DEPARTMENT OF ECONOMICS

Working Paper

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Working Paper No. 1999-10

ISSN 1396-2426

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Propagation of Nominal Shocks in Open Economies

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May 1999

The propagation of nominal shocks is analyzed in a fully specified stochastic intertemporal two-country model. We show how to solve for the equilibrium analytically and analyze the role of real and nominal propagation mechanisms. First we consider the dynamic implications of nominal shocks having an impact effect due to one-period nominal contracts when the propagation over time runs via a basic real propagation mechanism in open economies (current account). We find that this case is characterized by strong persistency in the real effects of nominal shocks, but the dynamic adjustment path is strongly at odds with empirical evidence. Secondly, we introduce a nominal propagation mechanism in the form of staggered nominal contracts. This turns out to imply a radical change in the dynamic response to nominal shocks, and to generate a dynamic adjustment path of the form observed empirically.

JEL classification: E32; F41

Keywords: Persistence; Staggering; Exchange rates; Nominal shocks; Current account.

[*]We gratefully acknowledge comments and suggestions from Niels Haldrup and Hans Timmer as well as by seminar participants at the NHH (Bergen), University of Warwick, University of Aarhus and at the conference "General Equilibrium and Monetary Transmission" organized by the Dutch Central Bank November 1998. An earlier version of this paper has appeared as Staff Report no 31, De Nederlandsche Bank, 1999.

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1 Introduction

One of the most well documented empirical facts is the finding that nominal exchange rate changes lead to persistent deviations in real exchange rates and the terms of trade.[1] Thus, nominal and real exchange rates tend to move in the same direction in the short to medium run, and the return to long-run equilibrium is very slow. It is often found that ARMA processes with strong autoregressive elements capture the processes for real exchange rates quite well. The consensus being that the half-life of the relative price effects induced by nominal shocks is 3-4 years. This finding possesses a puzzle to open macroeconomics since it is hard to reconcile with economic theory (Rogoff, 1995).

The problem of accounting satisfactorily for persistency effects is shared with business cycle theory in general (see eg Cogley and Nason, 1995). In fully specified dynamic general equilibrium models it is difficult to specify real propagation mechanisms which generate persistency in output of a quantitative importance matching that observed in the data. For real shocks this problem can be circumvented by assuming persistency in the underlying shocks, but this procedure cannot be readily applied to nominal shocks since persistency in unanticipated nominal shocks is not possible under rational expectations. Since the real propagation mechanism is weak, the impact effect generated by nominal rigidities will not have lasting effects. Currently it is debated to what extent inertia in nominal wage or price adjustment can generate persistency of quantitative importance (see Taylor, 1998 for a discussion and references).

Is there any qualitative difference between closed and open economies in respect to the endogenous propagation mechanisms which generate persistency? One potential important difference arises via wealth reallocation (current account) between countries following (asymmetric) shocks and which via consumption smoothing would affect the structure of future demand. While this mechanism is central to the so-called intertemporal approach to open macroeconomics (see eg Obstfeld and Rogoff, 1996) there has been surprisingly little effort devoted to explore the implications of this potential mechanism relative to the general persistency puzzle in the business cycle literature and the specific open-economy problem of how exchange rates and (nominal and relative) prices interact.

A significant achievement of the new open macroeconomics[2] is the explicit

[1] Recent empirical evidence on the role of nominal shocks for business cycle fluctuations and movements of exchange rates can be found in eg Canova and De Nicoló (1999), Eichenbaum and Evans (1995) and Rogers (1998).

[2] The literature took off with the framework suggested in the "Redux"-paper by Obstfeld

formulation of dynamic general equilibrium models. This allows an explicit analysis of intertemporal aspects including the dynamic adjustment process to various types of shocks. As concerns nominal shocks, there is a number of papers studying the role of one-period nominal rigidities in two-country models with a flexible exchange rate (see eg Lane, 1999). These models show how nominal shocks can have both short-term and long-term real effects where the latter is dependent on the wealth reallocation induced by the short-run nominal rigidities. However, these model do not have much to say on the dynamic adjustment process since the new steady state is reached already after one period. There is no transitional dynamics and the model basically boils down to a two-period model generating an impact effect and a steady-state effect. Moreover, most models are deterministic precluding an analysis of how a given process for, say, nominal shocks via endogenous propagation mechanisms are transmitted into a process for nominal and relative prices. The basic analytical problem encountered here is to keep track of the wealth reallocations induced by shocks. The existing stochastic models circumvent this problem by ruling out wealth reallocations either by assuming a complete set of contingent capital markets (see Chari et al, 1998) or by making assumptions ensuring that the current account is never affected (see Corsetti and Pesenti, 1998, and Obstfeld and Rogoff, 1998). The present paper shows how to solve an explicit stochastic dynamic two-country general equilibrium model analytically for the general case where shocks affect the current account and via this route causes wealth reallocations between countries.[3]

The particular problem addressed in this paper is the transmission of nominal shocks over time, that is, how are nominal shocks propagated in open economies. We consider how an impact effects of nominal shocks generated by one-period nominal contracts can be propagated over time via real mechanisms. This runs through wealth reallocation induced by current account changes and which via consumption smoothing effects future demand. Although the adjustment process is characterized by strong persistency in the sense that the terms of trade displays a unit root, we find that the impulse-response to a nominal shock is implausible. This suggests a basic problem in accounting for persistent effects of nominal shocks in the presence of short-term nominal rigidities.

The second step is thus to introduce staggering of nominal contracts as a possible reinforcing (nominal) propagation mechanism. Staggered nominal

and Rogoff (1995) and the textbook, Obstfeld and Rogoff (1996). For a recent survey of the new open macroeconomics, see Lane (1999).

[3]Thereby we avoid the black box often involved in simulations of fairly complicated models to gain better insight into the specific process generated for endogenous variables like the terms of trade (see also Campbell, 1994).

contracts can be seen as a convenient way by which to capture the essential characteristics of a decentralized market economy that all price and wage decisions are not made simultaneously by one coordinating agency, but rather made by numerous agents possessing different information. It represents a nominal propagation mechanism which potentially could account for persistent effects of nominal shocks. In the closed-economy literature there is an ongoing debate on the extent to which staggering can generate persistency of a quantitative importance matching that observed in the data. We find that a staggered contract structure produces a much more plausible dynamic adjustment pattern to shocks, and we identify the key parameters determining the autoregressive elements in the adjustment process. In contrast to closed-economy models we find that inelastic labor supply reinforces persistency.

This paper explores the propagation mechanism arising in a, by now, standard intertemporal open-economy model for two countries (flexible exchange rate) without real capital. As in most models we focus on the behavior of the terms of trade[4]. This is motivated partly by analytical convenience[5] and partly by the fact that empirical evidence indicates that movements in the prices of nontradables contribute very little to movements in real exchange rates. Accordingly, we adopt a model with specialized production and under the assumption of costless trade and identical preferences for domestic and foreign households it follows that PPP always hold.

This paper is organized as follows. Section 2 sets up a stochastic version of a by now fairly standard dynamic two-country model. Section 3 shortly outlines the case with no nominal rigidities. Section 4 explores the interaction between one-period nominal contracts causing nominal shocks to be nonneutral and consumption smoothing as the persistency generating mechanism. Section 5 introduces nominal two-period staggering and evaluates how this generates persistency and interacts with consumption smoothing. In section 6 three-period staggering is introduced to evaluate the role of the contract length. Section 7 summarizes and concludes the paper.

2 A Stochastic Two-Country Model

We consider a two-country model with a flexible exchange rate. Both countries, Home and Foreign, produce a separate tradable commodity which is demanded by consumers in both countries. Money is demanded for the trans-

[4]In Andersen and Beier (1999) we show in a model including both tradeable and nontradeable goods that the real exchange rate qualitatively behaves as the terms of trade.

[5]By assuming asymmetric preferences, nominal shocks would affect real exchange rates. However, the basic mechanisms would be the same.

action services it provides which is captured by including real balances in the (semi-indirect) utility function of households (cf Feenstra, 1986). There is a real asset (bond) which is traded in a perfect international capital market. To focus on the interdependencies between the two countries, the model is symmetric.

We formulate an explicit labor market and analyze the role nominal wage rigidities may have for the transmission of nominal shocks in open economies. While nominal rigidities may prevail both in product and labor markets we find it natural to focus on nominal wage rigidities since empirical evidence indicates that they are more important than nominal price rigidities (see eg Spencer, 1998) and traditional open-macro models tend also to be based on an assumption of rigid nominal wages.[6] We assume staggered nominal wage contracts partly for illustrative purposes and partly to reflect the fact that labor market relations frequently involve contracts of nontrivial length. The contract structure in the labor market is exogenous and the strategy is to analyze the implications of various contract forms for the dynamic adjustment process.

We shall consider four versions of the supply side distinguished by the mode of wage determination, namely, a competitive labor market, one-period nominal wage contracts, two-period nominal wage staggering and three-period nominal wage staggering. These formulations of the supply side allow us to analyze how persistency generated from the demand side via consumption smoothing interacts with persistency mechanisms originating on the supply side.

The model structure is closely related to that of Betts and Devereux (1999), Chari et al (1998), Corsetti and Pesenti (1998), Kollmann (1997, 1998), Obstfeld and Rogoff (1995, 1996, 1998), Sutherland (1996) and Tille (1999).

2.1 Consumers

The representative consumer's preferences are given by

$$U_t = E_t \sum_{j=0}^{\infty} \delta \left[\frac{\sigma}{\sigma - 1} C_{t+j}^{\frac{\sigma-1}{\sigma}} + \frac{\lambda}{1-\varepsilon} \left(\frac{M_{t+j}}{P_{t+j}} \right)^{1-\varepsilon} + \frac{\kappa}{1+\mu} N_{t+j}^{1+\mu} \right],$$

$$\sigma > 0, \quad \lambda > 0, \quad \varepsilon > 0, \quad \kappa > 0, \quad \mu > 0, \quad 0 < \delta \leq 1.$$

E_t is the expectations operator conditional on period t information, N is labor supplied and M denotes nominal balances. P is the consumer price

[6] The qualitative implications of nominal price and wage rigidities are the same in the "Redux"-model, see Obstfeld and Rogoff (1996), chapter 10.

index and C is a real consumption index defined over consumption of the Home good and the Foreign good:

$$C_t = \left[\left(\frac{1}{2}\right)^{\frac{1}{\rho}} \left(C_t^h\right)^{\frac{\rho-1}{\rho}} + \left(\frac{1}{2}\right)^{\frac{1}{\rho}} \left(C_t^f\right)^{\frac{\rho-1}{\rho}} \right]^{\frac{\rho}{\rho-1}}, \ \rho > 0,$$

where ρ is the elasticity of substitution between Home and Foreign goods. The minimum cost at which one unit of the consumption bundle can be acquired defines the corresponding price index

$$P_t = \left[\frac{1}{2} \left(P_t^h\right)^{1-\rho} + \frac{1}{2} \left(P_t^f\right)^{1-\rho} \right]^{\frac{1}{1-\rho}},$$

where $P_t^h (P_t^{*h})$ is the price of the Home good in Home (Foreign) currency and $P_t^f (P_t^{*f})$ is the price of the Foreign good in Home (Foreign) currency. We assume that there are no impediments to trade so that the Law of One Price holds for both goods, ie

$$P_t^h = S_t P_t^{*h}, \qquad P_t^f = S_t P_t^{*f}.$$

An asterisk refers to Foreign variables. S is the nominal exchange rate defined as the Home price of Foreign currency. The assumption that the Law of One Price holds implies straightforwardly that Purchasing Power Parity holds as well, that is, $P_t = S_t P_t^*$.

We assume that there is one internationally traded real bond denoted in the composite consumption good C. Let r_t be the consumption based real interest rate between dates t and t+1. The consumer's dynamic budget constraint is given by

$$P_t B_t + M_t + P_t C_t = (1 + r_{t-1}) P_t B_{t-1} + M_{t-1} + W_t N_t + \Pi_t + P_t \tau_t.$$

The right-hand side gives available resources as the sum of the gross return on bondholdings $(1+r_{t-1})P_t B_{t-1}$, initial money holdings M_{t-1}, labor income $W_t N_t$, nominal profit income Π_t and transfers from the government $P_t \tau_t$. Resources are allocated to consumption $P_t C_t$, nominal money holdings M_t and bondholdings $P_t B_t$.

Given the constant elasticity consumption index Home consumers' demands for the Home good and the Foreign good are

$$D_t^h = \frac{1}{2} \left(\frac{P_t^h}{P_t}\right)^{-\rho} C_t, \qquad D_t^f = \frac{1}{2} \left(\frac{P_t^f}{P_t}\right)^{-\rho} C_t,$$

respectively, and similarly for the Foreign consumers' demands. Aggregating demands, we find demands for the Home and Foreign goods to be

$$D_t = \frac{1}{2}\left(\frac{P_t^h}{P_t}\right)^{-\rho} C_t^W, \qquad D_t^* = \frac{1}{2}\left(\frac{P_t^{*f}}{P_t^*}\right)^{-\rho} C_t^W,$$

where world consumption $C_t^W = \frac{1}{2}C_t + \frac{1}{2}C_t^*$.

The consumer maximizes expected utility subject to the budget constraint and the first-order conditions determining the optimal choice of B_t, N_t and M_t are readily found to be

$$C_t^{-\frac{1}{\sigma}} = \delta\left(1 + r_t\right) E_t\left(C_{t+1}^{-\frac{1}{\sigma}}\right), \tag{1}$$

$$C_t^{-\frac{1}{\sigma}} = \lambda\left(\frac{M_t}{P_t}\right)^{-\varepsilon} + E_t\left(\delta C_{t+1}^{-\frac{1}{\sigma}}\frac{P_t}{P_{t+1}}\right), \tag{2}$$

$$C_t^{-\frac{1}{\sigma}}\frac{W_t}{P_t} = \kappa N_t^{\mu}. \tag{3}$$

It is assumed that the usual transversality condition holds.

Notice that the parameter μ determines the elasticity of individual labor supply with respect to the real wage. The higher μ, the less elastic is labor supply. The income (consumption) elasticity is determined by $\sigma\mu$. The higher $\sigma\mu$, the less the income elasticity.

In order to solve the model analytically, it is convenient to work with the model in log-deviations from steady state. Later it will be shown that the variables of the model are log-normally distributed under the assumed stochastic processes for the exogenous variables. The first-order conditions in log-linear form are[7]

$$E_t c_{t+1} = c_t + \sigma \log\left(1 + r_t\right), \tag{4}$$

$$m_t - p_t = \eta_{mc} c_t + \eta_{mc}^1 E_t c_{t+1} + \eta_{mp}\left(p_t - E_t p_{t+1}\right), \tag{5}$$

$$n_t = \frac{1}{\mu}\left(w_t - p_t\right) - \frac{1}{\mu\sigma} c_t. \tag{6}$$

Lowercase letters denote the log-deviations from steady state of the corresponding uppercase variables.[8] All constants are neglected here and in the following log-linear version of the model.[9]

[7]Consult appendix A for details on log-linerization and definitions of the constants.

[8]In the rest of the paper η_{xz} denotes the elasticity of the variable X with respect to the variable Z. Superscripts are included when the right hand side variable has more than one entry, eg lagged and leaded variables (cf η_{mc} and η_{mc}^1 in equation (5)).

[9]Notice, that the constant terms include variance terms which are also constant under the stochastic process considered here (see below).

2.2 Firms

There is perfect competition in the product markets. The representative firm is a price and wage taker and produces subject to a decreasing returns technology linking output Y^h and labor input N[10]

$$Y_t^h = N_t^\gamma, \qquad 0 < \gamma < 1.$$

Maximizing profits yields the following labor demand and output supply for the representative firm

$$\begin{aligned} N_t &= \alpha_n \left(\frac{P_t^h}{W_t}\right)^{\eta_{nw}}, \qquad \alpha_n = (1-\gamma)^{\frac{1}{1-\gamma}}, \qquad \eta_{nw} = (1-\gamma)^{-1}, \\ Y_t^h &= \alpha_y \left(\frac{P_t^h}{W_t}\right)^{\eta_{yw}}, \qquad \alpha_y = (1-\gamma)^{\frac{\gamma}{1-\gamma}}, \qquad \eta_{yw} = \gamma (1-\gamma)^{-1}. \end{aligned}$$

The elasticity of labor demand with respect to product real wage is $-\eta_{nw}$ and the elasticity of output supply with respect to product real wage is $-\eta_{yw}$. Profits are distributed to households.

2.3 Government

We assume the only role for the government is to issue money. Thus the government's budget constraint is

$$M_t - M_{t-1} = P_t \tau_t.$$

Money is transferred to consumers in a lump-sum fashion.

We end the description of the model by noting that Foreign is completely symmetric.

3 Competitive Labor Market

As a benchmark for the subsequent analysis of nominal rigidities, it is useful to consider the case where the labor market is Walrasian. This allows us to identify the underlying dynamic mechanisms which arise independently from

[10] Real capital is disregarded to simplify. Decreasing returns can be interpreted as arising from a second factor of production in fixed supply. $Y^h(Y^{*f})$ is used as notation for Home (Foreign) output as we leave Y and Y^* as notation for real incomes (see appendix A).

nominal rigidities. Equalizing demands and supplies in the labor markets, we find that Home and Foreign wages are determined as

$$w_t = \eta_{wp} p_t^h + \left(1 - \eta_{wp}\right) \left(s_t + p_t^{*f}\right) + \eta_{wc} c_t, \tag{7}$$

where

$$\eta_{wp} = \frac{\frac{1}{2} + \mu \eta_{nw}}{1 + \mu \eta_{nw}}, \qquad \eta_{wc} = \frac{1}{\sigma} \frac{1}{1 + \mu \eta_{nw}}.$$

In deriving the wage equation we use the log-linearized versions of the price indices:

$$p_t = \frac{1}{2} \left(p_t^h + s_t + p_t^{*f}\right), \qquad p_t^* = \frac{1}{2} \left(p_t^h - s_t + p_t^{*f}\right).$$

Equalizing (relative) demands and supplies for outputs we end up with

$$q_t = \frac{\eta_{yw} \eta_{wy}}{\rho + 2\left(1 - \eta_{wp}\right) \eta_{yw}} \left(c_t - c_t^*\right),$$

where q is the terms of trade

$$q_t = p_t^h - s_t - p_t^{*f}.$$

Note that relative consumption affects the terms of trade via a supply-side effect, the higher relative consumption, the higher relative wages and thus the terms of trade. Changes in the terms of trade have a direct demand effect and also a supply effect via wage formation.

There exists a Walrasian equilibrium (see appendix A) to the model in which money is neutral (see also Obstfeld and Rogoff, 1995).

Note furthermore, that the random-walk property[11] of relative consumption following from the Euler equations,

$$E_t \left(c_{t+1} - c_{t+1}^*\right) = c_t - c_t^*,$$

implies strong persistency in the terms of trade since (see Rogoff, 1992)

$$E_t q_{t+1} = q_t.$$

[11] More precisely, martingale property.

4 One-Period Nominal Wage Contracts

To break neutrality of money we introduce nominal wage contracts, and the important question is how nominal shocks affect the terms of trade and the adjustment process initiated by such shocks.

Wage setting is now characterized by one-period nominal wage contracts. The wage is set equal to the expected value of the (log) Walrasian wage[12]

$$w_t = E_{t-1}\left[\eta_{wp}p_t^h + \left(1-\eta_{wp}\right)\left(s_t + p_t^{*f}\right) + \eta_{wc}c_t\right].$$

For the present analysis of nominal shocks the critical property of the wage setting rule is that it fulfils basic homogeneity properties. We assume that employment is determined by labor demand at the quoted wage.

4.1 Nominal Exchange Rate

The nominal exchange rate can be found from the money market equilibrium conditions in the two countries as

$$s_t = \eta_{sc}\left(c_{t-1} - c_{t-1}^*\right) + \eta_{ss}E_t s_{t+1} + \eta_{sm}\left(m_t - m_t^*\right),$$

where,

$$\eta_{sc} = \left(1+\eta_{mp}\right)^{-1}\left(\eta_{mc}^1 - \eta_{mc}\right),$$

$$\eta_{ss} = \left(1+\eta_{mp}\right)^{-1}\eta_{mp},$$

$$\eta_{sm} = \left(1+\eta_{mp}\right)^{-1}.$$

To proceed we have to specify a process for (relative) money supply. We assume that it follows a random walk, ie

$$m_t - m_t^* = m_{t-1} - m_{t-1}^* + u_t, \tag{8}$$

where $u_t \sim nid(0,\sigma_u^2)$. This specification implies that all (unanticipated) nominal shocks are fully permanent. We assume full current information, ie u_t is commonly observed in period t.

[12] Wage formation could also be affected by market power of the supply side in the form of eg unions. While this have implications for the level of real wages, it would not have any direct implications for the dynamic properties of the model. This ensures that the assumption that supply accomodates demand is time-consistent (for a range of shock-values).

The dynamic equation for the nominal exchange rate can now easily be solved by the method of undetermined coefficients. First, we guess a solution to be of the following form

$$s_t = \pi_{sc} (c_t - c_t^*) + \pi_{sm} (m_t - m_t^*) , \tag{9}$$

where π_{sc} and π_{sm}[13] are coefficients to be determined and relative money supplies follow the process given in (8). Taking expectations and inserting we find the following restrictions

$$\pi_{sc} = \eta^1_{mc} - \eta_{mc} = - (\sigma\varepsilon)^{-1} ,$$

$$\pi_{sm} = 1.$$

The determination of the nominal exchange rate is thus equivalent to the "monetary approach" except that the relevant activity variable is relative consumption rather than output.

4.2 Terms of Trade and Relative Consumption

Equating relative supply and demand implies that the equilibrium terms of trade is determined as

$$\begin{aligned} q_t &= \frac{\eta_{yw}}{\rho + \eta_{yw}} [\left(2\eta_{wp} - 1\right) E_{t-1} q_t \\ &\quad + \eta_{wc} E_{t-1} (c_t - c_t^*) - (s_t - E_{t-1} s_t)]. \end{aligned} \tag{10}$$

Equation (10) reveals the basic difficulty in finding an analytical solution to the model, namely, that the terms of trade depends on relative consumption which in turn depends on wealth and thus the terms of trade. Relative consumption is also crucial to the development of nominal exchange rates. We show in appendix C how to handle this interdependency so as to determine the terms of trade and relative consumption. For later reference note that relative output is determined by the terms of trade, ie relative output evolves proportionally to the terms of trade.

We make the conjecture that

$$c_t - c_t^* = c_{t-1} - c^*_{t-1} + \pi_{cu} u_t. \tag{11}$$

This conjecture follows from the Euler equation implying that consumption changes can only be driven by unanticipated changes, and that monetary shocks (u) are the only shocks in the model.

[13] Note that we, henceforth, use π_{xz} as notation for elasticities in guesses.

Given this conjecture for relative consumption and (10), it is natural to guess that the terms of trade can be written as

$$q_t = \pi_{qc}\left(c_{t-1} - c_{t-1}^*\right) + \pi_{qu} u_t. \tag{12}$$

In appendix C we demonstrate the existence of an equilibrium satisfying (11) and (12) and where

$$\pi_{qc} > 0,$$

$$\pi_{qu} < 0,$$

and[14]

$$\pi_{cu} \gtreqless 0 \qquad if \qquad \rho \gtreqless 1.$$

It is noted that the solution found above for the nominal exchange rate and the terms of trade confirms the earlier made conjecture that all endogenous variables are log-normally distributed.

4.3 Adjustment to Nominal Shocks

The presence of wage contracts causes nominal shocks to have real effects, ie money is nonneutral ($\pi_{qu} \neq 0$). Notice that the impact effect of a nominal shock captured by the coefficient π_{qu} is independent of the wage setting (η_{wp}, η_{wc}) rule and depends only on the demand elasticity (ρ) and the responsiveness of firms to changes in profitability (η_{yw}) (see appendix C). This follows simply from the fact that nominal wages are predetermined for one period.

To consider the dynamic implications of the model we use the process for the money stock to rewrite the nominal exchange rate equation as

$$s_t = s_{t-1} + \left(1 - (\sigma\varepsilon)^{-1}\pi_{cu}\right) u_t.$$

[14]In appendix C it is shown that $\pi_{cu} < 0$ holds for $\rho \in [\underline{\rho}, 1)$. The reason why $\pi_{cu} < 0$ does not hold generally for $\rho < 1$ is the following. With an inelastic demand a fall in production leads to an increase in income and vice versa. For a low value of ρ the following scenario is possible. A monetary expansion induces an appreciation of the nominal exchange rate because the induced fall in production leads to a large increase in income and thus consumption. The latter is so large that the increase in money demand dominates the increase in money supply and as a consequence the nominal exchange rate appreciates. We consider this case to be extremely implausible and hence the text only discusses the case where $\rho \in [\underline{\rho}, 1)$ for $\rho < 1$.

The nominal exchange rate follows a random walk process. The effect of a monetary expansion on the nominal exchange rate is found to be (see appendix C)

$$\frac{\partial s_t}{\partial u_t} = 1 - (\sigma\varepsilon)^{-1}\pi_{cu} > 0,$$

ie there is a nominal depreciation following a monetary shock. The higher the elasticity of consumption with respect to the money shock the less the variability of the nominal exchange rate relative to the variability of the money shock.[15] It is seen that overshooting of the nominal exchange rate arises if $\pi_{cu} < 0$ (which holds when $\rho < 1$). However, due to the random-walk property this effect is permanent contrary to overshooting of the "Dornbusch-type".

Similarly the terms-of-trade equation can by use of (11) be written as

$$q_t = q_{t-1} + \pi_{qu}u_t + (\pi_{qc}\pi_{cu} - \pi_{qu})\,u_{t-1},$$

implying that the terms of trade follows an ARIMA(0,1,1) process although the money shocks are white noise. The terms of trade has a unit root which is also seen by rewriting it as

$$q_t = \pi_{qu}u_t + \pi_{qc}\pi_{cu}\sum_{j=0}^{\infty} u_{t-1-j},$$

from which it is easily recovered that the impact effect of a nominal expansion on the terms of trade is

$$\frac{\partial q_t}{\partial u_t} = \pi_{qu} < 0,$$

while the effect in all future periods $(t+j, j \geqq 1)$ is

$$\frac{\partial q_{t+j}}{\partial u_t} = \pi_{qc}\pi_{cu} \gtreqless 0 \qquad if \qquad \rho \gtreqless 1,$$

that is, the effects are permanent.

Figure 1 about here

[15] Betts and Devereux (1999) show that "Pricing to Market" lowers the expenditure switching effects of an exchange rate depreciation, but this in turn magnifies the exchange rate responsiveness to a monetary shock.

Figure 1 illustrates the impulse-response function for the terms of trade to a (positive) nominal shock (for $\rho \neq 1$). The impact effect is as expected, and there is strong persistency (except for $\rho = 1$ implying there is no wealth reallocation). However, the dynamic path does not correspond to the impulse-responses found in the data implying a slow return to the long-run equilibrium with half-lives of the impact effect of up to 3 to 4 years. The terms-of-trade effect reverses already after one period in the case where $\rho > 1$. The reason for this reversal is that the initial expansionary effect on income induces an increase in consumption which is smoothed over time. Due to the income effect on labor supply, it follows that higher consumption leads to a permanent reduction in labor supply. This induces an increase in the terms of trade in all subsequent periods. A reversal of the effect does not arise for $\rho < 1$ since the monetary expansion leads to an expansion of relative output, the low elasticity of demand implies that the country loses income, and there is a wealth reallocation to the disfavor of Home. This induces a fall in consumption ($\pi_{cu} < 0$) which via the income effect boosts labor supply and thus produces the persistent decrease in the terms of trade. However, after one period (= the length of the contract) the adjustment process is ended. Figure 1b illustrates this case.

Note that the case $\rho > 1$ corresponds to the case usually analyzed in the literature since most models have monopolistically competitive product markets and therefore need to impose the restriction that the elasticity of demand is numerically larger than one to have a well-defined maximization problem for firms (see Chari et al, 1998; Obstfeld and Rogoff, 1995; and Sutherland, 1996). Moreover, it is the "standard" case in the sense that the Marshall-Lerner condition is fulfilled (Marston, 1985).

Obstfeld and Rogoff (1995) found that "money supply shocks can have real effects that last well beyond the time frame of any nominal rigidities because of induced short-run wealth accumulation via the current account". The present analysis confirms this, but also bring out that the implied pattern for the terms of trade is not matching the type of dynamics observed in the data. Moreover, it is easily seen that this generalizes as it depends on the random-walk property of relative consumption which does not rely on the specific process for the shock nor the specific way one-period nominal rigidities are modelled.

Chari et al (1998) dismiss the channel running from money shocks over permanent wealth redistributions to persistent terms-of-trade movements as being unimportant.[16] In particular, it is argued that the effects of wealth

[16] In the presence of a full set of contingent markets, the household would be able to fully diversify the consumption risk, implying that shocks do not affect relative consumption.

reallocations are mitigated by changes in the terms of trade and domestic consumption so as to leave Foreign consumption unaffected. Our analysis shows this only holds for $\rho = 1$. In general, as revealed by equation (11), consumption differences follow a random walk and innovations are driven by unanticipated changes in (relative) incomes, The critical parameter here is the elasticity of demand ρ (cf appendix C). Moreover, if wealth redistributions are quantitatively unimportant, it implies that the so-called intertemporal approach to the current account has relatively little predictive power.

5 Two-Period Nominal Wage Staggering

Staggered or asynchronized nominal wage determination is a potential important propagation mechanism since it implies a sluggish adjustment of nominal variables (Taylor, 1998). Specifically in this section, we assume that half the contracts are signed in even periods and the other half in odd periods. The nominal wage is set for two periods according to the following rule for the wage set at the end of period t-1 and applying for periods t and t+1:

$$\frac{1}{2}E_{t-1}\left(w_t + w_{t+1}\right),$$

where w_t is the (log) Walrasian wage rate. The aggregate wage faced by firms in period t, $\overline{w}_t$ is then given by

$$\overline{w}_t = \frac{1}{4}\left(E_{t-2}w_{t-1} + E_{t-2}w_t + E_{t-1}w_t + E_{t-1}w_{t+1}\right).$$

Labor supply is assumed to accommodate labor demand at the given wage.

5.1 Terms of Trade and Relative Consumption

We prove in appendix D that there exists an equilibrium in which the terms of trade and relative consumption are determined as

$$q_t = \pi_{qc}\left(c_{t-1} - c^*_{t-1}\right) + \pi_{qq}q_{t-1} + \pi_{qu}u_t + \pi^1_{qu}u_{t-1}, \tag{13}$$

$$c_{t+1} - c^*_{t+1} = c_t - c^*_t + \pi_{cu}u_t, \tag{14}$$

with parameters defined in appendix D. It is noted that the nominal exchange rate equation (9) still applies and that the relevant endogenous variables are log-normally distributed.

Equation (13) can be rewritten by the use of the expression for relative consumption (14) as

$$\begin{aligned} q_t &= (1+\pi_{qq})\, q_{t-1} - \pi_{qq} q_{t-2} \\ &\quad + \pi_{qu} u_t + \left(\pi_{qu}^1 - \pi_{qu} + \pi_{qc}\pi_{cu}\right) u_{t-1} - \pi_{qu}^1 u_{t-2}, \end{aligned}$$

showing that the terms of trade follows an ARIMA(1,1,2) process when the two propagation mechanisms are merged. Note that consumption smoothing alone generates an ARIMA(0,1,1) while staggered contracts produce a similar process but with a stronger autoregressive part. This indicates that the more plausible dynamic path generated by staggering can be merged with the strong persistency effect generated by consumption smoothing to generate a dynamic path matching that observed in the data.

In appendix D it is shown that $\pi_{qq} \in (0,1)$ and

$$\frac{\partial \pi_{qq}}{\partial \rho} < 0, \quad \frac{\partial \pi_{qq}}{\partial \gamma} > 0, \quad \frac{\partial \pi_{qq}}{\partial \mu} > 0,$$

that is, the autoregressive element is strengthened the less elastic demand (ρ) is, the larger the productivity parameter (γ) and the less elastic labor supply is (the higher μ). From closed-economy models it is well known that the elasticity of labor supply is critical to the quantitative importance of persistency, and it is found that quantitatively important persistency requires implausible large values of labor-supply elasticities, see eg Ascari (1998) and Chari et al (1996). In the present open-economy context it is interesting to note that the elasticity of labor supply plays a qualitatively different role than in closed economy models. Hence, a more inelastic labor supply (higher values μ) implies more persistency following a nominal shock. This is also reflected in the numerical illustrations below. The intuition for this result is found by returning to equation (7) giving the underlying incentives in wage formation. We have that

$$\frac{\partial \eta_{wp}}{\partial \mu} > 0,$$

that is, the higher μ (the less elastic labor supply), the more wages are depending on the prices of domestically produced products and the less on the price of Foreign produced goods measured in domestic currency. Basically, this just reflects that consumers consider the consumption real wage whereas firms consider the product real wage. Hence, the supply-side effect of a currency depreciation inducing wage increases is smaller the less elastic labor supply is. This implies that the demand effects of a nominal depreciation to a lesser extent is counteracted by the supply effects.

5.2 Adjustment to Nominal Shocks

The dynamic implications may be seen more clearly by the following stochastic trend representation of the terms-of-trade equation

$$q_t = \frac{1}{1-\pi_{qq}L}\left(\pi_{qu}u_t + \pi_{qu}^1 u_{t-1} + \pi_{qc}\pi_{cu}\sum_{j=0}^{\infty} u_{t-1-j}\right),$$

where L is the lag-operator. The two first terms on the right-hand side captures the dynamics induced by staggered two-period contracts while the last term captures the stochastic trend driven by consumption smoothing. The obvious implication being that not only does the dynamics run forever due to staggered contracts, but the effects running via consumption smoothing have both a direct effect (the $\pi_{qc}\pi_{cu}$-terms) as well as an indirect arising form the interaction with the dynamics introduced by staggering (π_{qu} depends on π_{cu}). This way of expressing the terms of trade also brings out that the π_{qq} parameter is crucial for the speed at which the system converges to steady state.

It can be shown (see appendix D) that $\pi_{qu} < 0$ and that the terms of trade follows a plausible path in response to a monetary expansion.[17] That is, there is an initial decrease in the terms of trade which then gradually is worked out of the system. The long-run effect $((\pi_{qc}\pi_{cu})/(1-\pi_{qq}))$[18] remains a decrease if $\pi_{cu} < 0$ and vice versa for $\pi_{cu} > 0$. The model is thus capable of generating a path for the terms of trade similar to that observed in the data, whether it generates persistency of sufficient quantitative importance is another question (see below).

In the case of $\rho > 1$ (implying $\pi_{cu} > 0$) there exists a period in time t+j such that

$$\frac{\partial q_{t+j}}{\partial u_t} < 0 \quad \text{and} \quad \frac{\partial q_{t+j+1}}{\partial u_t} > 0, \;\; j > 0,$$

that is, up to and including period t+j the terms of trade is below its initial value, but afterwards the long-run effect dominates, and is above its initial value.

Note that in the absence of wealth reallocations ($\rho = 1$ implying $\pi_{cu} = 0$) the dynamics does not disappear contrary to the case with one-period contracts. In this case the dynamics is driven solely by the staggered contracts.

[17] This is always the case when $\rho \geq 1$. If $\rho < 1$ the dynamic adjustment is gradual at least from the period after the shock. More specifically, we cannot rule out that the terms of trade, in the period after the initial fall, moves in the opposite direction of the long-run level and then from there adjusts gradually towards the long-run level. Numerical exercises indicated that this perverse adjustment is highly unlikely.

[18] It is easily shown that $\pi_{qc} > 0$ (see appendix D).

For illustrative purposes we report some numerical examples. Since the model is highly abstract focussing only on a few mechanisms and relying on particular functional forms, we do not find that such numerical illustrations can be used to make inferences on the empirical power of the mechanisms considered here. At best such examples can be suggestive.

Figure 2 shows the impulse-response functions for the terms of trade following a 1 percent increase in the (relative) domestic money supply in period 1. The figure also shows how the impulse-response functions change to variations in the six parameters ρ, γ, μ, σ, ε and δ. The figures build on a baseline case where the parameter values are given in table 1

Table 1. Baseline values.[19]

ρ	γ	μ	σ	ε	δ
2	0.67	10	0.75	9	1/1.05

Figure 2 about here

The numerical illustrations indicate that the short-run relative price changes can be substantially larger than those observed in the long run and that they can take place despite relatively small current-account effects. This is related to the so-called Feldstein-Horioka paradox that relatively small current-account imbalances are observed despite perfect capital mobility. The present analysis suggests that substantial current-account imbalances do not necessarily arise despite asymmetric shocks and perfect capital mobility.

The numerical illustrations provided here may seem to indicate that the long-run effects are likely to be quantitatively small. This suggests that the propagation mechanism running via the current account is not important. Since current accounts are not affected by shocks under a complete set of capital markets this suggests moreover that incomplete capital markets do not have important implications for the dynamic adjustment path. Furthermore, it may also be concluded that the workhorse stochastic version which precludes current-account effects by assumption may provide a reasonable approximation to the results arising in the general case. However, these inferences are not supported by simply observing that the long-run effects seem to be quantitatively small. The sensitivity analysis clearly shows that the dynamic adjustment pattern captured by the persistency parameter changes substantially by variations in the parameters even though the long-run effects

[19] The elasticity parameter ρ is chosen to ensure that the Marshall-Lerner condition is fulfilled, γ is chosen to match the wage share of about 2/3 while μ is chosen so as to imply a labor-supply elasticity of 0.1. The three last coefficients correspond to those adopted in eg Hairault and Portier(1993) and Sutherland (1996).

tend to be small. The intuition for this is that the long-run effects on the terms of trade depends both on the sensitivity of labor supply to wealth and the current-account imbalances created by shocks.

Does the model generate effects of nominal shocks beyond the time period of the exogenously imposed contract length of two periods? It does if the demand elasticity is low, the elasticity of output with respect to labor is high or if labor supply is inelastic. Since all three properties may seem likely to hold (in the short run) this yields support to the view that staggering not only has an important qualitative role in producing a plausible path for the terms of trade (contrary to the one-period contracts) but also that it has quantitative importance. However, except in the limiting case where the labor elasticity of output is close to one the persistency generated is not as strong as observed in the data. This suggests that staggered two-period nominal wage contracts cannot fully solve the persistency puzzle.

Assessing the quantitative strength of the propagation mechanism, we find that staggered nominal wage contracts have an important effect both when compared to the effects arising in the case of one-period contracts and compared to the almost absent endogenous propagation in standard models, see eg Cogley and Nason (1995) and Hairault and Portier (1993). On the other hand, it is also clear that staggered two-period contracts cannot match a half-life of the effects of shocks at the level of 3-4 years even if the period length is interpreted as one year.

The numerical analysis thus brings out that staggered contracts have a nontrivial quantitative effect on the propagation mechanism, but also that the persistency puzzle cannot be resolved by this single mechanism. An open question is how long contracts have to be to yield a persistency mechanism as strong as that observed in the data.

6 Three-Period Nominal Wage Staggering

It is a natural next step to analyze how the dynamic properties change when the number of overlapping contracts is extended. We consider in this section overlapping three-period contracts. Longer duration of staggered contracts has two effects. First, longer nominal contracts prolong the impact real effects of nominal shocks. Secondly, the dynamic adjustment process changes due to the interaction between an increasing number of contracts set at different points in time. By interpreting the period length under three-period contracts as 2/3 of the period length under two-period contracts it is possible to analyze how less synchronization of wage formation affects the dynamic adjustment path for given contract lengths.

In line with the previous analysis we assume that nominal wages in a three-period contract are set as

$$\frac{1}{3}E_{t-1}\left(w_t + w_{t+1} + w_{t+2}\right),$$

implying that the aggregate wage holding in period t is given by

$$\begin{aligned}\overline{w}_t &= \frac{1}{9}(E_{t-3}w_{t-2} + E_{t-3}w_{t-1} + E_{t-3}w_t + E_{t-2}w_{t-1} \\ &\quad + E_{t-2}w_t + E_{t-2}w_{t+1} + E_{t-1}w_t + E_{t-1}w_{t+1} + E_{t-1}w_{t+2}).\end{aligned}$$

It is seen that less synchronization of wage formation extends both the backward and the forward looking elements in wage formation.

It can be shown (see appendix) that the terms of trade under this contract structure evolves according to

$$\begin{aligned}q_t &= \left(1+\pi_{qq}^1\right)q_{t-1} + \left(\pi_{qq}^2 - \pi_{qq}^1\right)q_{t-2} - \pi_{qq}^2 q_{t-3} + \pi_{qu}u_t \\ &\quad + \left(\pi_{qu}^1 - \pi_{qu} + \pi_{qc}\pi_{cu}\right)u_{t-1} + \left(\pi_{qu}^2 - \pi_{qu}^1\right)u_{t-2} - \pi_{qu}^2 u_{t-3}.\end{aligned}$$

It is immediately seen that the unit root property is maintained and that longer contract length extends the period over which shocks have an impact effect. The crucial question is how the persistency properties are changed. The terms of trade now follow an ARIMA(2,1,3) process, which suggests a qualitative difference compared to the case of two-period staggering.

To provide a numerical illustration, figure 3 plots the impulse-response functions for the terms of trade in the case of two- and three-period staggered contracts, respectively, for the baseline case considered in section 4 as well as showing how the impulse-response depends on the six parameters ρ, γ, μ, σ, ε and δ. It is seen that the persistency property is only affected very moderately in the case of three-period staggering.

Figure 3 about here

Summarizing our findings we find that the introduction of staggering (compare one-period contracts with staggered two-period contracts) has strong qualitative implications, while a strengthening of asynchronization (compare staggered two-period contracts with staggered three-period contracts) only has a moderate effect. We interpret this as indicating that the introduction of backward and forward looking elements via staggering is the important mechanism while further asynchronization has little effects. The latter might explain the apparent similarity of terms-of-trade (real exchange-rate) adjustment following shocks between countries with centralized wage determination and between countries between with decentralized wage determination.

Countries where few unions bargain in an asynchronized fashion might fit into our case with two-period overlapping contracts (eg Denmark vis-à-vis Sweden) whereas American-style flexible labor markets where wages change all the time might fit our case with n-period overlapping contracts where n is "large" (eg USA vis-à-vis UK). As just illustrated the dynamic adjustment did not differ.

7 Concluding Remarks

The present paper has shown how to explicitly find the stochastic equilibrium in the general case where current-account changes are allowed for. It was shown that current-account changes play a crucial role for the dynamic adjustment path. The study of the propagation of nominal shocks in open economies has brought forward two important insights on the possibility of accounting for persistent real effects of nominal shocks. First, if impact effects are generated by short-run nominal rigidities and propagation runs via real mechanisms, it is not possible to account for sluggish adjustment. The reason is that the impact effect under the standard assumption underlying the Marshall-Lerner condition via wealth effects will induce a reversal of the relative price effects after a period of length equal to the contract period. Second, plausible adjustment patterns are generated by staggered nominal contracts, showing that nominal inertia is needed to produce reasonable impulse-responses. One potential mechanism is asynchronized or staggered wage contracts capturing that price and wage decisions are not coordinated and made simultaneously in a decentralized market economy.

It is an open question whether the persistency generating mechanism induced by staggered contracts in itself is strong enough to match the persistency observed in the data. This may require the introduction of other (real) propagation mechanisms. One potential important channel would be real capital accumulation since the results of this paper show that the closer output and inputs move together, the stronger is persistency. Moreover, closed-economy models have shown that real capital accumulation and staggering reinforce each other as propagation mechanisms (see eg Andersen, 1999). An important topic for future research is thus to analyze how staggering and capital accumulation interacts in open economies.

It is interesting to note that the analytical approach demonstrates that the insights obtained by traditional short-run models based on the elasticity approach to some extent can be merged with the modern intertemporal analysis. In particular, it turns out that the elasticity condition determining whether the standard Marshall-Lerner condition is fulfilled plays a crucial role for the adjustment mechanism. Accordingly, the short-run predictions of standard models may be in accordance with those derived from fully specified intertemporal models. However, the dynamics implied by wealth reallocation may differ significantly from what can be inferred from standard models (compare to eg Marston, 1985).

A Steady State and Log-linearization

Our analysis builds on a version of the model set up in section 2 in log-deviations from steady state. As is apparent from the first-order conditions not all expressions are linear in logs and subsequently we have to approximate around the steady state. The steady-state version of the model is similar to that analyzed in eg Obstfeld and Rogoff (1995) and Tille (1999). We focus on a symmetric steady state where $B = B^* = 0$ and

$$C = C^* = Y^h = Y^{*f} = Y = Y^* = \alpha_y \left(\alpha_n \left(\kappa \alpha_y^{\sigma}\right)^{\frac{1}{\mu}}\right)^{\frac{-\mu\eta_{yw}}{\mu\eta_{nw}+\sigma\eta_{yw}+1}}, \tag{15}$$

$$r = \delta^{-1} - 1, \tag{16}$$

$$\frac{P^h}{P} = \frac{P^f}{P} = \frac{P^{*h}}{P^*} = \frac{P^{*f}}{P^*} = 1, \tag{17}$$

$$\frac{W}{P} = \frac{W^*}{P^*} = \left(\alpha_n \left(\kappa \alpha_y^{\sigma}\right)^{\frac{1}{\mu}}\right)^{\frac{\mu}{\mu\eta_{nw}+\sigma\eta_{yw}+1}}. \tag{18}$$

and where money is neutral and the price level is determined from (2).[20] Real incomes are

$$Y = \frac{P^h Y^h}{P}, \qquad Y^* = \frac{P^{*f} Y^{*f}}{P^*}.$$

Steady-state values are indicated by omission of time subscripts.

Next step is to log-linearize the first-order conditions arising from consumer optimization (1)-(3). The log-linearized Euler equation (4) is obtained by using the convenient formula for log-normally distributed variables

$$\log E\left(X^b\right) = bE\left(\log\left(X\right)\right) + \frac{b^2}{2} Var\left(\log\left(X\right)\right),$$

[20] The reader can convince himself that (15)-(18) is indeed a steady state by plugging into the first-order conditions, labor demands and supplies and output demands and supplies.

where b is a scalar and X is log-normally distributed. The labor-supply equation is easily linearized whereas the money demand warrants a comment. Taking logs on both sides of (2) yields the log of a sum and it is easy to show that around a steady state (disregarding constants)

$$\log(X_t + Z_t) = \frac{X}{X+Z}\log(X_t) + \frac{Z}{X+Z}\log(Z_t).$$

Using this we get that

$$\begin{aligned}\log\left[\lambda\left(\frac{M_t}{P_t}\right)^{-\varepsilon} + E_t\left(\delta C_{t+1}^{-\frac{1}{\sigma}}\right)\right] &= (1-\delta)\log\left[\lambda\left(\frac{M_t}{P_t}\right)^{-\varepsilon}\right] \\ &\quad +\delta\log\left[E_t\left(\delta C_{t+1}^{-\frac{1}{\sigma}}\right)\right].\end{aligned}$$

Equation (5) follows immediately with

$$\eta_{mc} = \frac{1}{\sigma(1-\delta)\varepsilon}, \qquad \eta_{mc}^1 = \frac{\delta}{\sigma(1-\delta)\varepsilon}, \qquad \eta_{mp} = \frac{\delta}{(1-\delta)\varepsilon}.$$

While the model is specified so as to yield a log-linear structure, we have that the budget constraint is linear in levels, ie

$$B_t = (1 + r_{t-1}) B_{t-1} + Y_t - C_t. \tag{19}$$

Subtracting the steady-state version of the budget constraint from (19) and dividing by Y(=C) we get

$$\begin{aligned}\frac{B_t - B}{Y} &= (1+r)\frac{B_{t-1}-B}{Y} + \frac{Y_t - Y}{Y} - \frac{C_t - C}{C} \\ &\quad + [(1+r_{t-1}) - (1+r)]\frac{B_{t-1}-B}{Y}.\end{aligned}$$

The last term on the right-hand side is negligible as we look at small deviations around steady state. We end up with

$$b_t = \delta^{-1} b_{t-1} + y_t - c_t, \tag{20}$$

as $1 + r = \delta^{-1}$ and

$$\begin{aligned} y_t &= \log\left(\frac{Y_t}{Y}\right) \approx \frac{Y_t - Y}{Y}, \\ b_t &= \log\left(\frac{B_t}{Y}\right) \approx \frac{B_t}{Y}, \\ c_t &= \log\left(\frac{C_t}{C}\right) \approx \frac{C_t - C}{C}. \end{aligned}$$

B Monopoly Union

This appendix demonstrates that the dynamic implications are unchanged if the labor market is characterized by imperfect competition.[21] We demonstrate this for a monopoly union under a right-to-manage structure, that is, the union sets the wage given the labor-demand function

$$N_t = \alpha_n \left(\frac{P_t^h}{W_t}\right)^{\eta_{nw}}.$$

The union is assumed to be utilitarian and thus sets the wage so as to maximize individual utility. From the household objective function this is found to imply the following first-order condition

$$C_t^{-\frac{1}{\sigma}} \left(\frac{N_t}{P_t} + \frac{W_t}{P_t}\frac{\partial W_t}{\partial W_t}\right) - \kappa N_t^{\mu}\frac{\partial N_t}{\partial W_t} = 0,$$

or

$$\frac{C_t^{-\frac{1}{\sigma}}}{P_t}(1-\eta_{nw}) = \kappa N_t^{\mu}\frac{\partial N_t}{\partial W_t}\frac{1}{N_t},$$

which can be written

$$\frac{W_t}{P_t}C_t^{-\frac{1}{\sigma}} = \kappa N_t^{\mu}\frac{\eta_{nw}}{\eta_{nw}-1}.$$

This is seen to be equivalent to the individual labor-supply curve up to the multiplicative factor $\frac{\eta_w}{\eta_{nw}-1} = \frac{1}{\gamma} > 1$ which reflects the market power of the union. This is a level effect which induces higher real wages and lower employment, but which does not have any implications for the dynamic properties of the model.

C Equilibrium with One-Period Nominal Wage Contracts

We conjecture a solution for the terms of trade and relative consumption as

$$q_t = \pi_{qc}\left(c_{t-1} - c_{t-1}^*\right) + \pi_{qu}u_t, \tag{21}$$

$$c_t - c_t^* = \pi_{cb}\left(b_{t-1} - b_{t-1}^*\right) + \pi_{cc}\left(c_{t-1} - c_{t-1}^*\right) + \pi_{cu}u_t. \tag{22}$$

Note that the Euler equation implies

$$E_t\left(c_{t+1} - c_{t+1}^*\right) = c_t - c_t^*,$$

which by use of (22) implies that

$$c_{t+1} - c_{t+1}^* = c_t - c_t^* + \pi_{cu}u_t.$$

[21] This is based on Andersen and Toulemonde (1999).

C.1 Terms of Trade

Form the equilibrium condition for the goods market we have

$$\begin{aligned} q_t &= \frac{\eta_{yw}}{\rho+\eta_{yw}}\eta_{wc}\left(c_{t-1}-c^*_{t-1}\right)+\frac{\eta_{yw}}{\rho+\eta_{yw}}\left(2\eta_{wp}-1\right)E_{t-1}q_t \\ &\quad +\frac{\eta_{yw}}{\rho+\eta_{yw}}\left(E_{t-1}s_t-s_t\right), \end{aligned}$$

where the Euler equation has been invoked. By use of the nominal exchange rate equation we find

$$q_t=\eta_{qc}\left(c_{t-1}-c^*_{t-1}\right)+\eta_{qq}E_{t-1}q_t+\eta_{qu}u_t,$$

$$\eta_{qc}=\frac{\eta_{yw}}{\rho+\eta_{yw}}\eta_{wc},$$

$$\eta_{qq}=\frac{\eta_{yw}}{\rho+\eta_{yw}}\left(2\eta_{wp}-1\right),$$

$$\eta_{qu}=-\frac{\eta_{yw}}{\rho+\eta_{yw}}\left(\pi_{sm}+\pi_{sc}\pi_{cu}\right).$$

Using (21) to determine $E_{t-1}q_t$ we find

$$q_t=\left(\eta_{qq}\pi_{qc}+\eta_{qc}\right)\left(c_{t-1}-c^*_{t-1}\right)+\eta_{qu}u_t. \tag{23}$$

Equalizing coefficients in (21) and (23) yields

$$\pi_{qc}=\eta_{qq}\pi_{qc}+\eta_{qc},$$

$$\pi_{qu}=\eta_{qu}.$$

C.2 Relative Consumption

From equation (20) we have

$$b_t-b^*_t=\delta^{-1}\left(b_{t-1}-b^*_{t-1}\right)+\left(y_t-y^*_t\right)-\left(c_t-c^*_t\right),$$

since

$$y_t-y^*_t=(1-\rho)\,q_t=(1-\rho)\left(\pi_{qc}\left(c_{t-1}-c^*_{t-1}\right)+\pi_{qu}u_t\right),$$

we have that

$$\begin{aligned} b_t-b^*_t &= \delta^{-1}\left(b_{t-1}-b^*_{t-1}\right) \\ &\quad +(1-\rho)\left(\pi_{qc}\left(c_{t-1}-c^*_{t-1}\right)+\pi_{qu}u_t\right)-\left(c_t-c^*_t\right). \end{aligned}$$

The next step is to find an expression for relative consumption consistent with the Euler equation. Leading our guess we find

$$\begin{aligned} E_t\left(c_{t+1}-c_{t+1}^*\right) &= \pi_{cb}\left(b_t-b_t^*\right)+\pi_{cc}\left(c_t-c_t^*\right) \\ &= \pi_{cb}\delta^{-1}\left(b_{t-1}-b_{t-1}^*\right)+\pi_{cb}\left(1-\rho\right)\pi_{qc}\left(c_{t-1}-c_{t-1}^*\right) \\ &\quad +\pi_{cb}\left(1-\rho\right)\pi_{qu}u_t+\left(\pi_{cc}-\pi_{cb}\right)\left(c_t-c_t^*\right). \end{aligned}$$

Using the Euler equation yields

$$\begin{aligned} c_t-c_t^* &= \left(1+\pi_{cb}-\pi_{cc}\right)^{-1}(\delta^{-1}\pi_{cb}\left(b_{t-1}-b_{t-1}^*\right) \\ &\quad +\pi_{cb}\left(1-\rho\right)\pi_{qc}\left(c_{t-1}-c_{t-1}^*\right)+\pi_{cb}\left(1-\rho\right)\pi_{qu}u_t. \end{aligned}$$

Consistency requires

$$\pi_{cb}=\left(1+\pi_{cb}-\pi_{cc}\right)^{-1}\delta^{-1}\pi_{cb},$$

$$\pi_{cc}=\left(1+\pi_{cb}-\pi_{cc}\right)^{-1}\pi_{cb}\left(1-\rho\right)\pi_{qc},$$

$$\pi_{cu}=\left(1+\pi_{cb}-\pi_{cc}\right)^{-1}\pi_{cb}\left(1-\rho\right)\pi_{qu}.$$

C.3 Analytical Characterization of the Solution

Proposition 1 $\pi_{qc}>0$.

Proof. From the restriction for π_{qc} it follows that $\pi_{qc}=\left(1-\eta_{qq}\right)^{-1}\eta_{qc}$ which is unambiguously positive as $\eta_{qq}\in(0,1)$ and $\eta_{qc}>0$. ■

Proposition 2 $\begin{cases} \pi_{cu}>0 \ \textit{if}\ \rho>1 \\ \pi_{cu}=0 \ \textit{if}\ \rho=1 \\ \pi_{cu}<0 \ \textit{if}\ \underline{\rho}\leq\rho<1, \quad \underline{\rho}\in(0,1) \end{cases}.$

Proof. It follows directly from the restrictions for π_{cc} and π_{cu} that

$$\frac{\pi_{cc}}{\pi_{cu}}=\frac{\pi_{qc}}{\pi_{qu}},$$

and by substitution we find

$$\pi_{cc}=\frac{\left(1-\delta\right)\left(1-\rho\right)\pi_{qc}}{1-\delta\left(1-\rho\right)\pi_{qc}},$$

implying that

$$\pi_{cu} = \frac{(1-\delta)(1-\rho)\pi_{qu}}{1-\delta(1-\rho)\pi_{qc}},$$

which can be rewritten using

$$\pi_{qu} = -\frac{\eta_{yw}}{\rho+\eta_{yw}}\left[1-(\sigma\varepsilon)^{-1}\pi_{cu}\right],$$

as

$$K_1\pi_{cu} = K_2,$$

where,

$$K_1 = 1-\delta(1-\rho)\pi_{qc} - (1-\delta)(1-\rho)\frac{\eta_{yw}}{\rho+\eta_{yw}}\frac{1}{\sigma\varepsilon},$$

$$K_2 = (1-\delta)(\rho-1)\frac{\eta_{yw}}{\rho+\eta_{yw}}.$$

There are three cases:
$\rho > 1 \Rightarrow K_1 > 0, K_2 > 0 \Rightarrow \pi_{cu} > 0,$
$\rho = 1 \Rightarrow K_1 > 0, K_2 = 0 \Rightarrow \pi_{cu} = 0,$
$\underline{\rho} \leq \rho < 1 \Rightarrow K_1 > 0, K_2 < 0 \Rightarrow \pi_{cu} < 0,$
where $\underline{\rho}$ is defined such that $K_1 > 0$ if $\rho \geq \underline{\rho}$. Note that $K_1 \to 1$ as $\rho \to 1$. ■

Proposition 3 $\pi_{qu} < 0$.

Proof. π_{qu} is given as $-\frac{\eta_{yw}}{\rho+\eta_{yw}}\left[1-(\sigma\varepsilon)^{-1}\pi_{cu}\right]$ and the result follows trivially for $\rho \leq 1$. For $\rho > 1$ note that $\pi_{cc} < 0 \Rightarrow \pi_{qu} = \frac{\pi_{qc}\pi_{cu}}{\pi_{cc}} < 0$ as $\pi_{cu} > 0$ and $\pi_{qc} = \eta_{qc} > 0$. ■

Proposition 4 $\frac{\partial s_t}{\partial u_t} > 0$.

Proof. $\pi_{qu} < 0 \Leftrightarrow 0 < 1-(\sigma\varepsilon)^{-1}\pi_{cu} = \frac{\partial s_t}{\partial u_t}$. ■

D Equilibrium with Two-Period Nominal Wage Staggering

We conjecture a solution for the terms of trade and relative consumption as

$$q_t = \pi_{qc}\left(c_{t-1} - c^*_{t-1}\right) + \pi_{qq} q_{t-1} + \pi_{qu} u_t + \pi^1_{qu} u_{t-1},$$

and

$$\begin{aligned} c_t - c^*_t &= \pi_{cb}\left(b_{t-1} - b^*_{t-1}\right) + \pi_{cc}\left(c_{t-1} - c^*_{t-1}\right) \\ &\quad + \pi_{cq} q_{t-1} + \pi_{cu} u_t + \pi^1_{cu} u_{t-1}. \end{aligned}$$

By the same reasoning as in appendix C

$$c_{t+1} - c^*_{t+1} = c_t - c^*_t + \pi_{cu} u_t. \tag{24}$$

D.1 Terms of Trade

Using the expressions for aggregate wages, product market equilibrium determines the terms of trade as

$$\begin{aligned} q_t &= \frac{\eta_{yw}}{4\rho + 4\eta_{yw}} 2\eta_{wc}\left[\left(c_{t-1} - c^*_{t-1}\right) + \left(c_{t-2} - c^*_{t-2}\right)\right] \\ &\quad + \frac{\eta_{yw}}{4\rho + 4\eta_{yw}}\left(2\eta_{wp} - 1\right)\left(E_{t-2}q_{t-1} + E_{t-2}q_t + E_{t-1}q_t + E_{t-1}q_{t+1}\right) \\ &\quad + \frac{\eta_{yw}}{4\rho + 4\eta_{yw}}\left(E_{t-2}s_{t-1} + E_{t-2}s_t + E_{t-1}s_t + E_{t-1}s_{t+1} - 4s_t\right), \end{aligned}$$

where we have invoked the Euler equation. Using the expression for the nominal exchange rate and (24) we arrive at

$$\begin{aligned} q_t &= \eta_{qc}\left(c_{t-1} - c^*_{t-1}\right) \\ &\quad + \eta_{qq}\left(E_{t-2}q_{t-1} + E_{t-2}q_t + E_{t-1}q_t + E_{t-1}q_{t+1}\right) \\ &\quad + \eta_{qu} u_t + \eta^1_{qu} u_{t-1}, \end{aligned}$$

where

$$\eta_{qc} = \frac{4\eta_{yw}}{4\rho + 4\eta_{yw}} \eta_{wc},$$

$$\eta_{qq} = \frac{\eta_{yw}}{4\rho + 4\eta_{yw}}\left(2\eta_{wp} - 1\right),$$

$$\eta_{qu} = -\frac{4\eta_{yw}}{4\rho + 4\eta_{yw}} \left(\pi_{sm} + \pi_{sc}\pi_{cu}\right),$$

$$\eta_{qu}^{1} = -\frac{2\eta_{yw}}{4\rho + 4\eta_{yw}} \left(\pi_{sm} + \pi_{sc}\pi_{cu} + \eta_{wc}\pi_{cu}\right).$$

Using our guess to find $E_{t-2}q_{t-1}$, $E_{t-2}q_t$, $E_{t-1}q_t$, and $E_{t-1}q_{t+1}$ we end up with

$$\begin{aligned} q_t &= \left(\eta_{qc} + 3\eta_{qq}\pi_{qc} + \eta_{qq}\pi_{qq}\pi_{qc}\right)\left(c_{t-1} - c_{t-1}^{*}\right) \\ &\quad + \left(\eta_{qq} + 2\eta_{qq}\pi_{qq} + \eta_{qq}\pi_{qq}^{2}\right) q_{t-1} + \eta_{qu}u_t \\ &\quad + \left[\eta_{qu}^{1} - \eta_{qq}\left(\pi_{qu} + \pi_{qc}\pi_{cu} + \pi_{qq}\pi_{qu} - \pi_{qu}^{1} - \pi_{qq}\pi_{qu}^{1}\right)\right] u_{t-1}. \end{aligned}$$

Hence,

$$\pi_{qc} = \eta_{qc} + 3\eta_{qq}\pi_{qc} + \eta_{qq}\pi_{qq}\pi_{qc},$$

$$\pi_{qq} = \eta_{qq} + 2\eta_{qq}\pi_{qq} + \eta_{qq}\pi_{qq}^{2},$$

$$\pi_{qu} = \eta_{qu},$$

$$\pi_{qu}^{1} = \eta_{qu}^{1} - \eta_{qq}\left(\pi_{qu} + \pi_{qc}\pi_{cu} + \pi_{qq}\pi_{qu} - \pi_{qu}^{1} - \pi_{qq}\pi_{qu}^{1}\right).$$

D.2 Relative Consumption

Given that

$$\begin{aligned} y_t - y_t^{*} &= (1-\rho)\, q_t \\ &= (1-\rho)\left[\pi_{qc}\left(c_{t-1} - c_{t-1}^{*}\right) + \pi_{qq}q_{t-1} + \pi_{qu}u_t + \pi_{qu}^{1}u_{t-1}\right], \end{aligned}$$

we have

$$\begin{aligned} b_t - b_t^{*} &= \delta^{-1}\left(b_{t-1} - b_{t-1}^{*}\right) - \left(c_t - c_t^{*}\right) \\ &\quad + (1-\rho)\left[\pi_{qc}\left(c_{t-1} - c_{t-1}^{*}\right) + \pi_{qq}q_{t-1} + \pi_{qu}u_t + \pi_{qu}^{1}u_{t-1}\right]. \end{aligned}$$

It follows that

$$\begin{aligned} E_t\left(c_{t+1} - c_{t+1}^{*}\right) &= \pi_{cb}\left[\delta^{-1}\left(b_{t-1} - b_{t-1}^{*}\right) - \left(c_t - c_t^{*}\right)\right] \\ &\quad + \pi_{cb}(1-\rho)\left[\pi_{qc}\left(c_{t-1} - c_{t-1}^{*}\right)\right. \\ &\quad \left. + \pi_{qq}q_{t-1} + \pi_{qu}u_t + \pi_{qu}^{1}u_{t-1}\right] \\ &\quad + \pi_{cc}\left(c_t - c_t^{*}\right) \\ &\quad + \pi_{cq}\left[\pi_{qc}\left(c_{t-1} - c_{t-1}^{*}\right) + \pi_{qq}q_{t-1} + \pi_{qu}u_t + \pi_{qu}^{1}u_{t-1}\right] \\ &\quad + \pi_{cu}^{1}u_t. \end{aligned}$$

Using the Euler equation yields

$$\begin{aligned}\left(1+\pi_{cb}-\pi_{cc}\right)\left(c_t-c_t^*\right) &= \delta^{-1}\pi_{cb}\left(b_{t-1}-b_{t-1}^*\right)\\ &+\left[\pi_{cb}\left(1-\rho\right)\pi_{qc}+\pi_{cq}\pi_{qc}\right]\left(c_{t-1}-c_{t-1}^*\right)\\ &+\left[\pi_{cb}\left(1-\rho\right)\pi_{qq}+\pi_{cq}\pi_{qq}\right]q_{t-1}\\ &+\left[\pi_{cb}\left(1-\rho\right)\pi_{qu}+\pi_{cq}\pi_{qu}+\pi_{cu}^1\right]u_t\\ &+\left[\pi_{cb}\left(1-\rho\right)\pi_{qu}^1+\pi_{cq}\pi_{qu}^1\right]u_{t-1}.\end{aligned}$$

Hence,

$$\pi_{cb}=\left(1+\pi_{cb}-\pi_{cc}\right)^{-1}\delta^{-1}\pi_{cb},$$

$$\pi_{cc}=\left(1+\pi_{cb}-\pi_{cc}\right)^{-1}\left[\pi_{cb}\left(1-\rho\right)\pi_{qc}+\pi_{cq}\pi_{qc}\right],$$

$$\pi_{cq}=\left(1+\pi_{cb}-\pi_{cc}\right)^{-1}\left[\pi_{cb}\left(1-\rho\right)\pi_{qq}+\pi_{cq}\pi_{qq}\right],$$

$$\pi_{cu}=\left(1+\pi_{cb}-\pi_{cc}\right)^{-1}\left[\pi_{cb}\left(1-\rho\right)\pi_{qu}+\pi_{cq}\pi_{qu}+\pi_{cu}^1\right],$$

$$\pi_{cu}^1=\left(1+\pi_{cb}-\pi_{cc}\right)^{-1}\left[\pi_{cb}\left(1-\rho\right)\pi_{qu}^1+\pi_{cq}\pi_{qu}^1\right].$$

D.3 Analytical Characterization of the Solution

Proposition 5 $\pi_{qq}\in(0,1)$.

Proof. π_{qq} is determined by the following quadratic $\eta_{qq}\pi_{qq}^2+\left(2\eta_{qq}-1\right)\pi_{qq}+\eta_{qq}=0$. It is easily seen that $\eta_{qq}=\frac{\eta_{yw}\left(2\eta_{wp}-1\right)}{4\rho+4\eta_{yw}}\in(0,\frac{1}{4})\Rightarrow\pi_{qq}=\frac{1-2\eta_{qq}-\sqrt{1-4\eta_{qq}}}{2\eta_{qq}}\in(0,1)$. ■

Proposition 6 $\frac{\partial\pi_{qq}}{\partial\rho}<0$, $\frac{\partial\pi_{qq}}{\partial\gamma}>0$ *and* $\frac{\partial\pi_{qq}}{\partial\mu}>0$.

Proof. Writing out the expression for η_{qq} we get $\eta_{qq}=\frac{\eta_{yw}\left(2\eta_{wp}-1\right)}{4\rho+4\eta_{yw}}=\frac{\gamma\mu}{(1-\gamma+\mu)[4\gamma+4\rho(1-\gamma)]}$. It is seen that $\frac{\partial\eta_{qq}}{\partial\rho}>0$, $\frac{\partial\eta_{qq}}{\partial\gamma}>0$ and $\frac{\partial\eta_{qq}}{\partial\mu}<0$ and the result follows straightforwardly as $\frac{d\pi_{qq}}{d\eta_{qq}}>0$. ■

Proposition 7 $\pi_{qc}>0$.

Proof. From the restriction governing π_{qc} we find $\pi_{qc} = \left(1 - 3\eta_{qq} - \eta_{qq}\pi_{qq}\right)^{-1}\eta_{qc}$. The result follows as both the denominator and the numerator are always positive as $\pi_{qq} \in (0,1)$, $\eta_{qq} \in (0, \frac{1}{4})$ and $\eta_{qc} = \frac{\eta_{yw}}{\rho+\eta_{yw}}\eta_{wc} = \frac{\eta_{yw}}{\rho+\eta_{yw}}\frac{1}{\sigma}\frac{1}{1+\mu\eta_{nw}} > 0$. ■

Proposition 8 $\pi_{cc} \lesseqqgtr 0$ *if* $\rho \gtreqqless 1$.

Proof. By substitution we find $\pi_{cc} = \frac{(1-\delta)(1-\rho)\frac{1}{1-\delta\pi_{qq}}\pi_{qc}}{1-\delta(1-\rho)\frac{1}{1-\delta\pi_{qq}}\pi_{qc}}$ and it follows directly that $\rho > 1 \Rightarrow \pi_{cc} < 0$ and $\rho = 0 \Rightarrow \pi_{cc} = 0$.We can find $\frac{\partial \pi_{cc}}{\partial \rho}$ to be $\left[(1-\rho)\frac{\partial \pi_{qc}}{\partial \rho} - \pi_{qc}\right](1-\delta)(1-\delta\pi_{qq}) + \delta(1-\delta)(1-\rho)\pi_{qc}\frac{\partial \pi_{qq}}{\partial \rho} \le 0$ for $\rho \le 1$. Since $\pi_{cc} = 0$ if $\rho = 1$ it follows that $\pi_{cc} > 0$ if $\rho \in (0,1)$. ■

For later reference it will be useful to define the following constants

$$K_1 = \frac{\pi_{cb}(1-\rho) + \pi_{cq}}{1 - \pi_{cb} + \pi_{cc}} = \delta\left[\pi_{cb}(1-\rho) + \pi_{cq}\right] = \frac{\pi_{cc}}{\pi_{qc}},$$

$$K_2 = \frac{\frac{1}{2} - \eta_{qq}(1+\pi_{qq})}{1 - \eta_{qq}(1+\pi_{qq})} > 0,$$

$$K_3 = \frac{\frac{2\eta_{yw}}{4\rho+4\eta_{yw}}\eta_{wc} + \eta_{qq}\pi_{qc}}{1 - \eta_{qq}(1+\pi_{qq})} > 0.$$

Lemma 9 $\frac{K_3}{\pi_{qc}} = \frac{1}{2}$.

Proof. $\frac{K_3}{\pi_{qc}} = \frac{1}{\pi_{qc}}\frac{\frac{2\eta_{yw}}{4\rho+4\eta_{yw}}\eta_{wc}+\eta_{qq}\pi_{qc}}{1-\eta_{qq}(1+\pi_{qq})} = \left[1 - \eta_{qq}(1+\pi_{qq})\right]^{-1}\left[\frac{2\eta_{yw}}{4\rho+4\eta_{yw}}\frac{\eta_{wc}}{\pi_{qc}} + \eta_{qq}\right]$

$= \left[1 - \eta_{qq}(1+\pi_{qq})\right]^{-1}\left[\frac{1}{2}\frac{4\eta_{yw}}{4\rho+4\eta_{yw}}\frac{\eta_{wc}\left(1-3\eta_{qq}-\eta_{qq}\pi_{qq}\right)}{\eta_{wc}\frac{4\eta_{yw}}{4\rho+4\eta_{yw}}} + \eta_{qq}\right]$
$= \left[1 - \eta_{qq}(1+\pi_{qq})\right]^{-1}\left[\frac{1}{2}\left(1 - 3\eta_{qq} - \eta_{qq}\pi_{qq}\right) + \eta_{qq}\right]$
$= \left[1 - \eta_{qq}(1+\pi_{qq})\right]^{-1}\left\{\frac{1}{2}\left[1 - \eta_{qq}(1+\pi_{qq})\right]\right\} = \frac{1}{2}$ ■

Lemma 10 $1 + \delta K_1 K_3 > 0$.

Proof. From $\pi_{cc} = K_1 \pi_{qc}$ it is seen that $\rho < 1 \Rightarrow K_1 > 0 \Rightarrow 1 + \delta K_1 K_3 > 0$ since $\pi_{cc} > 0$ and $\pi_{qc} > 0$. For $\rho = 1$ we have that $K_1 = \frac{\pi_{cc}}{\pi_{qc}} = 0 \Rightarrow 1 + \delta K_1 K_3 > 0$. For $\rho > 1$ ($\Rightarrow K_1 < 0$) we simply insert the expressions for K$_1$ and K$_3$: $1 + \delta K_1 K_3 > 0 \Rightarrow \delta \frac{\pi_{cc}}{\pi_{qc}} K_3 > -1 \Rightarrow \delta \pi_{cc} > -2 \Rightarrow -\frac{(1-\delta)(1-\rho)\frac{\pi_{qc}}{1-\delta\pi_{qq}}}{1-\delta(1-\rho)\frac{\pi_{qc}}{1-\delta\pi_{qq}}} < \frac{2}{\delta} \Rightarrow$
$(1+\delta)(1-\rho)\frac{\pi_{qc}}{1-\delta\pi_{qq}} < \frac{2}{\delta}$ and this is always fulfilled when $\rho > 1$. ■

Proposition 11 $\begin{cases} \pi_{cu} > 0 \;\; \textit{if} \; \rho > 1 \\ \pi_{cu} = 0 \;\; \textit{if} \; \rho = 1 \\ \pi_{cu} < 0 \;\; \textit{if} \; \underline{\rho} \leq \rho < 1, \quad \underline{\rho} \in (0,1) \end{cases}$.

Proof. Substituting the restriction governing π^1_{cu} into π_{cu} we obtain

$$\pi_{cu} = K_1 \left(\pi_{qu} + \delta \pi^1_{qu} \right).$$

Using that $\eta^1_{qu} = \frac{1}{2}\pi_{qu} - \frac{2\eta_{yw}}{4\rho + 4\eta_{yw}} \eta_{wc} \pi_{cu}$ we find

$$\pi^1_{qu} = K_2 \pi_{qu} - K_3 \pi_{cu}.$$

This implies that we can write π_{cu} as

$$(1 + \delta K_1 K_3) \pi_{cu} = K_1 (1 + \delta K_2) \pi_{qu},$$

or substituting in for π_{qu}

$$K_4 \pi_{cu} = K_5,$$

where,

$$K_4 = 1 + \delta K_1 K_3 - K_1 (1 + \delta K_2) \frac{\eta_{yw}}{\rho + \eta_{yw}} \frac{1}{\sigma \varepsilon},$$

$$K_5 = -\frac{\eta_{yw}}{\rho + \eta_{yw}} K_1 (1 + \delta K_2).$$

Again we have three cases:
$\rho > 1 \Rightarrow K_1 < 0, 1 + \delta K_1 K_3 > 0 \Rightarrow K_4 > 0, K_5 > 0 \Rightarrow \pi_{cu} > 0,$
$\rho = 1 \Rightarrow K_1 = 0 \Rightarrow K_4 > 0, K_5 = 0 \Rightarrow \pi_{cu} = 0,$
$\underline{\rho} \leq \rho < 1 \Rightarrow K_1 > 0 \Rightarrow K_4 > 0, K_5 < 0 \Rightarrow \pi_{cu} < 0,$
where $\underline{\rho}$ is defined such that $K_4 > 0$ if $\rho \geq \underline{\rho}$. Note that $K_4 \to 1$ as $\rho \to 1$. ■

Proposition 12 $\pi_{qu} < 0$.

Proof. Same as for proposition 3. ■

Lemma 13 *The terms of trade can be written as* $q_t = \sum_{j=0}^{\infty} \pi^j u_{t-j}$*, where,* $\pi^0 = \pi_{qu}$*,* $\pi^1 = \pi^1_{qu} + \pi_{qq}\pi_{qu} + \pi_{cu}\pi_{qc}$ *and* $\pi^{j+1} = \pi_{qq}\pi^j + \pi_{qc}\pi_{cu}$ *for* $j = 1, 2, ...$

Proof. From $q_t = (1 + \pi_{qq}) q_{t-1} - \pi_{qq} q_{t-2} + \pi_{qu} u_t + \left(\pi^1_{qu} - \pi_{qu} + \pi_{qc}\pi_{cu}\right) u_{t-1} - \pi^1_{qu} u_{t-2}$ the result follows straightfowardly by recursive substitution. ■

Proposition 14 *The terms of trade adjusts gradually to its long-run value if* $\rho \geq 1$.

Proof. $\rho > 1$: We know that $\pi_{cu} > 0$, $\pi_{qu} < 0$ and $\pi^1_{qu} = K_2\pi_{qu} - K_3\pi_{cu} < 0$. Furthermore, the long-run value $\frac{\pi_{qc}\pi_{cu}}{1-\pi_{qq}}$ is strictly positive. The basic strategy of the proof is to show $\pi^j < \pi^{j+1}$, $j = 0, 1, 2, ...$First, let us show that $\pi^0 < \pi^1$. The expression for π^1 is $\pi^1_{qu} + \pi_{qq}\pi_{qu} + \pi_{cu}\pi_{qc}$ which can be written as $(K_2 + \pi_{qq})\pi_{qu} + (\pi_{qc} - K_3)\pi_{cu}$. Since $(K_2 + \pi_{qq}) \in \left(\frac{1}{2}, 1\right)$ and $\pi_{qc} - K_3 > 0$ (by Lemma 9) π^1 has to be strictly greater that π^0. Next, we will show that $\pi^j < \pi^{j+1}$ for $j = 1, 2, ...$If $\pi^j < 0$, then π^{j+1} has to be larger than π^j as π^{j+1} is some fraction of π^j ($\pi_{qq} \in (0, 1)$) plus $\pi_{qc}\pi_{cu} > 0$. If $\pi^j > 0$ the result follows from observing that if $\pi^{j+1} < \pi^j$ then q_t would converge to zeros as $\pi^{j+1} < \pi^j \Rightarrow \pi^{j+2} < \pi^{j+1} \Rightarrow \pi^{j+3} < \pi^{j+2}$.....and we know q_t converges to $\frac{\pi_{qc}\pi_{cu}}{1-\pi_{qq}} > 0$. Note that π^j would never exceed the long-run value as this would imply π^{j+1} would be greater than the long-run value as well.

$\rho = 0$: When the demand elasticity is zero we have $\pi_{cu} = 0$, $\pi_{qu} < 0$ and $\pi^1_{qu} = K_2\pi_{qu} \in \left(\frac{1}{2}\pi_{qu}, 0\right)$. It is easily seen that $\pi^1 = (K_2 + \pi_{qq})\pi_{qu} > \pi_{qu} = \pi^0$. Furthermore, $\pi^{j+1} > \pi^j$ for all $j = 1, 2, ...$ as π^{j+1} is some fraction $\pi_{qq} \in (0, 1)$ of π^j. ■

Proposition 15 *If* $\underline{\rho} \leq \rho < 1$ *the terms of trade adjusts gradually to its long-run value at least from the period after the shock.*

Proof. With $\rho \in [\underline{\rho}, 1)$ we have that $\pi_{cu} < 0$, $\pi_{qu} < 0$ and $\frac{\pi_{qc}\pi_{cu}}{1-\pi_{qq}} < 0$. Lets split this case into two subcases: One (plausible), where the long-run effect is larger ($\pi_{qu} < \frac{\pi_{qc}\pi_{cu}}{1-\pi_{qq}}$), and one, where the long-run effect is smaller than the impact effect.

In the first subcase $\pi_{qu} < \frac{\pi_{qc}\pi_{cu}}{1-\pi_{qq}} < 0$. First notice that π^j, $j = 2, 3, ...$ would never exceed the long-run value $(\frac{\pi_{qc}\pi_{cu}}{1-\pi_{qq}})$ if $\pi^1 < \frac{\pi_{qc}\pi_{cu}}{1-\pi_{qq}}$as this would imply π^{j+1} also would exceed the long-run value contradicting that q converges to $\frac{\pi_{qc}\pi_{cu}}{1-\pi_{qq}}$. Lastly, notice that if $\pi^1 < \frac{\pi_{qc}\pi_{cu}}{1-\pi_{qq}}$ then $\pi^j < \pi^{j+1}$ for $j = 1, 2, ...$ has to be the case as the q would otherwise diverge from the long-run value. Similar arguments apply if $\pi^1 > \frac{\pi_{qc}\pi_{cu}}{1-\pi_{qq}}$.

In the second subcase $0 > \pi_{qu} > \frac{\pi_{qc}\pi_{cu}}{1-\pi_{qq}}$. First notice that π^j, $j = 2, 3, ...$would never dip below the long-run value $(\frac{\pi_{qc}\pi_{cu}}{1-\pi_{qq}})$ if $\pi^1 > \frac{\pi_{qc}\pi_{cu}}{1-\pi_{qq}}$ as this would imply π^{j+1} would be further below the long-run value contradicting that q converges to it. Lastly, notice that if $\pi^1 > \frac{\pi_{qc}\pi_{cu}}{1-\pi_{qq}}$ then $\pi^j > \pi^{j+1}$ for $j = 1, 2, ...$ has to be the case as q would otherwise diverge from the long-run value. Similar arguments apply if $\pi^1 < \frac{\pi_{qc}\pi_{cu}}{1-\pi_{qq}}$. ■

One implication of this proposition is that we cannot rule out, in the subcase of $\rho < 1$ and a long-run effect of the terms of trade larger than the impact effect, that after the initial deterioration in the period of the shock the terms of trade deteriorates further in the period after and from there gradually adjusts to its long-run level. Similarly, we cannot rule out, in the other subcase of $\rho < 1$ and a long-run effect of the terms of trade smaller (numerically larger) than the impact effect, that after the initial deterioration of the terms of trade, the terms of trade actually improves in the period after (relative to the impact level) and from then on gradually deteriorates to its long-run level which is below the impact level. That said, our numerical exercises showed that only for extreme and implausible parameter values would these cases arise, as well as the long-run effect of the terms of trade being smaller than the impact effect (numerically larger) seemed to be highly unlikely.

Proposition 16 $\frac{\partial s_t}{\partial u_t} > 0$.

Proof. Same as for proposition 4. ■

E Equilibrium with Three-Period Nominal Wage Staggering

We conjecture a solution for the terms of trade and relative consumption as

$$\begin{aligned} q_t &= \pi_{qc}\left(c_{t-1} - c^*_{t-1}\right) + \pi^1_{qq}q_{t-1} + \pi^2_{qq}q_{t-2} \\ &\quad + \pi_{qu}u_t + +\pi^1_{qu}u_{t-1} + \pi^2_{qu}u_{t-2}, \end{aligned}$$

and

$$\begin{aligned} c_t - c_t^* &= \pi_{cb}\left(b_{t-1} - b_{t-1}^*\right) + \pi_{cc}\left(c_{t-1} - c_{t-1}^*\right) + \pi_{cq}^1 q_{t-1} \\ &\quad + \pi_{cq}^2 q_{t-2} + \pi_{cu} u_t + \pi_{cu}^1 u_{t-1} + \pi_{cu}^2 u_{t-2}. \end{aligned}$$

As usual

$$c_{t+1} - c_{t+1}^* = c_t - c_t^* + \pi_{cu} u_t.$$

E.1 Terms of Trade

Product market equilibrium implies

$$\begin{aligned} q_t &= \frac{3\eta_{yw}}{9\rho + 9\eta_{yw}} \eta_{wc} \sum_{i=1}^{3} \left(c_{t-i} - c_{t-i}^*\right) \\ &\quad + \frac{\eta_{yw}}{9\rho + 9\eta_{yw}} \left(2\eta_{wp} - 1\right) \sum_{i=0}^{2}\sum_{j=0}^{2} E_{t-3+i} q_{t-2+j+i} \\ &\quad + \frac{\eta_{yw}}{9\rho + 9\eta_{yw}} \sum_{i=0}^{2}\sum_{j=0}^{2} E_{t-3+i} s_{t-2+j+i} - \frac{9\eta_{yw}}{9\rho + 9\eta_{yw}} s_t. \end{aligned}$$

Incorporating the Euler equation and the nominal exchange rate equation we get

$$\begin{aligned} q_t &= \eta_{qc}\left(c_{t-1} - c_{t-1}^*\right) + \eta_{qq} \sum_{i=0}^{2}\sum_{j=0}^{2} E_{t-3+i} q_{t-2+j+i} \\ &\quad + \eta_{qu} u_t + \eta_{qu}^1 u_{t-1} + \eta_{qu}^2 u_{t-2}, \end{aligned}$$

with

$$\eta_{qc} = \frac{9\eta_{yw}}{9\rho + 9\eta_{yw}} \eta_{wc},$$

$$\eta_{qq} = \frac{\eta_{yw}}{9\rho + 9\eta_{yw}} \left(2\eta_{wp} - 1\right),$$

$$\eta_{qu} = -\frac{9\eta_{yw}}{9\rho + 9\eta_{yw}} \left(\pi_{sm} + \pi_{sc}\pi_{cu}\right),$$

$$\eta_{qu}^1 = -\frac{6\eta_{yw}}{9\rho + 9\eta_{yw}} \left(\pi_{sm} + \pi_{sc}\pi_{cu} + \eta_{wc}\pi_{cu}\right),$$

$$\eta_{qu}^2 = -\frac{3\eta_{yw}}{9\rho + 9\eta_{yw}} \left(\pi_{sm} + \pi_{sc}\pi_{cu} + \eta_{wc}\pi_{cu}\right).$$

Taking expectations and plugging back in we find that

$$\begin{aligned}
& \left\{1 - \eta_{qq}\left[3 + 2\pi_{qq}^1 + \left(\pi_{qq}^1\right)^2 + \pi_{qq}^2\right]\right\} q_t \\
= \; & \left[\eta_{qc} + \eta_{qq}\left(3\pi_{qc} + \pi_{qq}^1\pi_{qc}\right)\right]\left(c_{t-1} - c_{t-1}^*\right) \\
& + \eta_{qq}\left(2 + 2\pi_{qq}^2 + \pi_{qq}^1\pi_{qq}^2\right) q_{t-1} \\
& + \eta_{qq} q_{t-2} \\
& + \left\{\eta_{qu} - \eta_{qq}\left[3\pi_{qu} + 2\pi_{qq}^1\pi_{qu} + \left(\pi_{qq}^1\right)^2\pi_{qu} + \pi_{qq}^2\pi_{qu}\right]\right\} u_t \\
& + \{\eta_{qu}^1 - \eta_{qq}[2\pi_{qu}^1 + 3\pi_{qc}\pi_{cu} + 2\pi_{qq}^1\pi_{qu} + 2\pi_{qu} + \pi_{qq}^1\pi_{qu}^1 \\
& + \pi_{qq}^1\pi_{qc}\pi_{cu} + \left(\pi_{qq}^1\right)^2\pi_{qu} + \pi_{qq}^2\pi_{qu} - \pi_{qu}^2 - \pi_{qq}^1\pi_{qu}^2]\} u_{t-1} \\
& + \{\eta_{qu}^2 - \eta_{qq}[\pi_{qu} + 2\pi_{qc}\pi_{cu} + \pi_{qu}^1 + \pi_{qq}^1\pi_{qu}^1 + \pi_{qq}^1\pi_{qc}\pi_{cu} \\
& + \pi_{qq}^1\pi_{qu} + \left(\pi_{qq}^1\right)^2\pi_{qu} + \pi_{qq}^2\pi_{qu} + \pi_{qu}^2]\} u_{t-2},
\end{aligned}$$

implying

$$\Phi = 1 - \eta_{qq}\left[3 + 2\pi_{qq}^1 + \left(\pi_{qq}^1\right)^2 + \pi_{qq}^2\right],$$

$$\pi_{qc} = \Phi^{-1}\left[\eta_{qc} + \eta_{qq}\left(3\pi_{qc} + \pi_{qq}^1\pi_{qc}\right)\right],$$

$$\pi_{qq}^1 = \Phi^{-1}\eta_{qq}\left(2 + 2\pi_{qq}^2 + \pi_{qq}^1\pi_{qq}^2\right),$$

$$\pi_{qq}^2 = \Phi^{-1}\eta_{qq},$$

$$\pi_{qu} = \Phi^{-1}\left\{\eta_{qu} - \eta_{qq}\left[3\pi_{qu} + 2\pi_{qq}^1\pi_{qu} + \left(\pi_{qq}^1\right)^2\pi_{qu} + \pi_{qq}^2\pi_{qu}\right]\right\},$$

$$\begin{aligned}
\pi_{qu}^1 = \; & \Phi^{-1}\{\eta_{qu}^1 - \eta_{qq}[3\pi_{qc}\pi_{cu} + \pi_{qq}^1\pi_{qc}\pi_{cu} + 2\pi_{qq}^1\pi_{qu} \\
& + \left(\pi_{qq}^1\right)^2\pi_{qu} + 2\pi_{qu}^1 + \pi_{qq}^1\pi_{qu}^1 \\
& + 2\pi_{qu} + \pi_{qq}^2\pi_{qu} - \pi_{qu}^2 - \pi_{qq}^1\pi_{qu}^2]\},
\end{aligned}$$

$$\begin{aligned}
\pi_{qu}^2 = \; & \Phi^{-1}\{\eta_{qu}^2 - \eta_{qq}[2\pi_{qc}\pi_{cu} + \pi_{qq}^1\pi_{qc}\pi_{cu} + \pi_{qu}^1 + \pi_{qq}^1\pi_{qu}^1 \\
& + \pi_{qq}^1\pi_{qu} + \left(\pi_{qq}^1\right)^2\pi_{qu} + \pi_{qq}^2\pi_{qu} + \pi_{qu}^2 + \pi_{qu}]\}.
\end{aligned}$$

E.2 Relative Consumption

Given that

$$\begin{aligned} y_t - y_t^* &= (1-\rho)\left[\pi_{qc}\left(c_{t-1} - c_{t-1}^*\right) + \pi_{qq}^1 q_{t-1} + \pi_{qq}^2 q_{t-2} \right. \\ &\left. \quad + \pi_{qu} u_t + + \pi_{qu}^1 u_{t-1} + \pi_{qu}^2 u_{t-2}\right], \end{aligned}$$

we have from (20) that

$$\begin{aligned} b_t - b_t^* &= \delta^{-1}\left(b_{t-1} - b_{t-1}^*\right) + (1-\rho)\left[\pi_{qc}\left(c_{t-1} - c_{t-1}^*\right) \right. \\ &\quad \left. + \pi_{qq}^1 q_{t-1} + \pi_{qq}^2 q_{t-2} + \pi_{qu} u_t + \pi_{qu}^1 u_{t-1} + \pi_{qu}^2 u_{t-2}\right] \\ &\quad - \left(c_t - c_t^*\right). \end{aligned}$$

Furthermore we have

$$\begin{aligned} E_t\left(c_{t+1} - c_{t+1}^*\right) &= \pi_{cb}\left(b_t - b_t^*\right) + \pi_{cc}\left(c_t - c_t^*\right) + \pi_{cq}^1 q_t \\ &\quad + \pi_{cq}^2 q_{t-1} + \pi_{cu}^1 u_t + \pi_{cu}^2 u_{t-1}, \end{aligned}$$

which using our expressions for the terms of trade, relative consumption and relative bondholdings can be written as

$$\begin{aligned} & E_t\left(c_{t+1} - c_{t+1}^*\right) \\ = \; & \pi_{cb}\left\{\delta^{-1}\left(b_{t-1} - b_{t-1}^*\right) + (1-\rho)\left[\pi_{qc}\left(c_{t-1} - c_{t-1}^*\right) + \pi_{qq}^1 q_{t-1} \right.\right. \\ & \left.\left. + \pi_{qq}^2 q_{t-2} + \pi_{qu} u_t + \pi_{qu}^1 u_{t-1} + \pi_{qu}^2 u_{t-2}\right] - \left(c_t - c_t^*\right)\right\} \\ & + \pi_{cc}\left(c_t - c_t^*\right) \\ & + \pi_{cq}^1\left[\pi_{qc}\left(c_{t-1} - c_{t-1}^*\right) + \pi_{qq}^1 q_{t-1} \right. \\ & \left. + \pi_{qq}^2 q_{t-2} + \pi_{qu} u_t + + \pi_{qu}^1 u_{t-1} + \pi_{qu}^2 u_{t-2}\right] \\ & + \pi_{cq}^2 q_{t-1} + \pi_{cu}^1 u_t + \pi_{cu}^2 u_{t-1}, \end{aligned}$$

and using the Euler equation we get

$$\begin{aligned} & \left(1 + \pi_{cb} - \pi_{cc}\right)^{-1}\left(c_t - c_t^*\right) \\ = \; & \pi_{cb}\left\{\delta^{-1}\left(b_{t-1} - b_{t-1}^*\right) + (1-\rho)\left[\pi_{qc}\left(c_{t-1} - c_{t-1}^*\right) + \pi_{qq}^1 q_{t-1} \right.\right. \\ & \left.\left. + \pi_{qq}^2 q_{t-2} + \pi_{qu} u_t + + \pi_{qu}^1 u_{t-1} + \pi_{qu}^2 u_{t-2}\right]\right\} \\ & + \pi_{cq}^1\left[\pi_{qc}\left(c_{t-1} - c_{t-1}^*\right) + \pi_{qq}^1 q_{t-1} \right. \\ & \left. + \pi_{qq}^2 q_{t-2} + \pi_{qu} u_t + + \pi_{qu}^1 u_{t-1} + \pi_{qu}^2 u_{t-2}\right] \\ & + \pi_{cq}^2 q_{t-1} + \pi_{cu}^1 u_t + \pi_{cu}^2 u_{t-1}, \end{aligned}$$

implying the following restrictions must hold

$$\pi_{cb} = \left(1 + \pi_{cb} - \pi_{cc}\right)^{-1} \delta^{-1} \pi_{cb},$$

$$\pi_{cc} = (1 + \pi_{cb} - \pi_{cc})^{-1} \left[\pi_{cb} (1 - \rho) \pi_{qc} + \pi^1_{cq} \pi_{qc} \right],$$

$$\pi^1_{cq} = (1 + \pi_{cb} - \pi_{cc})^{-1} \left[\pi_{cb} (1 - \rho) \pi^1_{qq} + \pi^1_{cq} \pi^1_{qq} \right],$$

$$\pi^2_{cq} = (1 + \pi_{cb} - \pi_{cc})^{-1} \left[\pi_{cb} (1 - \rho) \pi^2_{qq} + \pi^1_{cq} \pi^2_{qq} \right],$$

$$\pi_{cu} = (1 + \pi_{cb} - \pi_{cc})^{-1} \left[\pi_{cb} (1 - \rho) \pi_{qu} + \pi^1_{cq} \pi_{qu} + \pi^1_{cu} \right],$$

$$\pi^1_{cu} = (1 + \pi_{cb} - \pi_{cc})^{-1} \left[\pi_{cb} (1 - \rho) \pi^1_{qu} + \pi^1_{cq} \pi^1_{qu} + \pi^2_{cu} \right],$$

$$\pi^2_{cu} = (1 + \pi_{cb} - \pi_{cc})^{-1} \left[\pi_{cb} (1 - \rho) \pi^2_{qu} + \pi^1_{cq} \pi^2_{qu} \right].$$

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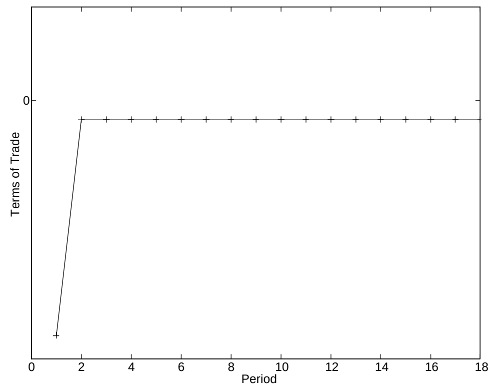
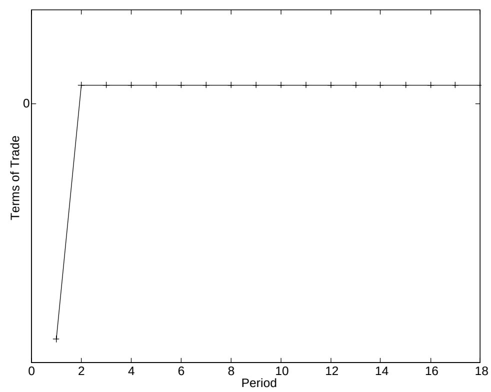
Figure 1
Qualitative terms-of-trade impulse-responses to an expansion in Home money supply (1 percent) with one-period wage contracts[22]



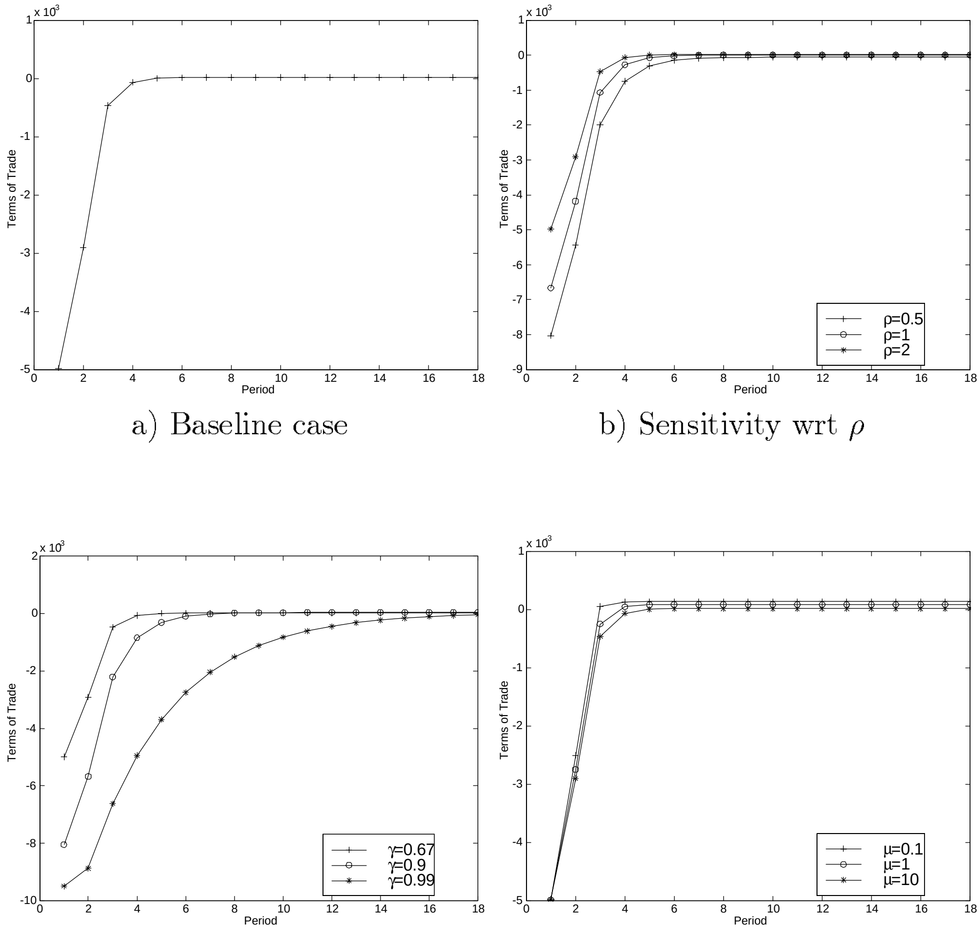
a) $\rho < 0$



b) $\rho > 0$

[22]For both $\rho > 0$ and $\rho < 0$ the long-run effects are numerically smaller than the impact-effects for the impulse-responses depicted in figure 1. Under mild conditions this is always the case. For $\rho > 1$ this is ensured if $\delta > \frac{1}{2}$. If $\underline{\rho} \leq \rho < 1$, the sufficient condition is $\sigma > \frac{(1-\rho)\gamma}{(1-\rho)\gamma+(1+\mu)\rho}$ which is likely to hold for plausible parameter values.

Figure 2
Terms-of-trade impulse-responses to an expansion in Home money supply (1 percent) with two-period staggered wage contracts



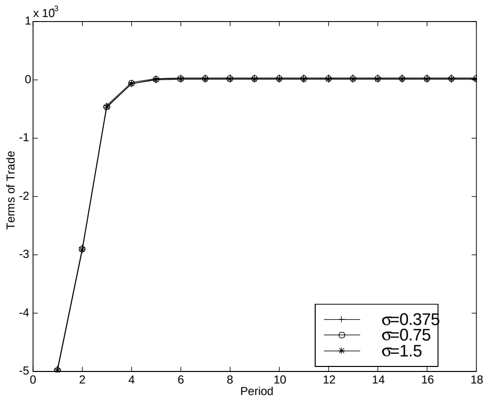
a) Baseline case

b) Sensitivity wrt ρ

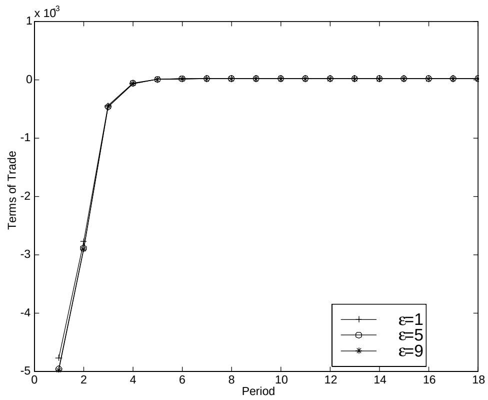
c) Sensitivity wrt γ

d) Sensitivity wrt μ

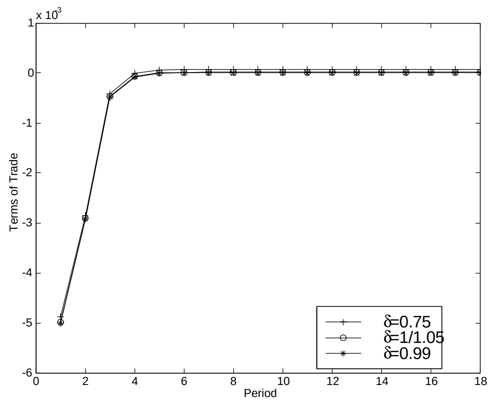
Figure 2
Terms-of-trade impulse-responses to an expansion in Home money supply (1 percent) with two-period staggered wage contracts (continued)



e) Sensitivity wrt σ

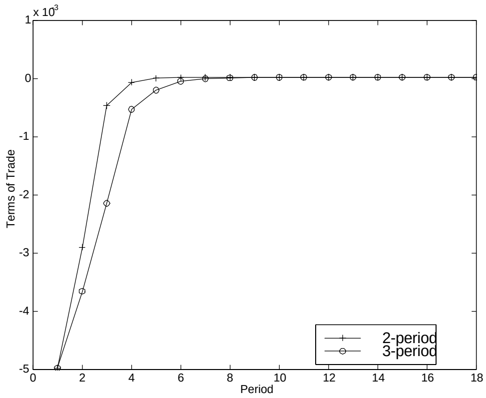


f) Sensitivity wrt ε

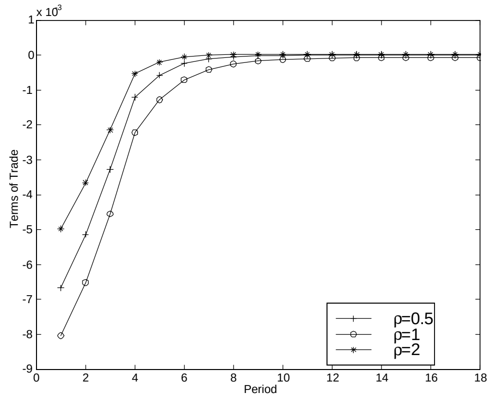


g) Sensitivity wrt δ

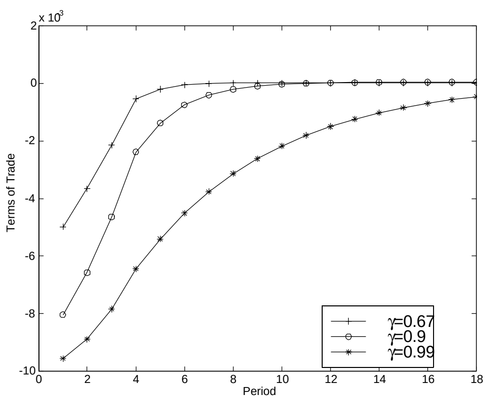
Figure 3
Terms-of-trade impulse-responses to an expansion in Home money supply (1 percent) with three-period staggered wage contracts



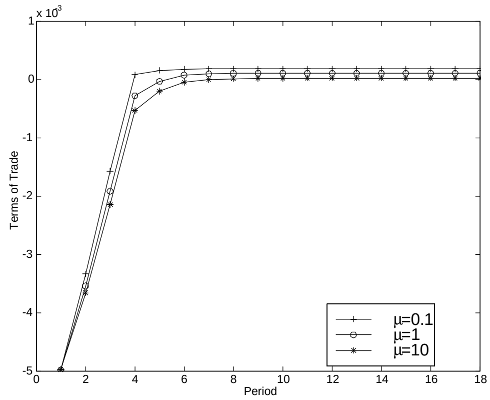
a) Baseline case



b) Sensitivity wrt ρ

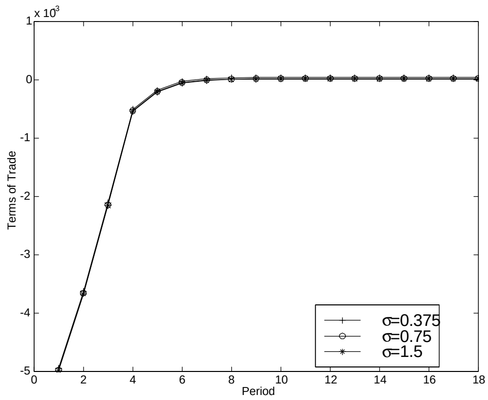


c) Sensitivity wrt γ

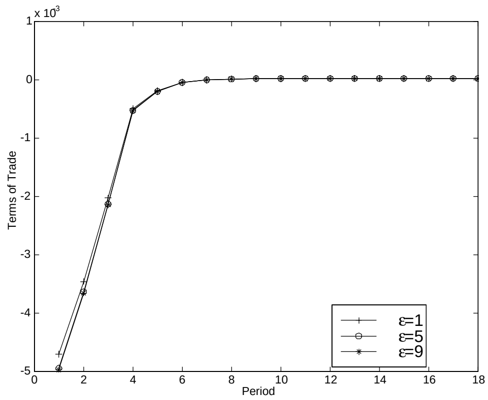


d) Sensitivity wrt μ

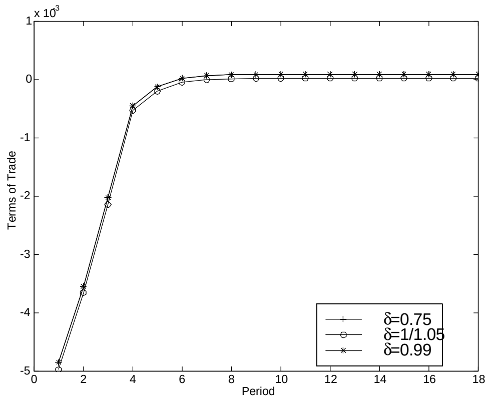
Figure 3
Terms-of-trade impulse-responses to an expansion in Home money supply (1 percent) with three-period staggered wage contracts (continued)



e) Sensitivity wrt σ



f) Sensitivity wrt ε



g) Sensitivity wrt δ

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