}{[\tilde{v}_2(\delta)]^2}\mathrm{d}\delta+\frac{1}{[\tilde{v}_2(\delta^*)]^2}\int_{\delta^*}^{\bar{\delta}}f(\delta)\,\mathrm{d}\delta\right],$$

$$\frac{\partial L_2}{\partial r^*}=-s\frac{1+\tilde{t}}{(1+\rho)(1+t)}\left[\int_{\underline{\delta}}^{\delta^*}\frac{1+\delta}{[\tilde{v}_2(\delta)]^2}f(\delta)\,\mathrm{d}\delta+\frac{1+\delta^*}{[\tilde{v}_2(\delta^*)]^2}\int_{\delta^*}^{\bar{\delta}}f(\delta)\,\mathrm{d}\delta\right],$$

Hence, for $s=0$, the signs of (A.6) can be summarized by

$$\begin{bmatrix}(-) & (-)\\ (-) & (-)\end{bmatrix}\begin{bmatrix}\mathrm{d}s\\ \mathrm{d}x_1^{\mathrm{p}}\end{bmatrix}=-\mathrm{d}r^*\begin{bmatrix}(+)\\ 0\end{bmatrix}. \quad (A.7)$$

Note that the second-order conditions for maximization imply

$$\left|\begin{pmatrix}\dfrac{\partial L_1}{\partial s} & \dfrac{\partial L_1}{\partial x_1^{\mathrm{p}}}\\ \dfrac{\partial L_2}{\partial s} & \dfrac{\partial L_2}{\partial x_1^{\mathrm{p}}}\end{pmatrix}\right|>0,$$

from which we infer that

$$\operatorname{sgn}\frac{dx_1^p}{dr^*} = \operatorname{sgn}\frac{(-)}{(+)} < 0,$$
$$\operatorname{sgn}\frac{ds}{dr^*} = \operatorname{sgn}\frac{(+)}{(+)} > 0. \tag{A.8}$$

Hence, when the income effect associated with changing the interest rate is small, higher interest rate will reduce the pre-buying of imports, and will increase saving.

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