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RESEARCH MEMORANDUM

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INTERREGIONAL PROPAGATION OF INFLATIONARY SHOCKS

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Abstract

This paper examines the propagation of imported inflation for an economy consisting of n interlinked identical regions, which together form a closed system. Stability of the global price system requires at least one pre-linkage elasticity multiplier of inflation with respect to foreign inflation which is smaller than one. Ranking of the pre-linkage multipliers gives rise to the concept of a hierarchy of regions.

1. Introduction

The common feature of models of the world economy is linkage through trade flows, so that domestic shocks may be transmitted abroad through the resulting changes in import demand of the initiating country. In addition direct linkages between foreign and domestic prices may also serve as international transmission channels.

This paper deals with the modelling of linkage through pricing. Using a wage-price model with cost-determined pricing, the paper focusses on the possibility of a hierarchy of the pre-linkage elasticity multipliers with respect to foreign inflation and the consequences of this for the inter-regional propagation of inflationary shocks.

The paper is organized as follows. Section 2 describes the model of the closed economy, which in section 3 is decomposed into an economy with n interlinked identical regions which together form a closed system. Section 4 presents the ranking of regions within the context of a three-region world economy and shows some examples.

2. The closed economy

Consider the following simple model, simultaneously predicting the growth rate of nominal wages w and the rate of inflation p:

$$w = \nu L_{\nu}^{j} p + \underline{w} \quad \text{and} \quad p = \varepsilon L_{\varepsilon}^{j} p + \psi w + \underline{p}$$

The underlined variables $\underline{w}$ and $\underline{p}$ represent wage shocks and price shocks respectively, but in a more elaborate setting they could be replaced and/or supplemented by an endogenous price adjustment mechanism (See Van Schaik, 1988). The coefficients ν, ψ and ε are behavioural parameters, which are positive and in the ultimate case zero. The lag operator is defined by: $L^{j}y = y_{-j}$. The paramater ν is the elasticity of wages with respect to prices. The parameter ψ denotes the short run elasticity of prices with respect to unit labour cost, whereas ε is the coefficient of subsequent adjustment. The long run adjustment coefficient equals $\psi/(1-\varepsilon)$. Full adjustment in the long run implies that this elasticity is unity, i.e. $\varepsilon+\psi=1$, so that there is full-cost pricing.

The final equation for the rate of inflation is obtained by substituting the wage equation into the price equation. For example, if $L_{\nu}^{0}p$ = p and $L_{\varepsilon}^{1}p$ = p_{-1}, then:

$$p - \frac{\varepsilon}{1-\nu\psi}\, p_{-1} = \frac{\psi}{1-\nu\psi}\, \underline{w} + \frac{1}{1-\nu\psi}\, \underline{p} \qquad (1)$$

The LHS shows that the dynamic behaviour of prices is convergent if the ratio $\varepsilon/(1-\nu\psi)$ is smaller than one. This ratio is the elasticity multiplier of inflation with respect to past inflation. If $\nu=1$ (full price compensation) it will be smaller than one if there exists less than full-cost pricing: $\psi<(1-\varepsilon)$, which is a well-known proposition from markup pricing literature. The other extreme is $\nu=0$ (no price compensation), in which case it must hold that: $\varepsilon<1$. The consequences of making this distinction can be recognized by considering the particular solution of the real wage equation, which for a constant rate of inflation reads as:

$$w-p = \frac{1-\varepsilon-\psi}{1-\varepsilon-\nu\psi}\, \underline{w} + \frac{\nu-1}{1-\varepsilon-\nu\psi}\, \underline{p}$$

Of course this solution embodies all possible lag-structures of the model given above. From this equation it can be deduced that in the case of full price compensation, i.e. $\nu=1$, real wages are rigid to a great extent. In that case - which will be called real wage rigidity - changes of the real wage, which may induce enterpreneurs to substitute between labour and capital, only depend on nominal wage pressures. In addition there is the possibility that real wages also depend on price shocks. The latter will be called nominal wage rigidity, because nominal wages as such do not react on price shocks, whereas real wages do, provided that there is less than full price compensation, i.e. $\nu<1$.

3. The world economy

The closed economy will now be decomposed into an economy with n interlinked regions which together form a closed system. By diagonalizing the scalar equation (1) the following vector equation results:

$$\mathbf{p} - \mathbf{p}^{*}_{-1}\mathbf{E} = \underline{\mathbf{w}}\mathbf{Y} + \underline{\mathbf{p}}\mathbf{Z} \tag{2}$$

Here big characters refer to square matrices and small characters to row vectors (with n entries). The meaning of the symbols is easily understood by realizing that the elements of the vectors represent the regional variables in question. Add to this that every element is provided with the superscript i (i=1,2,...,n).

Now on comparing equation (2) with equation (1), it appears that the scalars $\varepsilon/(1-\nu\psi)$, $\psi/(1-\nu\psi)$ and $1/(1-\nu\psi)$ have been replaced by the diagonal matrices **E**, **Y** and **Z**. Next to this $\mathbf{p}^{*}$ symbolizes the vector of import prices, whereas $\varepsilon^{i}/(1-\nu^{i}\psi^{i})$ is now the pre-linkage elasticity multiplier of inflation with respect to lagged foreign inflation.

Assuming non-discriminatory pricing the regional import prices are a weighted average of the export prices of the supplying regions, in which case equation (2) becomes:

$$\mathbf{p} - \mathbf{p}_{-1}\mathbf{X} = \underline{\mathbf{w}}\mathbf{Y} + \underline{\mathbf{p}}\mathbf{Z} \tag{3}$$

In this equation **X** = **AE**, which means that the linkage of the regional models takes place here with the aid of a matrix, denoted by **A**. This matrix is a set of trade shares. If countries are involved, the diagonal elements are zero. If regions are involved, intercountry trade is entered on the diagonal. Therefore it is clear that there are great simularities between **A** and the matrices used in input-output-analysis; the problem of allowing for changing trade shares is quite the same as the problem of allowing for changing technology in input-output analysis (See Klein, 1983).

In this paper it is assumed that **A** is a matrix with constant coefficients. Intra-trade will be left out of consideration. Moreover, the trade shares are assumed to have the same value, so that the regions can be called identical. The latter implies that **A** is a matrix with (per column) the shares of the other regions in the imports of region i, each with magnitude 1/(n-1).

Equation (3) shows that the regional rates of inflation may depend on each other according to the composition of interregional trade and the values of the behavioural parameters. In **X** every column of matrix A has been multiplied with its "own" multiplier $e^i=\varepsilon^i/(1-\nu^i\psi^i)$. Therefore it can be stated that **X** is a nonnegative matrix if: $0\leq\nu^i\psi^i<1$ and $\varepsilon^i\geq 0$.

The existence of these conditions is evident from the economic point of view: the regional pre-linkage elasticity multipliers must be positive or in the ultimate case zero. They do not guarantee however that the dynamic behaviour of the linked regional rates of inflation is convergent, i.e. that the global elasticity multiplier of inflation with respect to past inflation is smaller than one. Referring to the mathematical properties of nonnegative matrices it must be added that this is the case if the conditions of Hawkins and Simon are satisfied. (Berman and Plemmons, 1979). Then the inverse of the matrix **(I-X)** is a semipositive matrix. Consequently the particular solution of equation (3) exists and reads as:

$$\mathbf{p} = \underline{\mathbf{w}}\mathbf{Y}(\mathbf{I}-\mathbf{X})^{-1} + \underline{\mathbf{p}}\mathbf{Z}(\mathbf{I}-\mathbf{X})^{-1} \qquad (4)$$

This equation simply states that inflationary shocks lead to inflation. In addition, if all $\varepsilon^i>0$, inflation is propagated into every region.

4. Hierarchy of regions

As from the empirical point of view it is hard to imagine the existence of an arbitrary number of identical regions, it suffices to distinguish only three of them. In this case the conditions of Hawkins and Simon are specified as follows:

$$1>0,\quad \begin{vmatrix} 1 & -e^2/2 \\ -e^1/2 & 1 \end{vmatrix} >0,\quad \begin{vmatrix} 1 & -e^2/2 & -e^3/2 \\ -e^1/2 & 1 & -e^3/2 \\ -e^1/2 & -e^2/2 & 1 \end{vmatrix} >0$$

It is clear that these conditions generalize the proposition that in a closed economy the dynamic behaviour of the rate of inflation is convergent if the (closed economy) elasticity multiplier of inflation with respect to past inflation is smaller than one. But as a corollary in the case of completely identical price systems ($e^i=e$, for $i=1,2,3$), every regional multiplier must be smaller than one. Notice that this special case still embodies the possibility of regional differences in wage rigidity.

Generally speaking, however, for the conditions of Hawkins and Simon to be satisfied there must be at least one region where the pre-linkage multiplier is smaller than one. (At least one column sum of the matrix **I-X** must be smaller than one.) In this respect it is possible to make the following distinction. If the multiplier in some region is greater than one we shall call this a strong region. Next to this we speak of a neutral region if the multiplier in that region is exactly equal to one and of a weak region if the multiplier in that region is smaller than one. Thus by ranking the regional elasticity multipliers it is possible to describe a hierarchy of regions. The following matrix may serve to get acquainted with the consequences of making such a hierarchy (n=3):

$$(\mathbf{I}-\mathbf{X})\mathbf{Z}^{-1} = \begin{bmatrix} 1-\nu^1\psi^1 & -\varepsilon^2/2 & -\varepsilon^3/2 \\ -\varepsilon^1/2 & 1-\nu^2\psi^2 & -\varepsilon^3/2 \\ -\varepsilon^1/2 & -\varepsilon^2/2 & 1-\nu^3\psi^3 \end{bmatrix}$$

This matrix calculates the (row) vector of price shocks $\underline{\mathbf{p}}$ from $\mathbf{p}[(\mathbf{I}-\mathbf{X})\mathbf{Z}^{-1}]$.

If p is assumed to be the unit vector, the matrix shows how an uniform rate of world inflation can be matched with a variety of regional price shocks. To give an example, consider the case that region 2 is the neutral region and that the other regions are respectively weak and strong, such that $0<\nu^1\psi^1=\nu^2\psi^2=\nu^3\psi^3=1-\varepsilon^2<1$, $\varepsilon^1=(1-\delta)\varepsilon^2$ and $\varepsilon^3=(1+\delta)\varepsilon^2$, with $0<\delta 1$. (For this case the conditions of Hawkins and Simon are satisfied.) Thus it appears that the price shocks corresponding with the predetermined uniform rate of inflation are zero in the neutral region 2, whereas the positive price shocks of the weak region 1 are exactly counterbalanced by the negative price shocks of the strong region 3. In other words: there is global inflation, but the underlying aggregate of price shocks is zero. This is explained as follows.

The strong region exhibits a pre-linkage multiplier, which is greater than one. As a consequence a positive price shock in this region induces less world inflation than an equivalent shock in one of the other regions. Thus for inflation to be uniform all over the world, the positive price shock of the weak region has to be compensated for by a negative price shock of the strong region, whereas the neutral region can remain passive.

An important consequence of the distinction made above is that a weak region meets with losses in the terms of trade if there is a positive shock in some other region, whereas a neutral region exactly absorbs inflation from foreign origine, so that the terms of trade remains unchanged. An effective way to grasp this is to consider a numerical example. [Notice that the terms of trade or the real exchange rate is defined as $\mathbf{p}-\mathbf{p}^*$, whereas import prices are settled by $\mathbf{p}^*=\mathbf{pA}$, so that $\mathbf{p}-\mathbf{p}^*=\mathbf{p}(\mathbf{I}-\mathbf{A})$.]

For the example we assume full-cost pricing in every region, such that region 1 is fully insensitive for foreign inflation ($\varepsilon^1=0$), whereas for region 3 the opposite holds ($\varepsilon^3=1$). Region 2 takes a middle position, for instance $\varepsilon^2=0.5$. Next to this we assume there is nominal wage rigidity in region 1 ($\nu^1=0$) and real wage rigidity in region 2 ($\nu^2=1$). The value of the parameter ν^3 can be left open, because in this region the value of the elasticity of prices with respect to unit labour cost is zero. In this example $e^1=0$, so that region 1 can be called a weak region. For the other regions it holds that $e^2=e^3=1$, so that they can be called neutral. Using this information equation (4) reads as:

$$\mathbf{p} = \underline{\mathbf{w}} \begin{bmatrix} 1 & 1 & 1 \\ 0 & 4/3 & 2/3 \\ 0 & 0 & 0 \end{bmatrix} + \underline{\mathbf{p}} \begin{bmatrix} 1 & 1 & 1 \\ 0 & 8/3 & 4/3 \\ 0 & 2/3 & 4/3 \end{bmatrix}$$

The example shows that shocks from region 1 lead to an uniform rate of inflation "all over the world". As a consequence these shocks do not change the terms of trade. This is caused by the fact that the other regions exactly absorb inflation, originating from region 1. Contrary to this, shocks from region 2 are reinforced by the workings of the internal wage-price-spiral of this region. That is why these shocks do change the terms of trade, which is characteristic for the position of a weak region vis-à-vis the position of a neutral region. (The complete insensitivity of inflation in region 1 for foreign inflation does not matter in this respect.)

As both the regions 2 and 3 are neutral regions, the inflationary impulses originating from region 2 are carried forward to region 3 and vice versa, without affecting the terms of trade between these regions. As a consequence the terms of trade of the weak region 1 always deteriorates if there are inflationary impulses somewhere else in the world.

It must be remarked that these results refer to the long run. In the short run the terms of trade changes according to the usual expected pattern, i.e. that an inflationary shock originating from some region improves the terms of trade of that region.

5. Epilogue

Research on stability of global price systems is mainly found in applied econometric work. An example is in Hickman and Lima (1979), who report own- and cross-country multipliers for price changes induced by exogenous wage shocks in the various national models included in Project LINK. In these models the typical wage equation relates the rate of change in the wage rate to current or lagged rates of change of prices, who themselves depend on changes in unit labour costs and import prices. The authors conclude that over the four-year interval covered by the simulations a wage shock can produce radically different behaviour in the various models despite their general family resemblance. A striking result is that the inflation-rate multipliers for wages and prices increase continuously in The Netherlands and UK models, so that the process is explosive. However, Hickman and Lima do not give an effective explanation of the observed differences. In this respect as can be learned from the analysis given above it would be recommendable first to describe a hierarchy of countries in Project LINK and second to interprete the simulations with the aid of the results obtained from preliminary analysis.

Appendix 1 A numerical example for 3 regions

This appendix gives a complete exposition of the numerical example of section 4.

Parameters:

	ε	ψ	ν
Region 1:	0.0	1.0	0.0;
Region 2:	0,5	0.5	1.0;
Region 3:	1.0	0.0	ν.

Results:

$$p = \underline{w}\begin{bmatrix} 1 & 1 & 1 \\ 0 & 4/3 & 2/3 \\ 0 & 0 & 0 \end{bmatrix} + \underline{p}\begin{bmatrix} 1 & 1 & 1 \\ 0 & 8/3 & 4/3 \\ 0 & 2/3 & 4/3 \end{bmatrix}$$

$$w = \underline{w}\begin{bmatrix} 1 & 1 & \nu \\ 0 & 7/3 & 2\nu/3 \\ 0 & 0 & 1 \end{bmatrix} + \underline{p}\begin{bmatrix} 0 & 1 & \nu \\ 0 & 8/3 & 4\nu/3 \\ 0 & 2/3 & 4\nu/3 \end{bmatrix}$$

$$p^* = \underline{w}\begin{bmatrix} 1 & 1 & 1 \\ 1 & 1/3 & 2/3 \\ 0 & 0 & 0 \end{bmatrix} + \underline{p}\begin{bmatrix} 1 & 1 & 1 \\ 2 & 2/3 & 4/3 \\ 1 & 2/3 & 1/3 \end{bmatrix}$$

$$p-p^* = \underline{w}\begin{bmatrix} 0 & 0 & 0 \\ -1 & 1 & 0 \\ 0 & 0 & 0 \end{bmatrix} + \underline{p}\begin{bmatrix} 0 & 0 & 0 \\ -2 & 2 & 0 \\ -1 & 0 & 1 \end{bmatrix}$$

$$w-p = \underline{w}\begin{bmatrix} 0 & 0 & \nu-1 \\ 0 & 1 & 2(\nu-1)/3 \\ 0 & 0 & 1 \end{bmatrix} + \underline{p}\begin{bmatrix} -1 & 0 & \nu-1 \\ 0 & 0 & 4(\nu-1)/3 \\ 0 & 0 & 4(\nu-1)/3 \end{bmatrix}$$

The adjustment to the long run is illustrated by the following example of a sustained wage moderation in region 2.

Terms of trade	Period 1	Period 2	Period 3	Period 4	Long run
Region 1	0.5	0.75	0.875	0.9375	1.0
Region 2	-1.0	-0.75	-1.0	-0.9375	-1.0
Region 3	0.5	0.0	0.125	0.0	0.0

Appendix 2 The model for 2 regions

The main argument of the article can be worked through with the model for a two-region world economy.

By definition: $e^i=\varepsilon^i/(1-\nu^i\psi^i)$, i=1,2, so that:

$$X = AE = \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix}\begin{bmatrix} e^1 & 0 \\ 0 & e^2 \end{bmatrix} = \begin{bmatrix} 0 & e^2 \\ e^1 & 0 \end{bmatrix} \text{ and } I-X = \begin{bmatrix} 1 & -e^2 \\ -e^1 & 1 \end{bmatrix}$$

The determinant: $|I-X| = 1-e^1e^2 = \dfrac{(1-\nu^1\psi^1)(1-\nu^2\psi^2) - \varepsilon^1\varepsilon^2}{(1-\nu^1\psi^1)(1-\nu^2\psi^2)}$,so that

$$(I-X)^{-1} = \frac{1}{D}\begin{bmatrix} (1-\nu^1\psi^1)(1-\nu^2\psi^2) & \varepsilon^2(1-\nu^1\psi^1) \\ \varepsilon^1(1-\nu^2\psi^2) & (1-\nu^1\psi^1)(1-\nu^2\psi^2) \end{bmatrix} \text{ with } D = (1-\nu^1\psi^1)(1-\nu^2\psi^2)-\varepsilon^1\varepsilon^2$$

Thus it appears that the inverse of matrix **I-X** exists, if the product of the regional pre-linkage multipliers is smaller than one.

The diagonal matrices are:

$$Y = \begin{bmatrix} \psi^1/(1-\nu^1\psi^1) & 0 \\ 0 & \psi^2/(1-\nu^2\psi^2) \end{bmatrix} \text{ and } Z = \begin{bmatrix} 1/(1-\nu^1\psi^1) & 0 \\ 0 & 1/(1-\nu^2\psi^2) \end{bmatrix}$$

so that:

$$Y(I-X)^{-1} = \frac{1}{D}\begin{bmatrix} \psi^1(1-\nu^2\psi^2) & \varepsilon^2\psi^1 \\ \varepsilon^1\psi^2 & \psi^2(1-\nu^1\psi^1) \end{bmatrix} \text{ and } Z(I-X)^{-1} = \frac{1}{D}\begin{bmatrix} 1-\nu^2\psi^2 & \varepsilon^2 \\ \varepsilon^1 & 1-\nu^1\psi^1 \end{bmatrix}$$

The matrices in the equation for the terms of trade are found by multiplying these matrices by the matrix **I-A**:

$$Y(I-X)^{-1}(I-A) = \frac{1}{D}\begin{bmatrix} \psi^1(1-\nu^2\psi^2)-\varepsilon^2\psi^1 & -\psi^1(1-\nu^2\psi^2)+\varepsilon^2\psi^1 \\ \varepsilon^1\psi^2-\psi^2(1-\nu^1\psi^1) & -\varepsilon^1\psi^2+\psi^2(1-\nu^1\psi^1) \end{bmatrix}$$

and

$$Z(I-X)^{-1}(I-A) = \frac{1}{D}\begin{bmatrix} 1-\nu^2\psi^2-\varepsilon^2 & -(1-\nu^2\psi^2-\varepsilon^2) \\ -(1-\nu^1\psi^1-\varepsilon^1) & 1-\nu^1\psi^1-\varepsilon^1 \end{bmatrix}$$

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Nonstationarity in job search theory

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Local Times of Bernoulli Walk

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of subjective poverty definitions

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Sampling for Quality Inspection and Correction: AOQL Performance Criteria

247 D.B.J. Schouten
Algemene theorie van de internationale conjuncturele en strukturele afhankelijkheden

248 F.C. Bussemaker, W.H. Haemers, J.J. Seidel, E. Spence
On (v,k,λ) graphs and designs with trivial automorphism group

249 Peter M. Kort
The Influence of a Stochastic Environment on the Firm's Optimal Dynamic Investment Policy

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Evaluatie van marketing-activiteiten

253 H.P.A. Mulders, A.J. van Reeken
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254 P. Kooreman, A. Kapteyn
On the identifiability of household production functions with joint products: A comment

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Was er een profit-squeeze in de Nederlandse industrie?

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Economies with coalitional structures and core-like equilibrium concepts

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Industries with private and public enterprises

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Estimation of time dependent parameters in lineair models
using cross sections, panels or both

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Strategische bespiegelingen betreffende het Nederlandse kwaliteits-concept

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Determinanten van de vraag naar vakantiereizen: een verkenning van materiële en immateriële factoren

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Dynamic Firm Behaviour within an Uncertain Environment

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342 W.J. Selen and R.M. Heuts
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Multinationalisatie en coördinatie
De internationale strategie van Nederlandse ondernemingen nader beschouwd

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Estimation of the relationship between project attributes and the implementation of engineering management tools

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A simultaneous wage and labour supply model with hours restrictions

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Measuring the effectiveness of advertising in a positioning context with multi dimensional scaling techniques

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