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Abstract

In an empirical paper based on five large devaluation episodes in Argentina, Brazil, Korea, Mexico and Thailand, Burstein and al. (2005a) find a very slow adjustment in the prices of non-tradable goods and services after large devaluations. Burnstein and al. (2005b) develop a quantitative general-equilibrium model that can account for this phenomenon. I consider an alternative, simpler model and explore under which conditions moderate menu costs can explain the muted response of the prices of non-tradables. The key new element in this alternative model is a nominal friction in wage-setting (generated by menu costs for changing wages). I find, for example, that although my model is based on menu costs, it is able to deliver not only constant prices of non-tradables, but also small price changes (in reality these prices do change, albeit by far less than the exchange rate). I also discuss the existence of multiple equilibria and the role of central-bank credibility.

Keywords: large devaluation, exchange rate, pass-through, sticky prices, sticky wages. JEL Classification Number: F31.

1 Introduction

In an empirical paper based on five large devaluation episodes in Argentina, Brazil, Korea, Mexico and Thailand, Burstein and al. (2005a) find a very slow adjustment in the prices of non-tradable goods and services to large devaluations. Burnstein and al. (2005b), henceforth BER, address the question of why the rate of inflation for non-tradable goods is so much lower than the rate of devaluation. They develop a quantitative general-equilibrium model that can account for this phenomenon. They assume menu costs for changing a price and show that producers of non-tradables might prefer not to change their price at all even if the devaluation is large. There are also cases in which it is not sustainable as an equilibrium phenomenon for firms in the non-tradables sector not to change their prices at all (in these cases it is argued that real shocks are the primary driver of real exchange-rate movements). They incorporate several assumptions into their model that mute the response of the price of non-tradables to the exchange-rate shock. First, the share of tradable goods in the consumer price index (CPI) is small. Second, there are domestic distribution costs associated with the sale of traded goods. Third, there is a low elasticity of the demand for exports. Fourth, there is a moderate elasticity of substitution between tradables and non-tradables.[1] Moreover, they deviate from the Dixit-Stiglitz model, adopting Kimball's (1995) assumption that the elasticity of demand for the output of a monopolistic producer is increasing in its price relative to the prices of its competitors' goods. They conclude, however, by noting a shortcoming of their paper: the price of non-tradables does not change at all, while in reality these prices do change, albeit by far less than the exchange rate.[2]

Like BER, I aim at explaining why the rate of inflation for non-tradable

[1] The price of tradables will change after an exchange-rate shock. The direct impact of this price change on non-tradables will, however, be small since BER assume a moderate elasticity of substitution between tradables and non-tradables. But even if this elasticity were zero, there would still be other channels through which price adjusments could be induced. For example households would ask for higher wages in order to mute the impact of the increase of the prices of tradables on their real wages. This would incite firms to increase their prices in order to pass the price increase of the labor input on to consumers. However, incorporating several assumptions that mute responses allow BER to get sticky prices with moderate menu-costs.

[2] BER focus on rationalizing an equilibrium in which non-tradable goods prices do not change at all. They do not say if their model could yield an equilibrium in which prices do change a little. My conjecture is that it can not (at least if all firms have the same menu costs): I expect that reducing incentives to change the prices of non-tradables in BER's model would not lead to smaller price changes but might only determine whether prices adjust perfectly or not at all.

goods is so much lower than the rate of devaluation. I consider an alternative, simpler model and explore under which conditions moderate menu costs can explain the muted response of the prices of non-tradables. The key new element in this alternative model is a nominal friction in wage-setting (generated by menu costs for changing wages).[3] For tractability, I consider a partial-equilibrium model rather than a general-equilibrium model like that of BER.

The intuition as to why this may explain small (but possibly not zero) changes in the prices of non-tradables is the following. In a setting in which the markup is a constant proportion of the marginal cost, the desired price varies in the same proportion as the marginal cost. The marginal cost can vary through two channels: a productivity change (due to a change in the quantity produced if returns to scale are not constant) or a change in the prices of production factors. A devaluation increases the price of imported goods and tends to move consumption toward non-tradables, thus increasing the quantity of non-tradables produced and reducing marginal productivity (assuming decreasing economies of scale). Since I use the moderate elasticity

[3] I owe the idea of introducing wage stickiness, and, more generally, the model I use here, to Philippe Bacchetta and Olivier Jeanne.

of substitution between tradables and non-tradables assumed by BER, this first channel by itself motivates a price change, albeit by far less than the exchange rate. This leaves the second channel: the wage (I assume that labor is the only production factor). If workers do not want to reset their wage, this second channel is not active. Then the desired price change of non-tradables firms is small, and this small change will occur if their menu cost is small enough. But why would workers not reset their wage after a large devaluation although they have two incentives to do so: i) to preserve their real wage and ii) to compensate for higher labor disutility due to the increased quantity of labor they must furnish? These two incentives may be so weak that they do not outweigh even a moderate menu cost of resetting wages. First, the change in price level is moderate since the change of the price of non-tradables is small and the share of pure tradables (exclusive of distribution costs) in the CPI is assumed, as in BER, to be moderate. Second, the change of labor is also moderate since, as discussed above, production of non-tradables does not increase much (and the production of tradables doesn't change much either, since the prices of tradables are assumed to adjust completely and there is no substitution between domestic and foreign tradables[4]).

[4]For simplicity's sake, rather than modeling domestic tradables production, an exoge-

I will try to avoid the shortcoming of BER consisting in not explaining small positive changes in the prices of non-tradables. The difference between a small price response and no price response may seem to be irrelevant. It is not. A small difference may matter a great deal if it casts doubt upon the underlying theory. In our case, one could think that a simple menu-cost model can explain that prices do not change at all, if the menu cost is high enough, but would not be able to explain (without an exogenous price-staggering process) why prices adjust only partially. If a firm pays the menu cost, why would it not adjust fully? This paper shows that a menu-cost model can explain partial adjustment. In another setting, the same concern has been expressed, for example, by Midrigan (2006) (he proposes an extension of the state-dependent model in order to explain small price changes and other micro-economic facts): "The large number of small price changes observed in the micro-price data might lead one to conclude against state-dependent pricing models."

Assuming staggered price setting (like the Calvo process) and strategic complementarity in price setting is the standard way to generate partial adjustment. However, assuming a time-dependent process is particularly debat-

nous endowment of tradables is assumed.

able after a large shock. Moreover, whereas the Calvo process is motivated by menu costs, these menu costs do not appear explicitly. Since I want to examine how high these menu costs need to be to explain incomplete price adjustment after a large devaluation, I need to explicitly have these costs in the model.

For realistic values of the parameters, I get strategic complementarity in price and wage setting. If all firms and workers adjust their prices and wages, then any agent choosing to deviate would bear a large cost. Thus, the equilibrium at which all agents adjust always exists for realistic menu cost values. There may however also be other equilibria. If no agent adjusts, then no agent would gain much by adjusting. Since this gain can be wiped out by a small menu cost, no adjustment will also be an equilibrium as long as the menu cost is not too small.

Interestingly, there are still other equilibria. In particular, workers may prefer not to change their wages at all after a transitory devaluation. In this case, firms in the non-tradables sector will not choose to fully adjust their prices to the devaluation. I compute the minimal menu cost for wages and the maximal menu cost for prices such that the price of non-tradables increases by a small amount. The existence of this equilibrium, and more generally the discussion of multiple equilibria, are the main contributions of this paper, whereas BER focus on rationalizing an equilibrium in which non-tradable goods' prices do not change at all. At the core of my paper are figures that make it possible to understand how the set of multiple equilibria depends on values of menu costs.

I also discuss the role of central-bank credibility. A credible central bank can eliminate the equilibrium in which all agents adjust. If the central bank is not credible, it will have to generate a recession to achieve this result.

The plan of this paper is as follows. The assumptions of the model are presented in section 2. Section 3 presents the equilibrium equations. Section 4 shows that small menu costs are enough to prevent a large change in the non-tradables price and that it is possible for the prices of non-tradables to change by a small amount. Section 5 shows that wage rigidity plays a crucial role in getting this result. Section 6 discusses the importance of central-bank credibility. Section 7 presents concluding remarks.

2 Assumptions of the model

This is a small open economy model. Non-tradables are produced with labor, and there is a domestic endowment of tradables. The non-tradable goods market, as well as the labor market, are cleared. Producers of non-tradables are price setters and households are wage setters. The timing is as follows: firms and households predetermine nominal prices before the occurrence of a devaluation shock. First, domestic producers set their prices and households set their nominal wages. Then the state of the world (devaluation or no-devaluation) is revealed, and price and wage setters decide to maintain prices and wages at the preset levels, or to pay the menu cost and change them in response to the shock.

Firms maximize profit. There are two sectors: the tradables and the non-tradables sectors. There is a continuum of differentiated non-tradable goods produced by a mass 1 of monopolistic producers $i \in [0, 1]$ with the production function $y_i = A_N L_i^{\alpha}$.

The country exports or imports a tradable good (balanced trade account is not assumed) for which the law of one price applies. Normalizing the dollar price of this good to 1, the domestic currency price of the good P_T is equal to the exchange rate S:

$$P_T = S \ .$$

For simplicity's sake, the country is assumed to receive an exogenous endowment of tradable goods.

There is a continuum of mass 1 of atomistic households indexed by h. Each household provides its particular brand of labor, and the labor used in production is a CES composite of the different brands given by

$$L_i = \left(\int l_{h,i}^{\frac{\eta-1}{\eta}} \right)^{\frac{\eta}{\eta-1}} , \quad \eta > 1 \ ,$$

where $l_{h,i}$ is the amount of labor provided by household h to firm i. The total amount of this labor composite in this economy is given by $L = \int_0^1 L_i di$.

Households maximize the following utility

$$u_h = c_h - \gamma \frac{l_h^{1+\theta}}{1+\theta}$$

under the budget constraint $c_h P = w_h l_h$, where $P = \left[\nu P_T^{1-\rho} + (1-\nu) P_N^{1-\rho} \right]^{\frac{1}{1-\rho}}$ is the general price level, w_h is the wage received by household h, and c_h is a CES index of the consumption of tradable and non-tradable goods

$$C = \left[\nu^{\frac{1}{\rho}} C_T^{\frac{\rho-1}{\rho}} + (1-\nu)^{\frac{1}{\rho}} C_N^{\frac{\rho-1}{\rho}} \right]^{\frac{\rho}{\rho-1}} , \qquad \rho > 0 \ .$$

Notice that profit revenues are not included in the budget constraint. This will simplify the expression for the household's opportunity cost of not adjusting its wage after an exchange-rate shock. This assumes that workers have only labor income, while non-tradables producers earn profits but no labor income and do not consume any non-tradables.

The consumption of non-tradable goods is itself a CES composite of different varieties:

$$C_N = \left(\int C_{N,i}^{\frac{\mu-1}{\mu}} \, di \right)^{\frac{\mu}{\mu-1}} , \quad \mu > 1 \; .$$

The structure of nominal stickiness is as follows. In the non-tradables sector, nominal prices are set before the occurrence of the shock, and can be changed after this occurrence at a certain cost to the price-setter (all firms have the same menu cost): if a firm chooses to adjust its prices, then menu costs are subtracted from its profits. Prices can be changed at no cost the next period. This is the same assumption, as for example, in Fishman and Simhon (2005). Their interpretation is that firms receive new inventories in odd-numbered periods, at which time labels must be applied to newly-arrived units. Therefore, in an even-numbered period, changing a unit's price relative to the preceding period involves the additional cost of changing labels; in odd-numbered periods, in contrast, price labels must be applied anyway so a price change is costless. Thus, prices are assumed to be sticky for at most one period. In the same way, wages are set by the households for one period before the occurrence of the shock and can be changed after this occurrence at a certain cost (the same menu cost for all households): if a household chooses to adjust its wages, then menu costs are subtracted from its utility. Alternatively, the exchange-rate shock can be assumed to be transitory and to last (and be expected to last) only one period.

After prices have been set, the economy can be in one of two states characterized by different nominal demands and exchange rates. The state of no-devaluation occurs with a probability that, for simplicity's sake, is assumed to be very small, so that the dependence of the preset levels on what would happen in case of a shock can be disregarded although anticipations are rational. In the no-devaluation state, the exchange rate is given by $S = S_f$ and domestic nominal demand is given by $P_{N,f}C_{N,f} + P_{T,f}C_{T,f} = N_f$. In the devaluation state this becomes $S = S_d$ and $P_{N,d}C_{N,d} + P_{T,d}C_{T,d} = N_d$, where $\frac{S_d - S_f}{S_f}$ is the rate of devaluation. N_f and N_d are exogenous. Notice that $P_N C_N + P_T C_T = N$ can also be written $C * P = N$. There are two ways to interpret the exogeneity of N. First, one could assume that a transaction technology determines the relation between aggregate spending and real money balances: $C = \frac{M}{P}$, where M is the nominal money stock. Then N is simply equal to M chosen by the central bank.[5] A second interpretation of the exogeneity of N is that it is a way to capture other shocks. Whatever the interpretation, C is given by $\frac{N}{P}$ where N is exogenously given. This exogeneity explains why the impact on demand of interests paid or received from the rest of the world need not be considered.

3 Equilibrium equations

The equilibria are given by the six following equations. Each variable in this system of equations is a ratio of the corresponding variable in case of a shock to this variable in the absence of a shock (labelled by the name of the corresponding variable with an index "r").[6]

[5] The choice of M would also have an impact on the exchange rate. If we want to keep the exchange rate shock exogenous in this interpretation, we need to assume that there is a (transitory) disconnect between the exchange rate and M.

[6] w_r for wages, P_r for the price level, P_{Nr} for the price of the non-tradable aggregate, $C_r = \frac{N_r}{P_r}$ for the CES index of the consumption of tradable and non-tradable goods, N_r for nominal demand, L_r for labor.

3.1 Optimization by firms in the non-tradables sector

Since the probability of a devaluation is assumed to be very small, the preset price can be considered equal to the price that would maximize profits in the absence of a shock. Assuming that the firm is committed to satisfying any demand at the chosen price, profits in cases of price adjustment Π_a (menu costs not yet subtracted) and without price adjustment Π_n can be computed. The difference between Π_a and Π_n yields the firm's private cost of not adjusting (as it is well known, the social cost is higher because of externalities) during the sole relevant period (by assumption the impact of the shock is transitory). To get a sense of its magnitude, it is useful to take the ratio of this difference to profit $\overline{\Pi}$ in the absence of a shock. This yields:

$$\frac{\Pi_a - \Pi_n}{\overline{\Pi}} = (w_r)^{-\frac{\alpha(\mu-1)}{\mu\left[1-(1-\frac{1}{\mu})\alpha\right]}} Z^{\frac{1}{\mu\left[1-(1-\frac{1}{\mu})\alpha\right]}} - \left[1-\alpha\left(1-\frac{1}{\mu}\right)\right]^{-1} \left[Z - w_r Z^{\frac{1}{\alpha}}\left(1-\frac{1}{\mu}\right)\alpha\right], \tag{1}$$

where $Z = (P_{Nr})^{\mu-\rho}(P_r)^{\rho} C_r$ and $C_r = 1$ (except for section 6, real consumption will be assumed, for simplicity's sake, to be constant).

If G_N is the cumulative of non-tradables firms' menu costs (expressed as a proportion of $\overline{\Pi}$), then the proportion α_N of non-tradables firms that adjust their prices is given by $\alpha_N = G_N\left(\frac{\Pi_a - \Pi_n}{\overline{\Pi}}\right)$. Since G_N is assumed to be degenerated (all firms have the same menu cost), α_N is either 0 or 1 depending on whether $\frac{\Pi_a - \Pi_n}{\overline{\Pi}}$ is smaller or larger than the common menu cost (α_N may take an intermediate value in the special case when $\frac{\Pi_a - \Pi_n}{\overline{\Pi}}$ is exactly equal to the common menu-cost, since some firms may adjust while other firms do not).

3.2 Optimization by households

Similarly, the ratio of the household's utility cost of not adjusting $(U_a - U_n)$ to its utility in the absence of a shock $(\overline{U})$ can be computed, where U_a is the utility in case of wage adjustment (menu costs not yet subtracted) and U_n is the utility if the household does not adjust its wage. This household's private cost of not adjusting its wage during the sole relevant period (expressed as a proportion of its utility in the absence of a shock) is:

$$\frac{U_a - U_n}{\overline{U}} = \left[P_r^{-\eta} L_r w_r^{\eta}\right]^{\frac{1+\theta}{1+\eta\theta}} - \left(1 - \frac{1 - \frac{1}{\eta}}{1+\theta}\right)^{-1} \left[P_r^{-1} L_r w_r^{\eta} - \left(L_r w_r^{\eta}\right)^{1+\theta} \frac{1 - \frac{1}{\eta}}{1+\theta}\right]. \tag{2}$$

If G_w is the cumulative of households' menu costs (expressed as a proportion of $\overline{U}$), then the proportion α_w of households that adjust their wages is given by $\alpha_w = G_w\left(\frac{U_a - U_n}{\overline{U}}\right)$. Again, the cumulative is assumed to be degenerate (all households have the same menu cost).

3.3 Definitions and market clearing conditions

The aggregate wage level is given by $w = \left[\int_0^1 (w_h)^{1-\eta}\, dh\right]^{\frac{1}{1-\eta}}$ where w_h is the wage set by household h. Knowing that a proportion α_w of households adjust their wages, and knowing which proportion of adjusting households will change their wages, w_r can be computed:

$$w_r = \left\{\alpha_w \left[P_r (L_r)^{\theta} (w_r)^{\eta\theta}\right]^{-\frac{\eta-1}{1+\eta\theta}} + (1-\alpha_w)\right\}^{-\frac{1}{\eta-1}} . \tag{3}$$

A similar computation can be made for the aggregate price for non-tradables, the aggregate price level and aggregate labor:

$$P_{Nr} = \left\{\alpha_N \left[(w_r)^{\alpha} (P_r)^{\rho(1-\alpha)} (C_r)^{1-\alpha} (P_{Nr})^{(\mu-\rho)(1-\alpha)}\right]^{\frac{1-\mu}{\mu\left[1-(1-\frac{1}{\mu})\alpha\right]}} + (1-\alpha_N)\right\}^{\frac{1}{1-\mu}} , \tag{4}$$

$$P_r = \left[\frac{(P_{Tr})^{1-\rho}\,\Omega + (P_{Nr})^{1-\rho}}{\Omega + 1}\right]^{\frac{1}{1-\rho}} ,$$

where $\Omega = \frac{\overline{P}_T \overline{C}_T}{\overline{P}_N \overline{C}_N}$,

$$L_r = \alpha_N \left[(w_r)^{-\mu} (P_{Nr})^{\mu-\rho} (P_r)^{\rho} C_r \right]^{\frac{1}{\mu\left[1-(1-\frac{1}{\mu})\alpha\right]}} + (1-\alpha_N) \left[(P_{Nr})^{\mu-\rho} (P_r)^{\rho} C_r \right]^{\frac{1}{\alpha}} . \tag{6}$$

4 Cases when wages are not adjusted

A change in the price of tradables has an impact on the price of non-tradables through the goods market (if $\rho \neq 0$) and through wages (I assume C_r exogenous and equal to 1). If households' menu costs are high enough for wages to stay constant (and thus $w_r = 1$), then there is only the goods market channel left, through which the impact might not be strong if the elasticity of substitution ρ is close enough to 0 (BER set $\rho = 0.4$)[7].

Formally, equation (4) becomes:

$$(P_{Nr})^{1-\mu} = \alpha_N \left\{ \left[\frac{\left(\frac{P_{Tr}}{P_{Nr}}\right)^{1-\rho} \Omega + 1}{\Omega + 1} \right]^{\frac{\rho(1-\alpha)}{1-\rho}} (P_{Nr})^{\mu(1-\alpha)} \right\}^{\frac{1-\mu}{\mu\left[1-(1-\frac{1}{\mu})\alpha\right]}} + (1-\alpha_N),$$

where α_N is given by equation (1).

[7] Intuitively, if $w_r = 1$ and $\rho = 0$, then we should have $P_{Nr} = 1$ since there is no open channel left. Formally, equation (4) becomes in this case: $P_{Nr}^{1-\mu} = \alpha_N P_{Nr}^{(1-\mu)\frac{1-\alpha}{1-\alpha+\frac{\alpha}{\mu}}} + 1 - \alpha_N$ which has $P_{Nr} = 1$ as unique solution.

- If the menu costs of firms are sufficiently high, then $P_{Nr} = 1$. This happens if their menu costs are higher than their private costs of not adjusting their prices, which is equal (according to §3.1) to the following critical value: $Z^{\frac{1}{\mu\left[1-(1-\frac{1}{\mu})\alpha\right]}} - \left[1 - \alpha\left(1 - \frac{1}{\mu}\right)\right]^{-1}\left[Z - Z^{\frac{1}{\alpha}}\left(1 - \frac{1}{\mu}\right)\alpha\right]$ where $Z = (P_r)^{\rho}$ and $P_r = \left[\frac{(P_{Tr})^{1-\rho}\Omega+1}{\Omega+1}\right]^{\frac{1}{1-\rho}}$. The assumption that wages are not adjusted implies (according to §3.2) that households' menu costs are larger than $\left[(P_r)^{-\eta} L_r\right]^{\frac{1+\theta}{1+\eta\theta}} - \left(1 - \frac{1-\frac{1}{\eta}}{1+\theta}\right)^{-1}\left\{(P_r)^{-1} L_r - (L_r)^{1+\theta}\,\frac{1-\frac{1}{\eta}}{1+\theta}\right\}$ where $L_r = (P_r)^{\frac{\rho}{\alpha}}$ and $P_r = \left[\frac{(P_{Tr})^{1-\rho}\Omega+1}{\Omega+1}\right]^{\frac{1}{1-\rho}}$.

- If non-tradables firms have small enough menu costs then they will change their prices. Then $\alpha_N = 1$ (I assume that firms' menu costs are strictly smaller than the critical value and do not discuss the case in which they are exactly equal to the critical value). Equation (4) becomes: $(P_{Nr})^{\frac{\alpha}{1-\alpha}\frac{1-\rho}{\rho}}(\Omega + 1) = \left(\frac{P_{Tr}}{P_{Nr}}\right)^{1-\rho}\Omega + 1$. This implicit equation for P_{Nr} has only one solution. Knowing P_{Nr} and w_r, critical menu costs can be computed.

Numerical example

Let's numerically evaluate P_{Nr} and the critical menu costs for the following calibration:

Table 1: Calibration

Value	**Justification**
$\rho = 0.4$	BER. They quote Stockman and Tesar (1995), Lorenzo, Aboal and
	Osimani (2003), and Gonzales-Rozada and Neumeyer (2003).
$\theta = 0.25$	BER. This value implies a labor-supply elasticity that coincides with
	the standard value used in the real business-cycle literature.
$\Omega = 1/3$	Implies that the pre-devaluation share of tradable goods in CPI
	(distribution costs not included) is 25%. Burnstein et al. (2005a)
	argue that tradable goods (distribution costs included) account for
	roughly 50% of the CPI basket, but that about half of their costs
	are distribution costs. This leaves a share of 25% for pure
	tradable goods.
$\mu = 6$	This is a benchmark in the literature.
$\eta = 2$	Naknoi (2005) referring to the study by Huang and Liu (2002) who
	find that it can vary from 2 to 4.
$\alpha = 2/3$	Is a realistic value for the share of labor income in GDP.
$C_r = 1$	Real consumption is assumed not to be affected by the devaluation.
$P_{Tr} = 2$	The devaluation shock is such that the domestic currency loses
	half of its value and the price of tradables doubles.

For this calibration, I find the following values. Non-tradables firms do not change their prices if their menu costs are larger than 2.4×10^{-3}. In this case, households' menu costs must be larger than 2.8×10^{-2} for households not to change their wages. If non-tradables firms have menu costs small enough to change their prices, then they adjust their prices by a factor $P_{Nr} = 1.04$. The critical firms' menu cost, below which they adjust their prices, is 4.3×10^{-2}. This critical value is larger than the critical value obtained in the case that other non-tradables firms do not adjust (2.4×10^{-3}) since adjustment of other non-tradables prices create an extra incentive for a given non-tradables firm to adjust its price. This means that for a menu cost between 2.4×10^{-3} and 4.3×10^{-2} a non-tradables firm will adjust its price or not depending on whether other firms do or not (multiple equilibria). The menu cost of households has to be larger than 3.3×10^{-2} for them not to increase their wage although the prices of non-tradables have increased.

For this calibration, this numerical example shows that a low small firms' menu cost is enough to be consistent with non-tradables firms not changing their prices. Since the price of non-tradables does not change, a quite low households' menu cost is enough for households not changing their wage to be an equilibrium. Moreover, I also obtain the possibility that the price of non-tradables will change albeit by a small amount (this result was not obtained in the BER model).

5 Cases when wages are adjusted

Let's assume now that households' menu costs are small enough for all wages to adjust. Then equation (3) yields $w_r = P_r (L_r)^{\theta}$ where the amount of labor depends, according to (6), on the quantities the firms want to produce, and thus on the prices they set.

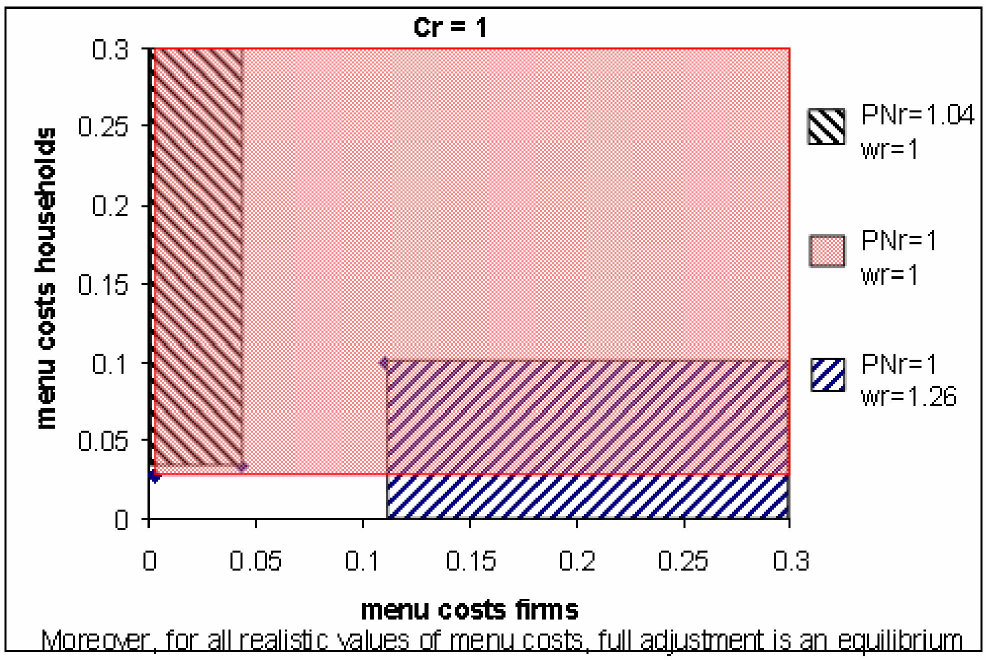
- If non-tradables firms have large enough menu costs to prevent them from adjusting their prices, then $P_{Nr} = 1$, $L_r = (P_r)^{\frac{\rho}{\alpha}}$, $w_r = (P_r)^{1+\frac{\rho}{\alpha}\theta}$ and the critical menu costs under which these results yield can be computed.

- Non-tradables firms will adjust if they have small enough menu costs. In this case equations (3) and (4) yield $(P_{Nr})^{\alpha+\rho(1-\alpha)} = (w_r)^{\alpha} (P_r)^{\rho(1-\alpha)}$ and $w_r = P_r \left[(w_r)^{-\mu} (P_{Nr})^{\mu-\rho} (P_r)^{\rho} \right]^{\frac{\theta}{\mu\left[1-(1-\frac{1}{\mu})\alpha\right]}}$. Plugging equation (5) for P_r into these equations yields two curves in the plane $< P_{Nr}; w_r >$. The solution is the intersection. Then knowing P_{Nr} and w_r, the critical menu costs under which these results yield can be computed.

For the above calibration I get the following values. A non-tradables firm will not adjust its price when other non-tradables firms do not adjust if its menu cost is larger than 0.11. This critical value is higher than what it was when households did not adjust their wages since wage adjustment creates an additional incentive for firms to adjust their prices (households multiply their wages by a factor 1.3 which is smaller than the exchange-rate shock but is still large enough to create a big incentive for firms to change their prices). This critical value is so large that in this model it is very unlikely that a firm will not adjust its price while the households are adjusting their wages. This is the case even when the other non-tradables firms do not adjust their prices. If they do, then the incentive to join them is even greater. I find that for any realistic menu-cost values, an agent will always adjust when all the other agents (households and non-tradables firms) do, and in this case price and wage adjustments are complete. Thus, for this calibration I do not get sticky prices for low firms' menu costs if households' menu costs are small enough for them to change their wages. Wage stickiness was crucial to get the results of the previous section.

The equilibria discussed in this and in the preceding section are shown as a function of firms' and households' menu costs in the Figure 1 (as mentioned below, other equilibria exist but they are unstable).

Figure 1: Stable equilibria as a function of menu costs for $C_r = 1$

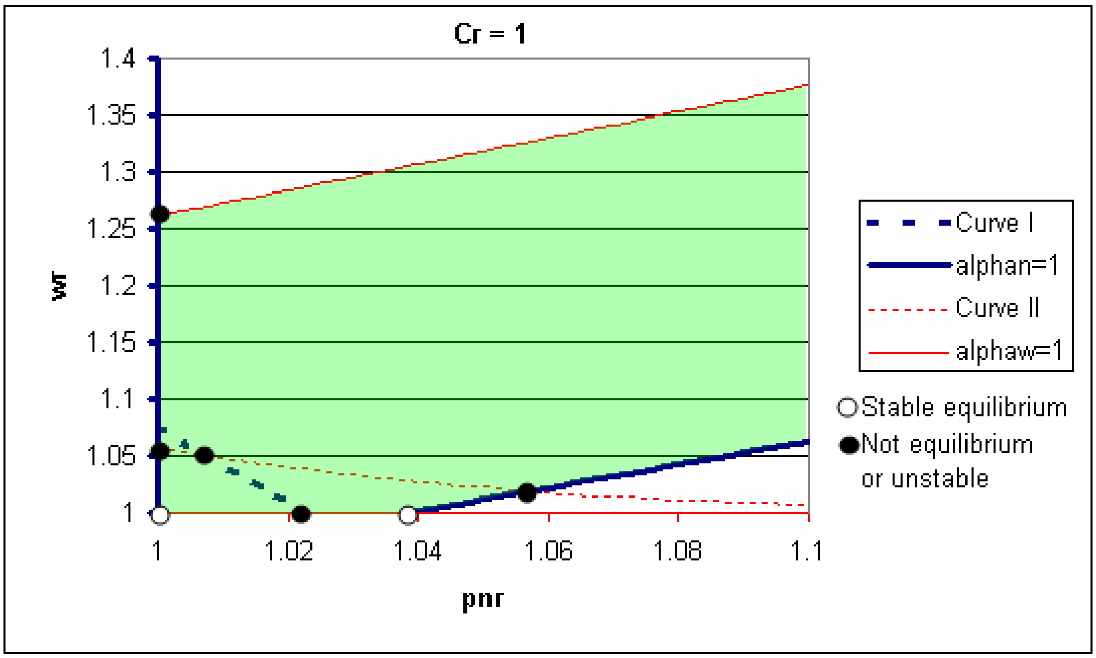


$\rho = 0.4$, $\theta = 0.25$, $\Omega = 1/3$, $\mu = 6$, $\eta = 2$, $\alpha = 2/3$, $C_r = 1$, $P_{Tr} = 2$.

This figure shows that full adjustment is an equilibrium for all realistic values of menu costs. If menu costs are sufficiently small, this is the only equilibrium. However, there are multiple equilibria for some larger menu costs. For these parameter values, the equilibrium (hatched slanting to the right), at which it is possible that the prices of non-tradable goods do not adjust while the wages adjust, exists only for unrealistically high firms' menu costs. But it is possible that neither the prices of non-tradables nor wages adjust (shaded area). It is also possible that wages do not adjust while prices do adjust (hatched slanting to the left).

This figure gives the equilibria as a function of firms' and households' menu costs. A figure showing the equilibria in the plane $< P_{Nr}; w_r >$ can also be drawn. If the menu cost of firms is 2% and the menu cost of households is 4%, then I get Figure 2:

Figure 2: Potential equilibria (zoom) for $C_r = 1$



$\rho = 0.4$, $\theta = 0.25$, $\Omega = 1/3$, $\mu = 6$, $\eta = 2$, $\alpha = 2/3$, $C_r = 1$, $P_{Tr} = 2$,

firms' menu costs = 2%, households' menu costs = 4%.

In this figure there are two types of curves: the ones in bold focus on non-tradables firms while the other ones focus on households. There are three curves in bold. One curve corresponds to the case in which all firms adjust ($\alpha_N = 1$). The vertical axes ($P_{Nr} = 1$) correspond to the case in which non-tradables firms do not adjust ($\alpha_N = 0$). Finally, Curve I corresponds to the case in which the menu cost is exactly equal to the private cost of not adjusting (and thus some non-tradables firms might choose to adjust while others choose not to adjust). If a point $< P_{Nr}; w_r >$ is located above this curve, then the cost of not adjusting is larger than the menu cost and all firms would prefer to adjust. At a point located below this curve, no non-tradables firm would prefer to adjust. Similarly, there are three curves not in bold (horizontal axe included). The shaded area is the locus of points for which $0 \leq \alpha_N \leq 1$ and $0 \leq \alpha_w \leq 1$. Thus, points outside the shaded area should be disregarded. Even a point in the shaded area cannot be an equilibrium if it is not at the intersection between a curve in bold and another curve. But the reverse is not true: an intersection is not necessarily an equilibrium. Whether a given intersection is or is not an equilibrium depends on the values of the menu costs for firms and households. For example, the intersection between $P_{Nr} = 1$ and $\alpha_w = 1$ is not an equilibrium because it is located above Curve I (the firms prefer to adjust their prices rather than stay at $P_{Nr} = 1$). But if the menu cost of firms became sufficiently high, then Curve I would move to the upper right-hand corner and would eventually have moved enough for this intersection to be located below that curve. Thus, an intersection is a potential equilibrium in the sense of being an equilibrium for some values of the menu costs. In addition to the intersection shown in Figure 2 (which is a zoom) there is an intersection at $< 2; 2 >$ corresponding to full adjustment.

Figure 2 also helps to discuss the stability of these equilibria. For example the intersection between Curve II and $\alpha_N = 1$ is unstable: starting from a point at the right but still near this intersection on the curve $\alpha_N = 1$, such a point would be above Curve II and all households would want to adjust their wages, increasing wages and prices even more until the equilibrium $< 2; 2 >$ is reached. It can be seen that each of the four equilibria shown in Figure 1 is stable for menu-cost values for which it is indeed an equilibrium.

It may be surprising to see in Figure 1 that no amount of change of one critical value can make up for a change in the other critical value in order to yield the same equilibrium. As an example, let's discuss this for the $P_{Nr} = 1$ & $w_r = 1$ equilibrium. If the households' menu cost is a little bit smaller than the needed critical value then this equilibrium vanishes. No change in the menu cost of firms can make up for it. In Figure 2 it is clear what happens. The point $< P_{Nr}; w_r > = < 1; 1 >$ is located below Curve II when the households' menu cost is equal to 4%. However, if the menu cost of households were small enough, then the point $< P_{Nr}; w_r > = < 1; 1 >$ would be located above Curve II and all households would want to adjust their wages. Increasing the menu cost of firms would move Curve I, but would not change the fact that $< 1; 1 >$ is located above Curve II. Intuitively, if the households' menu cost is too small then households will adjust their wage whatever non-tradables firms do.

One could reply that this example is special: the price of non-tradables should have an impact on whether a household adjusts or not (and by how much), but the price of non-tradables is a given in this example in which non-tradables firms do not adjust. Thus let's consider the equilibrium $< P_{Nr}; w_r > = < 1.04; 1 >$ at which the price of non-tradables adjusts. As before, this equilibrium disappears if the households' menu cost is too small. A decrease of P_{Nr} would indeed decrease the households' cost of not adjusting and could compensate a small decrease in the households' menu cost. But a change in the non-tradables firms' menu cost would have no impact on P_{Nr} except if it was so large that non-tradables firms prefer not to adjust their prices (in which case the equilibrium $< P_{Nr}; w_r > = < 1.04; 1 >$ disappears and the economy would be at $< P_{Nr}; w_r > = < 1; 1 >$). Intuitively, one could expect that the strong impact that a small menu cost change has in this model (when it is near the critical value) is a consequence of the assumption that all firms have the same menu cost and all households as well. I conjecture that if the menu cost distribution is not degenerated, then a change in the firms' menu cost would have an impact on the proportion of firms that adjust (and maybe on the price chosen by adjusting firms) and thus on the aggregate price of non-tradables. In this case there would exist a continuum of equilibria (differing by P_{Nr} and/or w_r) and a little change of the average menu cost would usually not have a strong impact.

6 The importance of central-bank credibility

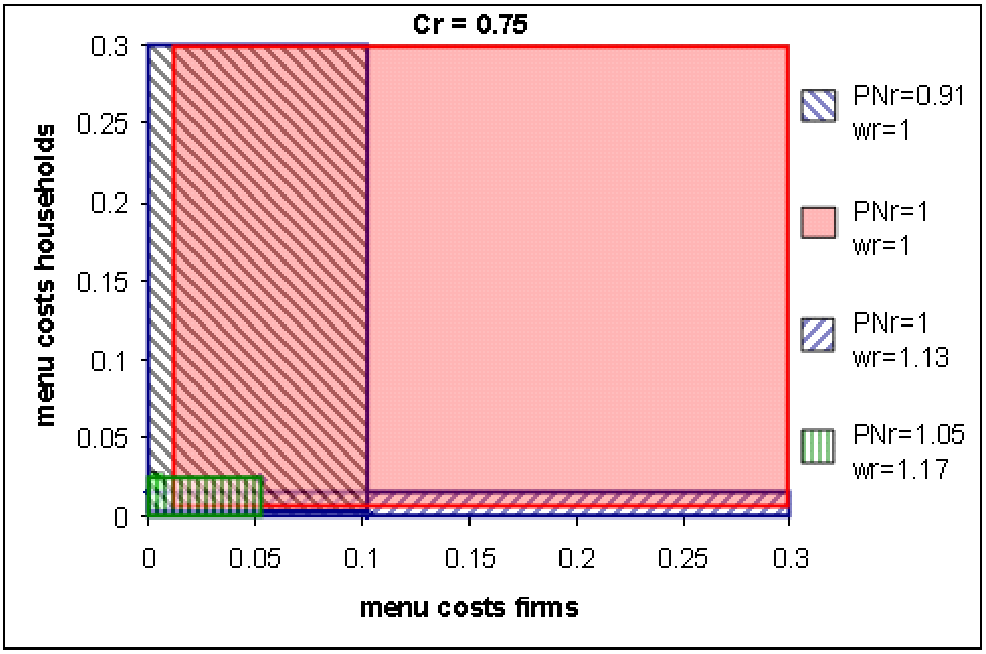
The central bank sets the real consumption of workers through setting money supply ($C_r = M/P$).[8] The central bank chooses C_r such that prices of non-tradables do not increase (or do not increase much) since it wants to avoid the exchange-rate shock leading to inflation. The problem is that there are usually multiple equilibria. The set of equilibria depends on C_r.

[8] I assume that monetary policy can indirectly determine real consumption C by choosing the nominal money supply M since $C = \frac{M}{P}$. Notice that all our equilibrium equations are still valid if we consider that M rather than C_r is exogenous. The reason is that the first-order equations are derived assuming that agents take P as exogenous. Thus $\frac{M}{P}$ will be treated by the optimizing agents as exogenous as C_r.

If the central bank is credible, it only needs its preferred equilibrium to belong to the set of equilibria (it will become the focal equilibrium). This, however, is not sufficient if the central bank is not credible. In that case, even if its preferred equilibrium belongs to the set of equilibria, agents will not necessarily focus on it. Thus, when the central bank is lacking in credibility, it will have to generate a large enough recession (choose C_r small enough) that the equilibrium it wants to avoid no longer belongs to the set of equilibria.

Let's assume that the monetary authorities want to avoid inflation and thus want firms of the non-tradables sector to choose not to adjust their prices. Monetary authorities can achieve this goal by choosing a C_r such that not (or barely) changing prices is the only optimal decision for price-setters. This is always possible by choosing C_r sufficiently small. Figure 3 reproduces Figure 1 for $C_r = 0.75$ instead of 1, and shows how these stable equilibria depend on menu costs.

Figure 3: Stable equilibria for $C_r = 0.75$

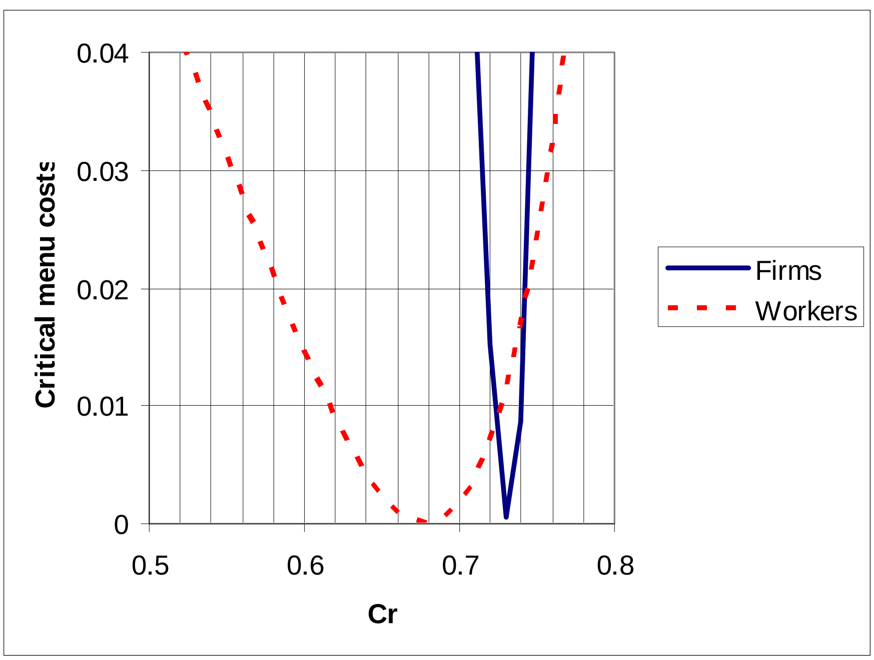


$\rho = 0.4$, $\theta = 0.25$, $\Omega = 1/3$, $\mu = 6$, $\eta = 2$, $\alpha = 2/3$, $C_r = 0.75$, $P_{Tr} = 2$.

Compared with Figure 1, the most important difference is that the area corresponding to the menu cost values for which there is an equilibrium, at which all agents adjust, has shrunk. In Figure 1 it took up the entire area visible on the graph (I didn't designate the corresponding zone in order not to overburden the figure). Here, the corresponding zone (hatched vertically) is smaller. For example, this equilibrium is no longer obtained if the firms' menu cost=2% and the households' menu cost=4%. Moreover, producers of non-tradables do not change their prices much when all agents adjust: they increase them by only 5%. Thus, when $C_r = 0.75$ there is not much danger of an increase of P_{Nr} and this increase would be small in any case (but there is a possibility of a decrease of P_{Nr}: the surface (hatched slanting to the left) corresponding to $P_{Nr} = 0.91$).

If the central bank wants to avoid an increase of P_{Nr}, it can do so by choosing C_r low enough. But how low C_r has to be (that is, how large the recession needs to be) depends on the credibility of the central bank. If the central bank is not credible, then it will need to chose a C_r low enough for no adjustment to be the only possible equilibrium at the given menu cost values (or at least to exclude equilibria which imply an inordinately large increase of P_{Nr}). If the central bank is credible, then it does not need to reduce C_r that much (depending on the menu costs, it might not need to reduce C_r at all) : it is enough that not adjusting belong to the multiple equilibria. This implies that two identical countries that differ only by the credibility of their central bank can end up with different C_r after an identical exchange-rate shock. For example, if the menu cost is 2% for firms and 4% for households, then, with the above parameter values, a credible central bank can keep real consumption constant while a central bank that does not benefit from this credibility would have to decrease real consumption by a large amount. One could ask what the maximum value of C_r would be such that the equilibrium at which all agents adjust is excluded for the above parameter values. Figure 4 (a zoom on the relevant zone) shows, as a function of C_r, the critical menu costs for firms and households such that all agents adjust only if menu costs are smaller than these critical values.

Figure 4: Critical menu costs for the equilibrium at which all agents adjust



$\rho = 0.4$, $\theta = 0.25$, $\Omega = 1/3$, $\mu = 6$, $\eta = 2$, $\alpha = 2/3$, $P_{Tr} = 2$.

To exclude the equilibrium at which all agents adjust, it is enough that one of the menu costs is above the corresponding critical value. When the menu cost of firms is 2% and the menu cost of households is 4%, then the equilibrium at which all agents adjust is excluded at $C_r = 0.76$. Notice that the curves are steep: a small change in C_r can have a large impact on the menu-cost values compatible with all agents adjusting.

7 Conclusion

I have shown that menu costs can explain not only why the price of non-tradables may remain unchanged after a large devaluation, but also why it may change by a small amount. I usually obtain multiple equilibria. If monetary policy is credible, the equilibrium preferred by the central bank will be selected. If monetary policy is not credible, then the central bank will have to generate a recession large enough that the equilibrium it wants to be certain of avoiding is no longer one of the multiple equilibria.

This paper could be extended in several directions. It would be interesting to extend the model to general equilibrium (for example, foreign demand for tradable goods could be modelized and real consumption endogenized), to relax simplifying assumptions (for example, the assumption that prices are fully flexible following the first period after the shock could be dropped), to introduce savings and the interest rate (and maybe a monetary policy using this interest rate as an instrument), to model the cause of the exchange-rate shock (and its possible links to monetary policy), to integrate substantial dynamics, and to allow for different firms having different menu costs (idem for households). One may also want to explain in terms of menu costs faced by producers of tradables why the price of tradables adjusts whereas the price of non-tradables adjusts only to a small extent (intuitively, one could expect that a firm's opportunity cost of not adjusting its price is higher in the tradables sector, in which the exchange-rate shock is felt more directly).

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