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Convergence and international policy coordination in the EU : a dynamic games approach

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Abstract

This is a normative study with theoretical and empirical aspects of the impact of the Maastricht Treaty's (1991) convergence conditions. The study is carried out in a dynamic game context. Starting from the Treaty, we compare four possible scenarios: a noncooperative scenario, a cooperative scenario, a noncooperative convergence scenario and cooperative convergence scenario. In these last two scenarios, the EU-Member States pursue a restricted policy. This restriction is implied by the convergence criteria. The dynamic game analysis is undertaken with an estimated multi-country model of the USA, Japan and eight EU-economies.

Our empirical results suggest that coordination is a necessary condition for convergence and that coordination is more profitable for the larger (leading and more interdependent) economies, such as Germany and France, than for the smaller (following and more dependent) economies, such as Belgium, Denmark and the Netherlands.

1 Introduction

Since the Maastricht Treaty (1991), there is a lot of debate on the agreed convergence conditions. The Treaty sets out four quantified convergence criteria, (1) (low) inflation performance, (2) fiscal consolidation, (3) interest rate stability, and (4) perfect exchange rate stability. For each Member State of the European Union (EU) it is a necessary condition to fulfil these four criteria in order to progress to Stage Three of the EMU by 1999. In order to design a reliable macroeconomic policy for a 'home' country, this country has to take into account influences of as well domestic as foreign economic activity. It is clear that during Stage Two, countries will only consider policies which are sustainable through time, i.e., Member States will only pursue policies which satisfy the four mentioned criteria in nominal values, provided these policies also lead to a reasonable macroeconomic performance in other real variables such as GDP growth, employment or unemployment (see, e.g., Crockett [5]). Since all EU-economies can be considered as open economies, there exist strong interdependent economic relationships among these economies. Furthermore, the increasing integration process will strengthen even more the economic interdependence between countries in the future, which will increase the importance of cross-border effects. Since the criteria indicate that each Member State has to follow the interest rates and the inflation rates set by other countries, it is likely that this 'convergence constraint' also influences economic policymaking of the EU-economies. We want to study the impact on EU-policymaking if Member States are constrained by conditions, in this case the convergence conditions, set out by a supranational authority as the European Commission. We will investigate the economic consequences for the EU-Member States for the short and medium term, i.e. for Stage Two of EMU. It is argued by many authors that in order to reach Stage Three, various costs are involved (see, e.g., Bean [2], Brandsma and Italianer [3], Buiter et al. [4] and Crockett [5]). For instance, the criteria emphasise a low inflation rate and a sound public finance for the EU-Member States, but it may well be that this hampers real welfare improvements like high GDP-growth or low unemployment in the short and/or medium term. Furthermore there is the argument in the literature, that the loss of freely using the exchange rate as a weapon of macroeconomic management may be costly (see, e.g., Feldstein [12]).

We will study these aspects in a dynamic games context. For example, consider a EU where the Member States fully cooperate. In that case any restriction, thus also the restriction implied by the convergence conditions, will decrease total welfare. In that case it is, therefore, reasonable to search for a measure of the costs of convergence for each country separately and for the EU as a whole. On the other hand, if we assume that within the EU Member States do not fully cooperate, i.e., if we are willing to consider a situation where EU-Member States agree on shared policy targets but do not necessarily cooperate in order to achieve these targets, then it is not straightforward that the imposition of the convergence conditions will always lead to a lower total welfare. In that case it may well be possible that the direction of the spillover effects are influenced in such a way that, through the imposition of the convergence conditions, the size of negative spillover effects decreases.

If that is the case, then the convergence restriction may not only be beneficial for total welfare in the EU but it may also be beneficial for each Member State independently in the short to medium term.

In this paper we model the impact of the convergence conditions as a restriction on each country's policymaking. In a cooperative scenario we consider the full coordination outcome and the outcome where the EU-Member States play cooperatively, but are restricted by the convergence criteria. We will investigate how much convergence is possible/desirable and what are the economic consequences for each Member State. For the noncooperative case we will check whether the imposition of the convergence conditions are profitable or not. As starting point we will return to the Maastricht Treaty (1991) and consider four types of hypothetical scenarios:
(1) Despite of the Maastricht Treaty there is no agreement reached among the EU-Member States: this is represented by a noncooperative scenario (feedback Nash solution).
(2) No agreement reached as in (1), but now each Member State is additionally constrained by the convergence criteria set out in the Maastricht Treaty ('noncooperative convergence solution').
(3) There is an agreement reached about full coordination: this is represented by a purely cooperative scenario (Nash bargaining solution).
(4) An agreement reached as in (3), but there is an additional constraint imposed by the convergence criteria ('cooperative convergence solution').
In this paper we compute these four (extreme) scenarios for the SLIM-model as described in Douven and Plasmans [7].

In the literature, there is a lot of intellectual debate about the consequences of the convergence conditions (see, e.g., Bean [2], Crockett [5] and Eichengreen [10]). However, an empirical dynamic game analysis of the consequences of the convergence conditions for the EU-economies during Stage Two is not made before. We are aware of one simulation study by Brandsma and Italianer [3] using the European Commission's Quest model. In that study the convergence criteria are considered as an example of agreement on shared policy targets in the sense that the desired paths of the individual economies are jointly finetuned and determined. They argue (see page 12): 'Since it is difficult to shoot at a moving target, the potentially best performers should make their targets explicit and also make it clear that they will not try to push inflation much below that point of reference, even when inflationary pressures are weakening abroad'. Therefore, the points of reference for the inflation rate and the long term interest rate are fixed beforehand in their analysis. It may be clear that, in a dynamic context, the reference points may change during Stage Two. For instance, if there is an upward swing of GDP-growth in all EU-countries it is likely that inflation rates, and, hence, also the reference points, will increase too. In that respect, the empirical analyses in this paper can be seen as an extension of the study of Brandsma and Italianer [3], since, by constructing a convergence function, we take the possibility of a moving target into account. As we will show, the distinction between a convergence function and individual welfare functions yields various additional advantages

since we are now able to study the following aspects:
(1) How will the reference points of the nominal long term interest rate and the consumer price inflation evolve over time?
(2) How much convergence is possible/desirable and how will the convergence aspects affect welfare in the short and medium run as well for real as for nominal variables in each Member State?
(3) Which Member States are able to fulfil the criteria, and which not?
(4) Are the convergence criteria, as set out in the Maastricht Treaty, reasonably specified or are (minor) revisions necessary? [1]

In section 2 we will first recall some key properties of the SLIM-model. In section 3 we will present a description about the four possible game outcomes where we will put most emphasis on the convergence solutions, since the ideas behind this concept are new in the international policy coordination literature. In section 4 we will start our empirical work and present objective functions for each country and a convergence function. We will specify desired paths and penalty weights for these functions. In section 5 we will present and analyse the outcomes of our experiment and in section 6 we will conclude.

2 The SLIM-model

As noted in the introduction use SLIM (Small Linear Interdependent Model) to perform our dynamic game analyses. For an extensive description of the model we refer to Douven and Plasmans [7]; here we will briefly recall some key properties of the model. The model is designed on the basis of the Mundell-Fleming theory and contains eight EU-Member States, i.e., Belgium, Denmark, France, Germany, Ireland, Italy, United Kingdom and the Netherlands and two countries outside the EU, USA and Japan, which can be considered as the two most important EU-trading partners. The model is estimated with annual data for the sample period 1960-1991. In the SLIM-model, each country is represented by six behavioural equations which contain strong interactions. In table 1 we summarise how these interdependencies are modelled. For example the dot in the upper row of Germany belonging to the column of France indicates that Germany directly depends on France. Thus, in the SLIM-model the EU-countries such as France, Germany and the United Kingdom are strongly mutually interdependent, whereas open economies as Belgium, Denmark, Ireland, Italy and the Netherlands are unilaterally affected by the larger EU-economies (i.e., there is no feedback transmission from the smaller EU-economies to the larger economies). The model is also designed such that all EU-economies are directly (or indirectly) interdependent with the USA and Japan. To illustrate the behaviour of the model we briefly state

[1] The empirical results of Brandsma and Italianer [3] imply that if the Member States play a purely cooperative strategy, almost all EU-countries will be able to fulfil the criteria. It is, however, important to note that in this research the authors use the wage rate as instrumental variable and they allow for dismissing (government) employees.

	Ge	Fr	UK	It	Nl	Be	Dn	Ir	USA	Japan
Ge		•	•						•	•
Fr	•		•						•	
UK	•	•							•	
It	•	•							•	
Nl	•	•	•			•			•	
Be	•	•			•					
Dn	•		•						•	
Ir	•		•						•	
USA	•									•
Japan	•								•	

Table 1: Direct Interdependencies among the countries in the SLIM-model

in table 2 the general form of the six behavioural equations. Equation (1) expresses that

Table 2: Equations in the SLIM-model for one country[a]

Equation number	*Equation*
(1)	$Y = f(E + P_y^* - P_y, RL - \Delta P_y, Y^*, G)$
(2)	$P_y = f(W, E + P_y^*, Y - \bar{Y})$
(3)	$P_c = f(P_y, E + P_y^*)$
(4)	$N = f(W - P_y, Y, E + P_y^* - P_y)$
(5)	$W = f(P_c, \Delta U, Y - N, P_c - P_y)$
(6)	$RL = f(RL^*, RS, \Delta P_c)$

a. All variables are in logaritmic form, except RS, RL and U which are in rates. Δ indicates 'first differences' and the superscript * denotes foreign variables.

real output, Y, depends positively on the real exchange rate, $E + P_y^* - P_y$, negatively on the real long term interest rate, $RL - \Delta P_y$, positively on foreign output, Y^*, and real government expenditure G. In equation (2) the output price, P_y, depends positively on nominal wages, W, import prices, $E + P_y^*$, and deviations from trend output, $Y - \bar{Y}$. In equation (3) consumer prices, P_c, depend positively on domestic output prices and foreign output prices $E + P_y^*$. Labour demand in equation (4) depends positively upon real wages, $W - P_y$, positively on real output and on the gap between domestic and foreign prices, $E + P_y^* - P_y$. The impact of the gap between foreign and domestic output prices in this labour demand equation is ambiguous and depends upon the country under consideration.

Nominal wages in equation (5) depend positively on consumer prices, negatively on the change in unemployment, $\Delta(L-N)$, and positively on labour productivity, $Y-N$. The nominal long term interest rate, RL, in equation (6) depends positively on the foreign nominal long term interest rate, RL^*, and the domestic nominal short term interest rate, RS, and consumer price inflation, ΔP_c.

Since unemployment is defined as the labour force minus employment, the model contains, for each country, four exogenous variables, G, government expenditure, RS, the short term interest rate, E, the nominal exchange rate, and L, the labour force. The model is designed for short and medium term projections. One important aspect of the model is that, in the short run, it produces stronger spill-over effects than related large-scale models like Quest, Interlink etc. For example, the quantitative size of a global positive GDP output shock in one of the major EU-economies has, in the first year, a substantial effect on output of other EU-economies and ranges (roughly) between 0-80% GDP output of the country originating the shock. Small open economies, like Belgium, Denmark and the Netherlands profit most from such a locomotive policy of one of the larger EU-economies. For the estimated elasticities and a detailed analysis of the model we refer to Douven and Plasmans[7].)

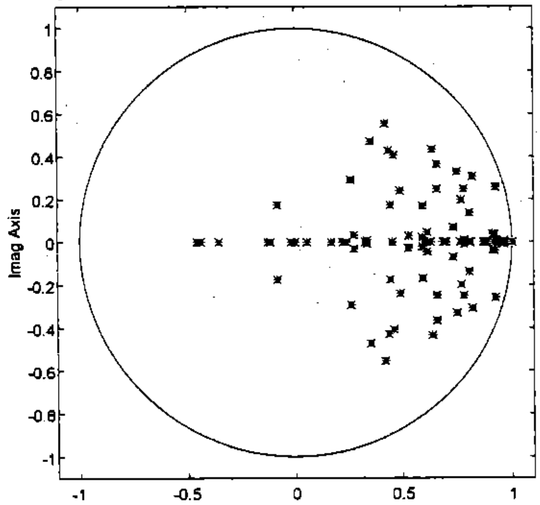

Figure 1: Eigenvalues of $\hat{A}$ in the imaginary plane.

The specifications of the model in table 2 are estimated using an error-correction approach. After estimation the SLIM model can be described by the following set of equations:

$$y_t = \hat{A}_0 y_t + \hat{A}_1 y_{t-1} + \hat{A}_2 y_{t-2} + \hat{B}_0 u_t + \hat{B}_1 u_{t-1} + \hat{B}_2 u_{t-2} + \hat{D}_0 ex_t + \hat{D}_1 ex_{t-1} + \hat{D}_2 ex_{t-2} + \hat{\varepsilon}_t$$

where $\hat{A}_0, \hat{A}_1, \hat{A}_2, \hat{B}_0, \hat{B}_1, \hat{B}_2, \hat{D}_0, \hat{D}_1$ and $\hat{D}_2$ contain the estimated coefficients and y represents the vector of endogenous variables, u_t the vector of instrumental variables, ex_t the vector of exogenous variables and $\hat{\varepsilon}_t$ the vector of errors in the model. Next, these equations are transformed into state-space form (see, e.g., de Zeeuw [23]). This yields the following set of equations:

$$\begin{aligned} x_{t+1} &= \hat{A}x_t + \hat{B}\bar{u}_t + z_t \\ \bar{y}_t &= \hat{C}x_t. \end{aligned}$$

In this standard discrete time state-space form, x_t, represents the vector of state variables involving endogenous and instrumental variables, $\bar{y}_t$, represents the vector of objective variables for all policymakers, $\bar{u}_t$, the vector of instrumental variables for all policymakers and z_t the vector of exogenous variables at time t, $\hat{C}$ is specified such that the objectives in $\bar{y}_t$ are, for each country, GDP-growth, GDP-inflation, consumer price inflation, growth in wages, growth in employment and the nominal long term interest rate. In this study we consider two sets of instrumental (policy) variables for $\bar{u}_t$. In our first dynamic game experiment we just consider the nominal short term interest rate and government expenditure as instrumental variables, whereas in the second experiment we also include the exchange rate as instrumental (policy) variable. To get an idea of the size of the model, $\hat{A}$ is a 180x180 matrix, $\hat{B}$ is a 20x180 matrix or 30x180 matrix depending on the set of instrumental variables used and $\hat{C}$ is a 60x180 matrix. In a discrete time-model, as used here, the stability properties of the model can be easily checked by an eigenvalue plot. This plot is shown in figure 1, where the eigenvalues of $\hat{A}$ and the unit circle are plotted. If the eigenvalues of $\hat{A}$ lie inside the unit circle then the model is said to be stable. As we can see, some of the eigenvalues fall on the unit circle in (1,0), and hence at least one equation contains a unit root. These equations are, e.g., price equations. These equations contain a unit root in their level specifications but are stable in their first differences. This is, however, not such a problem since in our dynamic game analyses we are mainly interested in the first differences (growth values) of the various variables.

3 Description of the dynamic game

It is common use to compare noncooperative and cooperative outcomes when applying dynamic game theory in economics. However, empirical studies with large scale models appear less often. One of the first well-known empirical studies is the Oudiz and Sachs paper [20]; more recent studies are Ghosh and Masson [14], Hughes Hallett [17] and McKibbin and Sachs [18]. In this paper we compare two generally known dynamic game equilibrium concepts, the noncooperative feedback Nash solution and a cooperative Pareto solution, represented by the axiomatic Nash bargaining outcome, with two other new concepts in which the players are restricted in their policy choice. This restriction is imposed by the convergence conditions, which can be interpreted as a dynamic constraint on the (non)cooperative game. We will now briefly explain the four solution concepts. Consider again the Maastricht Treaty (1991). The scheme in figure 2 describes the situation of the EU-Member States at the time of the Treaty. Each Member State enters the negotiation process with a certain target or objective function, represented by $J_i, i = 1, ..., N$. As is common practice in dynamic game theory, we assume that this function can be approxi-

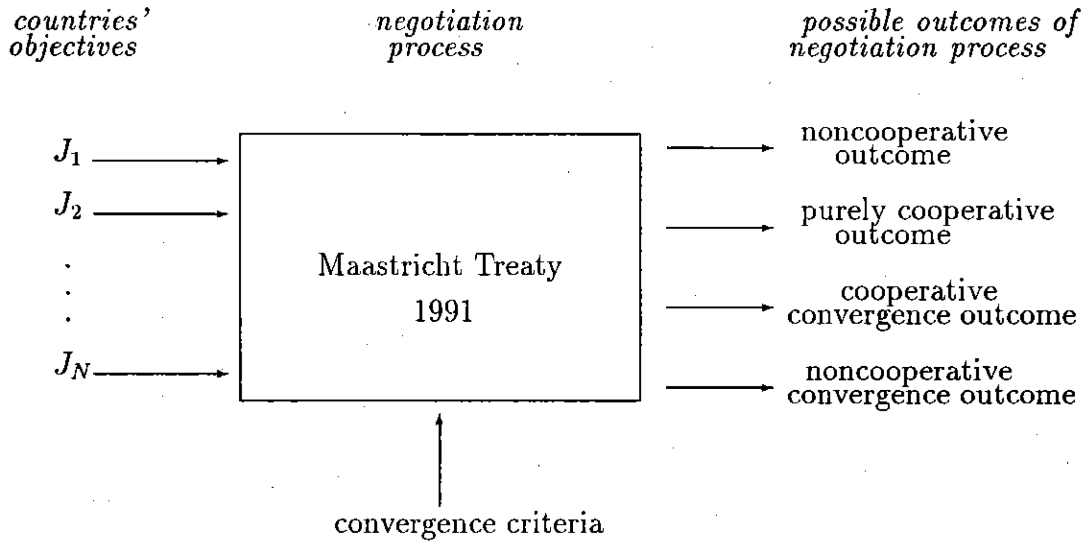

Figure 2: Scheme of the negotiation process of the Maastricht Treaty.

mated well by a quadratic functional[2]:

$$J_i = \sum_{t=1}^{T} y_i^A(t)' Q_i(t) y_i^A(t) + u_i^A(t)' R_i(t) u_i^A(t), \tag{1}$$

where $y_i^A(t) := y_i(t) - y_i^d(t)$ are the deviations of the values of the target variables from their desired values for each EU-Member State i at time t. Similarly, $u_i^A(t) := u_i(t) - u_i^d(t)$ is the vector of deviations of country i's instruments from their trend (desired) values. Furthermore, the matrix Q_i is assumed to be positive semi-definite and the matrix R_i positive definite for $i = 1, ..., N$. Now, each country $i, i = 1, ..., N$, enters the negotiation process with its objective J_i which has to be minimised subject to a set of linear(ised) dynamic constraints, represented by the SLIM-model as explained in section two. Furthermore, we assume that the European Commission enters the negotiation process with as objective criterion a quadratic functional on the convergence conditions of the Maastricht Treaty. It is clear that we are now entering the field of dynamic game theory since each country's behaviour is dependent on the other countries' behaviour. This can, of course, lead to many possible outcomes; therefore, we will restrict ourselves to four (extreme) cases.

3.1 case 1: Noncooperative policy

Since there are no clearly established 'rules of the game', we assume an environment where each Member State has complete information and acts individually rationally. For an

[2]Advantages and limitations of quadratic loss functions are discussed, a.o., in Petit [21]

appropriate description of a noncooperative game outcome we use the feedback Nash equilibrium. The feedback Nash equilibrium has some more desirable properties than other Nash equilibria, such as strong time consistency and stochastic robustness (see, e.g., Basar and Olsder [1], de Zeeuw and van der Ploeg [24] and Holly and Hughes Hallett [15] for a comparison of different Nash equilibria and for the mathematical expressions for computing the unique feedback Nash outcome). Furthermore, the feedback Nash equilibrium is generically unique in a linear quadratic framework with a finite planning horizon (see Basar and Olsder [1]). We will follow a similar strategy here and use the feedback Nash equilibrium as the threatpoint of the game. Thus, we assume that the EU-Member States play a noncooperative game without taking the convergence conditions into consideration. Remark that this is perfectly acceptable in the two player case, but, since in our case there are more players, we additionally assume that there will be no coalitions among the players [3]. So, here we assume that there is no cooperation among countries at all. In the sequel we will denote this outcome by *NC* and the welfare outcome of this noncooperative solution by $J^{NC} := \{J_1^{NC}, ..., J_N^{NC}\}$, where N represents the number of players (countries).

3.2 case 2: Cooperative policy

For the purely cooperative case we assume that the countries agree on the Nash bargaining outcome which is a Pareto optimal outcome (see, e.g., Nash [19]). It is well-known that this solution can be obtained by minimising the 'collective' loss function:

$$J = \sum_{i=1}^{N} \alpha_i J_i, \quad \text{with} \quad \alpha_i \geq 0, \ \sum_{i=1}^{N} \alpha_i = 1, \tag{2}$$

subject to the linear constraints represented by the SLIM-model, and in which the set $\{\alpha_1, ..., \alpha_N\}$ is chosen as $\alpha^{NB} := \{\alpha_1^{NB}, ..., \alpha_N^{NB}\}$ which corresponds to the Nash bargaining solution. This solution, which we will denote by *NB*, has some desirable properties. For instance, there exists a unique relationship between the 'welfare weights' α_i^{NB}, for $i = 1, ..., N$, the disagreement point, represented by the noncooperative solution J^{NC} in case 1 and the welfare outcome of the Nash bargaining solution, say $J^{NB} = \{J_1^{NB}, ..., J_N^{NB}\}$[4]:

$$\alpha_i^{NB} = \frac{\prod_{i \neq j}(J_i^{NC} - J_i^{NB})}{\sum_{i=1}^{N} \prod_{i \neq j}(J_i^{NC} - J_i^{NB})}$$

This relationship implies that:

$$\alpha_1^{NB}(J_1^{NC} - J_1^{NB}) = \alpha_2^{NB}(J_2^{NC} - J_2^{NB}) = \cdots = \alpha_N^{NB}(J_N^{NC} - J_N^{NB}). \tag{3}$$

Since the deviations in the welfare functions are all described in percentage points, we may assume that the welfare functions, J_i, are (roughly) comparable among countries,

[3] Of course, it is possible to take this coalition aspect into account. However, regarding the fact that the number of coalitions between 8 EU-countries is already very large, we use here this simplifying assumption.

[4] For a proof of this relationship we refer to Douven and Engwerda [6].

i.e., if $J_i > J_j$, then we can argue that policymaking for country i is more costly than for country j. This observation makes it possible to interprete relationship (3) as follows (see, e.g., Douven and Engwerda [8]): a player who gains more from playing cooperatively is more willing to accept a smaller 'welfare weight' than the player(s) who gain(s) less. Alternatively, a player who gains less may demand a higher 'welfare weight' by threatening not to coordinate, knowing that the potential loss from no agreement is larger for the other player(s). We will use this argument for interpreting some of our results.

The two previous cases are standard in dynamic economic game theory. In the following two subsections we will elaborate the concept which deals with the impact of the European Commission. In this case we assume that the European Commission, as an independent negotiation partner, is involved in the negotiation process as well. We assume that the European Commission has its own objectives, i.e., the convergence criteria as specified by the Maastricht Treaty, which can be quantified in a convergence function. We will denote this convergence function by C and assume that C is quadratic (like the individual objective functionals $J_i, i = 1, ..., N$). The general form of this function is

$$C = \sum_{i=1}^{N} C_i, \text{ with } C_i = \sum_{t=1}^{T} y_i^C(t)' Q_i^C(t) y_i^C(t), \tag{4}$$

where $y_i^C(t) := y_i(t) - y^c(t)$ represents, for each country, the deviation of its target vector from a reference vector at period t. Note that this 'reference vector' $y^c(t)$ will not be fixed beforehand for the complete planning period, but should at each time period t be considered as a function of the target vectors $y_1(t), ..., y_N(t)$ and will be determined within the optimisation procedure itself; C is defined as the sum of the individual countries' convergence functions C_i. In practice it is possible that each country has its own reference vector in mind to which it wants to converge in order to reach the convergence criteria but, for practical reasons, we assume that countries cooperatively agree on the same reference vector $y^c(t)$. The time dependent weight matrices $Q_i^c(t)$ contain the relative priorities which each individual country wants to assign to certain convergence aspects. We refer to Section 4 for these subjects and for a precise formulation of the convergence function and do not elaborate these subjects further here. In that section we will also discuss the fact that there may be some overlap between the countries' own objectives and the convergence objective. In the sequel we first discuss the two convergence game outcomes.

3.3 case 3: Cooperative convergence policy

The cooperative convergence outcome is modelled as a restricted cooperative outcome, where the restriction is modelled with the convergence function C. Furthermore, we assume that if one of the EU-Member States does not agree, none of the EU-Member States will agree to play in a cooperative mode, in which case 1 is the appropriate model formulation, i.e., we use NC of case 1 as the threatpoint of the game. Another way to look at the cooperative convergence outcome is that we are dealing with a game between $N+1$ players, where the N countries altogether agree with the convergence criteria as specified by the $(N+1)$st player. One could argue that this $(N+1)$st player, represented here by the European Commission, has the power to conduct the coordination process between the N Member States and that a possible withdraw of one of the Member States from the negotiation process would be the starting point of a breaking down of the European Union, i.e., will lead to case 1. Now we argue that there are not many incentives for one of the EU-Member States to disagree with this convergence condition as long as their corresponding individual costs $J_i, i = 1, ..., N$, will be lower than the costs which are represented by the noncooperative solution. Since all the EU-Member States are interested in the convergence aspect (in order to reach Stage Three which involves the creation of a full monetary union by 1999) we assume that they will try to converge as much as possible as long as each individual EU-Member State is better off compared to the noncooperative case. As an

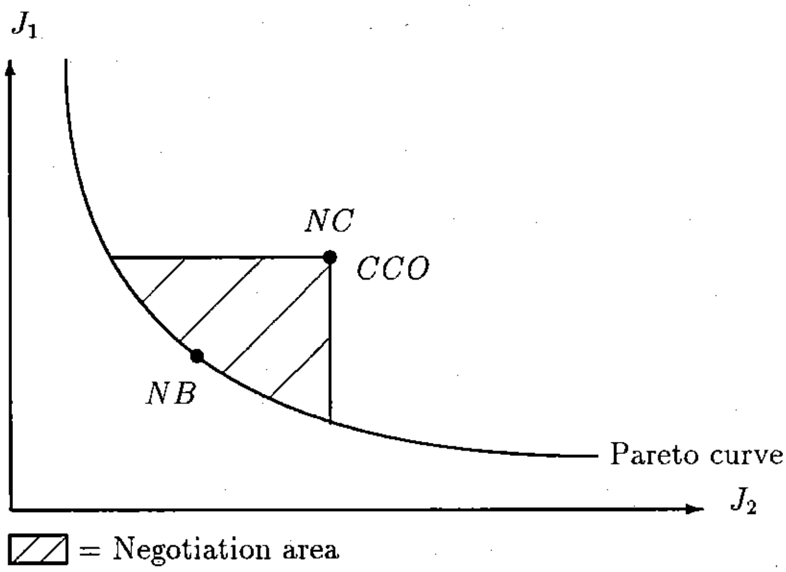

Figure 3: The negotiation area in the J_1, J_2-plane for the two player case.

example consider the two player case. The picture in figure 3 represents the J_1, J_2 plane. The convex Pareto curve represents all possible cooperative solutions. The Nash bargaining solution is denoted by NB and represents case 2. The outcome denoted by NC is the threatpoint and represents case 1. Remark now that all possible game outcomes outside the shaded 'negotiation area' are not interesting for at least one of the players since, then, at least one is better off in case 1. In case 3 the EU-Member States are restricted in their policy choice by this 'negotiation area'. The maximum convergence that can be reached is a cooperative policy which stays inside the 'negotiation area' and maximises convergence (i.e., minimises C). We denoted this outcome in the figure with CCO, which represents case 3. In Douven and Enwerda [6] we showed that, in the N-dimensional case, all possible cooperative convergence outcomes can be calculated by minimising an augmented 'collective' loss function:

$$J^C = (1-\lambda)\sum_{i=1}^{N}\alpha_i J_i + \lambda C, \quad \text{with} \quad \sum_{i=1}^{N}\alpha_i = 1, \;\; 0 \le \alpha_i, \lambda \le 1, \tag{5}$$

subject to a set of constraints represented by the SLIM-model in our case. Each cooperative convergence outcome can be represented by a particular set of $\{\alpha_1, ..., \alpha_N, \lambda\}$. In the sequel we will represent the CCO outcome, which maximises convergence within the 'negotiation area', by $\alpha^{CCO} := \{\alpha_1^{CCO}, ..., \alpha_N^{CCO}, \lambda^{CCO}\}$. In Douven and Engwerda [6] we also proved that this CCO outcome is uniquely determined, and that this outcome coincides in the $J_1, ..., J_N$ plane with the noncooperative outcome NC. Therefore, the dot in figure 3, which lies on the corner of the 'negotiation area', represents both; the NC and the CCO outcome. Note, however, that the belonging policy choices of both outcomes generally differ. In Appendix A we describe the formulae and the (constrained) numerical optimisation algorithm for finding this cooperative convergence solution CCO.

3.4 case 4: Noncooperative convergence policy

In this subsection we assume that the EU-Member States pursue a noncooperative policy which is restricted by the convergence criteria. We assume that each Member State i minimises $\tilde{J}_i$, with

$$\tilde{J}_i = (1-\lambda_i)J_i + \lambda_i C_i \quad \text{with} \quad C_i \text{ as in } (4), 0 \le \lambda_i \le 1$$

and where λ_i is the relative weight each player assigns to his own convergence. For simplicity, we assume that all players choose the same value for $\lambda_i := \lambda$ and we assume that there is an agreement that the Member States shoot on the same moving target $y^c(t)$. The main difference with case 3 is that each individual country, say country i, tries to minimise its part, C_i, of the total convergence function C in a noncooperative game, instead of minimising C cooperatively. Beforehand, it is hard to say whether this 'cooperative agreement' on $y^c(t)$ influences the individual welfare functions J_i, in comparison to the NC outcome of case 1, positively or negatively. Furthermore, it is interesting to see whether this agreement on the same moving target $y^c(t)$ really will lead to convergence in a noncooperative world. In our empirical application we will actually investigate whether this outcome falls inside or outside the negotiation area as specified in figure 3. In the sequel, we will represent this noncooperative convergence outcome by NCO and we willl denote its welfare costs by $J^{NCO} := \{J_1^{NCO}, ..., J_N^{NCO}\}$. Remark that we are interested in comparisons of different outcomes in the $J_1, ..., J_N$-plane and we specify the NCO outcome accordingly

[5]. To understand the impact of a constraint on a dynamic game more in general we discuss

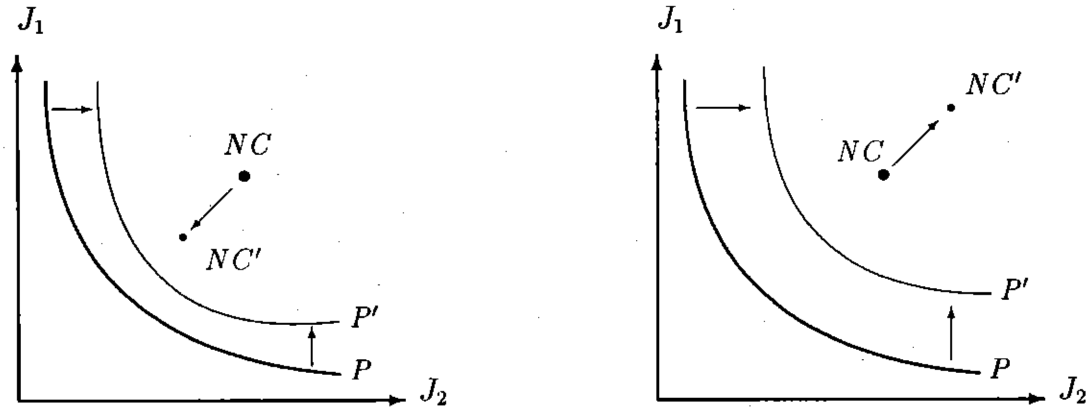

Figure 4: Two examples of effects on individual welfare-loss originating from a restriction.

graphically, in the two player case, what kind of properties an 'ideal' constraint (imposed by some kind of central authority) should posses. Remark, that in the following idea the authority, which imposes the restriction, does not know beforehand what kind of game the two players play. Consider again the Pareto curve P and the threatpoint NC in both diagrams of figure 4 and consider a possible restriction on the game. Since any restriction in the cooperative game leads to welfare loss in the J_1, J_2-plane, we observe that in the cooperative restricted game the Pareto frontier P (in the J_1, J_2-plane) moves to the north-east direction. In the noncooperative game it is, generally, unknown in which direction the NC point moves. It could move in any direction. As an example consider the two diagrams in figure 4. In general, the first diagram is an example of an 'ideal' restriction; the restricted Pareto frontier,P', lies close to the Pareto frontier, P, and the restricted noncooperative point, NC', moves to the south-west direction of the NC-outcome. An example of a 'bad' restriction is visible in the second diagram of figure 4; the NC threatpoint and the Pareto frontier move substantially to the north-west direction.

4 Specification of objectives and priorities

Since the dynamic game calculations with the SLIM-model are only relevant for the EU-Member States, we exogenise USA and Japan in the model. In Appendix C.2 we will

[5]Another viewpoint would be to scale everything into the $\tilde{J}_1, ..., \tilde{J}_N$-plane, but this yields the additional problem of the determination of λ_i.

describe the exogenous choices for these countries' exogenous variables and for the other exogenous variables in the model, such as the labour force. We will use for each country the nominal short term interest rate and the level of government expenditure as policy variables. For the other exogenous variable, the nominal exchange rate, the Maastricht Treaty imposes perfect exchange rate stability at Stage Three. Therefore, we adopt two approaches in this paper.
(1) Firstly, we fix the dollar exchange rate on the 1991 level for the complete planning period 1992-1999; in this case we assume a fixed (dollar) exchange rate regime.
(2) Secondly, we use the exchange rate as a policy variable wich receives a very high weight in the welfare function. In this case we allow for small movements of the exchange rate around the desired paths. Since in the SLIM-model each exchange rate within the EMS is modelled through the dollar we consider small movements around the ideal paths of their currency against the dollar. Hence, we have also tight exchange rates within the EMS.
The motivation behind these two approaches is that we want to investigate the possible gains from exchange rate management as well in a cooperative as in a noncooperative world.
It is clear that in practice the monetary authorities do not have the power to 'fully' control the exchange rate. Therefore, study (2) be interpreted as a sensitivity analysis to dynamic game study (1) and should give more insight into a question like: Is it possible to improve convergence considerably if we allow for small movements in the exchange rate?[6] For instance, the effect of exchange rate managenent in the noncooperative case is not clear, since it may well be the case that a noncooperative use of exchange rate management may lead to lower global and individual welfare for all Member States than in a situation where exchange rates are fixed. Remark, that in this research, we do not consider the possibility that monetary or fiscal policy could create tensions within the exchange rate system [7].

The choice of the desired paths $y_i^d(t)$ and $u_i^d(t)$ is mainly in line with previous studies (see, e.g., Hughes Hallett [16, 17]). We target growth values for Y, P_y, P_c, W, N, nominal level values for RL, RS and real level values for G. The ideal target values for the growth rates are constructed such that we start for each variable with a desired growth rate for 1992. These desired growth rates for 1992 were chosen such that they are in accordance with the actual growth rates of 1991. Then, we constructed linear growth paths towards the ideal growth rates for 1999. For the construction of the ideal paths of the level values we used, in most cases, the true 1991 values (also representing the end of the estimation period in the SLIM-model) as starting values and applied linear interpolation towards the 1999 desired values. In subsection 4.1 we describe an individual objective function of each Member State and in subsection 4.2 we specify our choice for the convergence function.

[6] Other arguments for using the exchange rate as instrumental variable are given by Petit [21]
[7] The case where the exchange rate is endogenous is a subject for future research.

4.1 Individual objective functions and relative priorities

The (growth) values for the ideal paths and their relative priorities are given in table 3, presenting each country's desired values for 1992 and 1999 respectively. The desired values for the years inbetween are constructed by linear interpolation. Since we target level variables for real government expenditure, we specify for all countries the levels for the year 1991. We assume that each country, except Ireland, will aim for real output growth of 4%

Table 3: The objective function specification for the years 1992-1999. [a]

	Countries Belg.	Denm.	Germ.	France	Irel.	Italy	Netherl.	U.K.
The desired values y_i^d for 1992 and 1999.								
ΔY	2.2-4.0	1.6-4.0	3.7-4.0	1.1-4.0	2.5-5.0	1.6-4.0	2.4-4.0	1.0-4.0
ΔP_y	2.5-2.0	2.4-2.0	3.8-2.0	2.8-2.0	1.5-2.0	6.6-3.0	2.8-2.0	5.8-2.0
ΔP_c	2.6-2.0	2.4-2.0	3.5-2.0	2.9-2.0	3.0-2.0	6.1-3.0	3.2-2.0	6.3-2.0
ΔW	6.0-5.0	3.9-5.0	4.6-5.0	4.5-5.0	5.7-6.0	8.2-7.0	4.4-5.0	7.9-7.0
ΔN	0.3-1.5	0.0-1.5	2.4-1.5	0.3-1.5	0.0-1.5	0.9-1.5	1.3-1.5	0.0-1.5
RL	9.0-7.0	9.1-7.5	8.2-6.0	9.2-7.5	8.9-7.0	12.6-8.0	8.4-6.0	9.8-7.5
The desired values u_i^d for 1992 and 1999.								
RS	8.9-6.0	9.5-7.0	8.7-5.0	9.3-7.0	9.5-7.0	11.4-7.0	8.8-5.0	10.9-8.0
ΔE	0.0-0.0	0.0-0.0	0.0-0.0	0.0-0.0	0.0-0.0	0.0-0.0	0.0-0.0	0.0-0.0
ΔG	1.6-0.0	2.1-1.0	2.4-1.0	2.2-1.0	1.6-1.0	1.4-0.0	3.7-1.0	1.7-1.0
G_{1991}	15.073	14.076	13.073	15.043	12.360	9.340	13.545	12.611

The relative priorities (equal for each country)

Matrix Q						*Matrix R*		
ΔY	ΔP_y	ΔP_c	ΔW	ΔN	RL	RS	G	E (*if included*)
2.0	0.5	1.0	0.5	2.0	0.5	2.0	2.0	10.0

[a]. All units in percentage changes per annum, except G_{1991} in logarithms.

and that Ireland aims for 5% by 1999. Each country strives for a low GDP- and consumer price inflation rate for which we assume 2% as ideal in most countries in 1999 (only Italy 3%). Due to the trade off between, on the one hand the inflation cost component and on the other hand the income component for the improvement/preservation of purchasing power we target growth in nominal wages around 5-7% for the year 1999[8]. Due to the above mentioned trade off the relative priority of nominal wages is assumed to be low (Q value of 0.5). Growth in employment, one of the main concerns of policymakers today, is

[8]The model considers private wages and therefore real labor income (real wages times employment) may grow slightly faster than GDP in 1999.

given a relatively high priority of 2 and a desired growth path of 1.5% in 1999. Since at the time of the Maastricht Treaty in 1991 the nominal long term interest rates were rather high in each country, we considered a decline of at least 2% during the period 1992-1999 for this variable. Note that at the Maastricht Treaty it is imposed that each Member State should strive for fiscal consolidation (before the end of this century, each country should have a public budget deficit of less than 3% of GDP and its governmental debt should not exceed 60 % of GDP). Therefore, we assume that some countries restrict their level of government expenditure substantially, e.g., for Belgium and Italy we assume a zero percentage growth of the desired government expenditure in 1999. For the other countries we assume an ideal growth path of 1% in 1999.
The priorities policymakers attach to the different variables are reflected in the weights Q and R of the individual objective functions. They are presented at the bottom of table 3. We assume that these weights are the same for each Member State and are constant over time[9]. For the desired paths y_i^d we give a relatively high priority to GDP growth and employment growth and relatively low priorities for the growth of nominal wages and the level of the long term interest rate. Concerning the inflation rates, we give a higher priority to the consumer price deflator than to the GDP-price deflator. For the desired paths u_i^d we choose a priority of 2, except for the case where the exchange rate is used as a policy variable. In that situation we give a very high priority of 10 to the exchange rate (and the other policy variables a value of 2), indicating that strong movements in the dollar exchange rates are heavily penalised.

The choice of the desired target values and weights needs some more explanation. Attempts in the literature, see for an overview, e.g., Frenkel, Goldstein and Masson [13], to evaluate the gains from policy coordination using empirical models led to the finding that gains are small. However, in the SLIM-model, where there are many countries and strong interactions among the countries, we find that these gains depend strongly on the number of countries and the relative weights attached to the target and the control part of the objective functional. It is our experience that the distance between the threatpoint and the Pareto curve increases with the number of countries and decreases if one lowers the relative weight of the control part (versus the target part) in the objective functional. Furthermore, we find that the noncooperative outcomes are more sensitive to changes in the desired values and weight changes than the cooperative outcomes. This led to the practical rule that we first constructed a reasonable noncooperative solution, by choosing appropriate weight values, and thereafter calculated the other three scenarios. Hence, the researcher can experiment to some extent with the gains of policy coordination, and thus also with the maximum degree of convergence [10].

One can decompose the convergence criteria in two types of conditions (see Siebrand [22]). On the one hand conditions which are conducted by the European Commission called

[9] This is a simplification. In practice the relative priorities (and also the desired paths) are (frequently) adjusted by the government.

[10] This clearly applies to almost all control studies in economics.

central conditions and on the other hand *decentral* conditions which are executed by each Member State individually. Examples of centralised policy behaviour are price stabilisation and interest rate stabilisation; budgetary policy is an example of decentralised behaviour. Since a restrictive budgetary policy seems to be sensible anyway, Maastricht Treaty or not, we decided to put this decentral criterion in the individual objective functions and the central criteria in the convergence function. The other distinction which can be made here is that the central conditions are an example of shared *flexible* policy targets, whereas the decentral conditions are an example of *fixed* policy targets. For instance, the reference values for the individual budgets are fixed beforehand, whereas the reference points for the long term interest rates and the inflation rates may fluctuate over time. This decision implies that we are comparing four dynamic game outcomes, all with a 'cooperative agreement' on fixed shared targets, which can be divided in two game outcomes (a noncooperative and a cooperative one) and two other game outcomes (a noncooperative and a cooperative one), where the Member States additionally give some priority to the two central criteria which are modelled as flexible shared targets.

4.2 The convergence function

As convergence function we propose the following specification:

$$C = \sum_{i=1}^{8} C_i, \quad \text{with } C_i := \sum_{t=1992}^{t=1999} \delta^t \{(RL^i(t) - \bar{RL}(t))^2 + (\Delta P_c^i(t) - \Delta \bar{P_c}(t))^2\}, \tag{6}$$

where $RL^i(t)$ and $\Delta P_c^i(t)$ are the long term interest rate and the consumer price deflator, in year t for country i, respectively; the bar values represent averages of that year. We make the following choice for these averages:

$$\bar{RL}(t) = \frac{1}{3}\{RL^{Ge}(t) + RL^{Fr}(t) + RL^{UK}(t)\},$$
$$\Delta \bar{P_c}(t) = \frac{1}{3}\{\Delta P^{Ge}(t) + \Delta P^{Fr}(t) + \Delta P^{UK}(t)\},$$

for each year t =1992,...,1999. By taking this particular choice we assume that during the planning period all EU-Member States follow the average level of the nominal long term interest rates and the average consumer price inflation values of the three largest Member States, Germany, France and the United Kingdom. Since the European Commission, (the $(N+1)$st player) acts as a representative of the N-players, we assume that the choice of this particular convergence towards the average of the 'large 3' represents the agreement between all EU-Member States about convergence in consumer price inflation and nominal long term interest rates[11]. The parameter δ_i represents the time preference and/or a convergence weight for each country i. It seems reasonable to assume that convergence

[11]Remark that we have to make this simplifying assumption, since constructing a convergence function which accurately represents the convergence conditions of the Maastricht Treaty is very difficult. This

becomes more desirable at the end of the planning period; therefore countries will put a higher weight on convergence towards the end of the planning period. We simplicity we assume a constant $\delta = 1.2$ which reflects the fact that the priority for convergence increases by 20% for each country each following year. Remark that the final policy choices will be sensitive for the chosen convergence function and note, furthermore, that the desired values $\bar{RL}(t)$ and $\Delta\bar{P_c}(t)$ for each year t, t =1992,...,1999, are not specified beforehand but will be determined by the optimization procedure, and, hence, by the convergence function itself.

5 Empirical Results

In this section we will describe the empirical results. In the first subsection we will show the results for the fixed echange rate regime. In the next subsection we perform the same experiment but consider the case where (slight) adjustments in the dollar exchange rate are possible. Exchange rates are kept very tight which is modelled through the high weight in the R-matrix. Therefore, if a particular country tries to adjust its dollar exchange rate it will be heavily penalised. In both dynamic game experiments we assume for the *NCO*-outcome $\lambda = 0.2$, indicating that each country gives a weight of 20% to minimise C_i and a weight of 80% to minimise J_i. We will study for this noncooperative outcome the sensitivity of our results related to the choice of λ and report some results we obtained with different choices for λ.

5.1 Empirical results in a fixed exchange rate regime

Table 4 contains, for each country, the objective function values and the convergence values for each game outcome. Since in our dynamic game analyses we minimise costs (convergence), we have that a low value for the objective function (convergence function) indicates there is much welfare (convergence). As explained in section 3.3, we observe that the objective function values $J_i, i = 1, ..., 8$ are the same for the *NC* and the *CCO* case. Furthermore, we observe that in the *NB*-solution each Member State has substantially more welfare than in both noncooperative solutions, *NC* and *NCO*. Also the *NB*-solution yields a substantially higher degree of convergence. This last aspect is remarkable since, in the *NCO*-outcome, each individual Member State additionally attributes some additional weight to minimise convergence, in contrary to the *NB*-solution. The experiments, where we tried different values for λ in the *NCO* game, did not change this result very much. In general, a higher

aspect, however, makes the dynamic game analyses not less interesting, since, in this case, it is possible to look for various convergence functions, which in fact could yield conditions which would be quite different from those specified at the Maastricht Treaty. To go even a step further, one could think of the possibility of constructing an 'optimal' convergence function. We refer to Appendix C for other specifications of the convergence function.

Table 4: The objective function values, convergence value and weights in a fixed exchange rate regime

	Countries								
	Belgium	Denmark	Germ.	France	Ireland	Italy	Netherl.	U.K.	Conv.
NC	0.73	1.24	1.57	2.78	1.50	2.32	0.97	1.57	9.10
NCO	0.41	1.75	1.05	2.79	1.98	3.70	0.70	1.76	8.46
NB	0.36	0.91	0.63	1.60	1.28	1.40	0.74	1.28	6.71
CCO	0.73	1.24	1.57	2.78	1.50	2.32	1.97	1.57	3.24
	Weights								
	Belgium	Denmark	Germ.	France	Ireland	Italy	Netherl.	U.K.	Conv.
α^{NB}	0.13	0.15	0.05	0.04	0.22	0.05	0.21	0.16	-
α^{CCO}	0.16	0.03	0.06	0.08	0.02	0.19	0.31	0.14	0.42

λ, and hence a higher weight on convergence in the *NCO*-solution yielded more or less the same results with respect to the degree of convergence[12]. Furthermore, in comparison to the *NB*-solution, the *CCO*-solution yields an additional degree of convergence. These observations give already some evidence to the fact that coordination is a necessary requirement for convergence, or as stated by Brandsma and Italianer [3, page 11]:'...in the absence of proper coordination, a majority of the Member States would fail to meet the convergence criteria, no matter how seriously they tried to converge'.

The next interesting question is whether the convergence conditions diminish negative spillovers in the noncooperative case. If we compare the two noncooperative outcomes, we observe that welfare is higher in the *NCO* outcome for three countries (Belgium, Germany and the Netherlands) and lower for the other five countries (Denmark, France, Ireland, Italy and the U.K.). These results suggest that the convergence criteria in a noncooperative game increase total welfare for the three traditionally low inflationary countries and decrease total welfare for the five traditionally higher inflationary countries. If we again consider figure 4 and translate the problem to the eight dimensional case, then we observe that the convergence constraint moves the $NC' = NCO$ in the 'right' direction for the above mentioned three countries and in the 'wrong' direction for the other five countries.

If we recall the interpretation of the α^{NB}-weights in the *NB*-solution (see section 3.2), we see that Germany, France and Italy have a rather low weight. Hence, these countries gain most if a purely cooperative strategy is adopted. The relatively higher α^{NB}-weights for Belgium, Denmark, Ireland, the U.K. and the Netherlands may imply that these countries can put heavy pressure on EU-negotiations, since their welfare gains from playing cooperatively are less than those for the other three economies. These outcomes suggest that most gains come from cooperation between Germany and France. Internalising the spillover effects in a positive way seems therefore most profitable for these two interdependent countries. The

[12] Changing λ from 0.2 to 0.6 yielded convergence values still higher than 8.0

dependent country Italy profits most from this cooperation between Germany and France, whereas all the other countries show only a slight increase in welfare. The explanation of the result that Germany and France profit most is that in a noncooperative world the additional costs Germany and France have to pay are for the greater part costs in terms of instruments and for a lesser part costs in terms of targets. The externalities are, however, only generated by the target variables and, therefore, the differences between the quantitative effects in the cooperative *NB*-solution or noncooperative solutions generated by the larger countries are relatively small for the dependent countries. This observation explains also why small dependent countries like Belgium Denmark, Ireland and the Netherlands do not gain so much from a cooperative strategy [13]. The intuition behind this result for the third interdependent country, the U.K., is that, in the SLIM-model, this country is more dependent on the USA than on Germany and France. Traditionally the U.K. is more isolated than most other countries in the EU which is reflected by the rather weak interdependencies with the other countries in the SLIM-model.

We now turn to the *CCO*-outcome. The results with respect to the chosen convergence function seem quite good. First, this result suggests that if countries are willing to coordinate their policies, then a lot of convergence is possible. This observation follows from the low convergence value and the high weight on convergence in the *CCO* solution. This result suggests also that in figure 4, if we again translate the problem to the eight dimensional case, that the Pareto curve P' tends to move slowly to the right if we increase λ. It is possible to compare the 'welfare weights' α^{CCO} and α^{NB}. The rule of thumb one can apply here is: The Member States whose weights increase, from the *NB* to the *CCO* case, contribute more to the minimisation of the convergence function than the Member States whose weights decrease. If we apply this rule of thumb, then we see that Italy contributes very much to the minimisation of the convergence function. This result is not surprising since Italy is the country with the highest inflation rates and long term interest rates and, thus, the $C_i, i =$Italy, term contributes a lot to the convergence function C. Applying again the rule of thumb, we observe that Denmark, Ireland and the UK do not contribute very much to the minimisation of the convergence function. This result may imply that these three countries face more welfare loss when trying to converge since their problems are more structural, whereas the other five countries can already create a lot of convergence by 'simply' internalising their externalities.

In order to discuss more country specific results we present in table 5, for each country, the (average) target values and policy choices for the four different game outcomes over the planning period. The first observation is that optimal growth is found to be moderate and that, except for Ireland, average growth is comparable to the average growth values during the eighties. These results are obtained with, on average, lower levels of government

[13]This result depends, of course, strongly on the simplifying assumption of the interdependencies in the SLIM-model in which Belgium and the Netherlands are modelled as dependent economies. If we would, for instance, consider the total Benelux-economy, then the impact of this economy on France and Germany might be substantial.

Table 5: The average target- and instrumental values (1992-1999)[a]

		Bel.	Germ.	Denm.	France	U.K.	Irel.	Italy	Neth.
	Target values								
ΔY	NC	1.86	2.51	1.40	2.26	2.64	4.60	2.34	1.47
	NCO	1.94	2.56	1.50	2.61	2.70	4.69	2.40	1.67
	NB	1.85	2.46	1.53	2.12	2.58	4.55	2.43	1.48
	CCO	1.66	2.20	1.44	1.76	2.55	4.62	2.22	1.22
ΔPy	NC	3.52	4.15	5.26	5.67	4.92	5.97	8.36	3.80
	NCO	3.78	4.14	5.40	6.15	5.00	6.02	9.10	4.09
	NB	3.01	3.76	4.94	4.28	4.55	5.74	7.32	3.37
	CCO	2.92	3.70	4.70	3.92	4.37	5.62	6.08	3.30
ΔPc	NC	3.67	3.71	5.41	5.66	4.77	5.10	8.90	3.76
	NCO	3.98	3.71	5.54	6.12	4.86	5.15	9.72	4.05
	NB	2.90	3.40	5.06	4.30	4.40	4.82	7.71	3.21
	CCO	2.75	3.32	4.82	3.95	4.23	4.70	6.38	3.11
ΔW	NC	5.50	5.43	6.82	7.14	7.48	9.10	9.89	4.84
	NCO	5.91	5.46	7.06	7.82	7.60	9.18	10.74	5.32
	NB	4.68	4.91	6.45	5.50	7.02	8.85	8.77	4.27
	CCO	4.50	4.66	6.09	4.97	6.79	8.77	7.31	4.08
ΔN	NC	0.01	0.35	0.36	0.33	-0.34	0.68	0.76	0.01
	NCO	0.02	0.39	0.38	0.50	-0.30	0.73	0.79	0.07
	NB	0.03	0.52	0.44	0.24	-0.43	0.64	0.77	0.08
	CCO	-0.06	0.47	0.43	0.08	-0.52	0.64	0.69	-0.06
RL	NC	7.92	6.97	9.60	10.34	8.72	8.93	11.80	8.02
	NCO	8.36	7.10	8.00	9.22	8.42	8.03	10.23	7.45
	NB	8.49	8.16	9.42	10.34	9.52	8.95	11.49	8.18
	CCO	8.85	8.91	9.54	9.96	9.66	9.48	10.86	8.71
	Instrumental values								
		Bel.	Germ.	Denm.	France	U.K.	Irel.	Italy	Neth.
RS	NC	6.59	4.71	8.39	9.71	8.27	8.95	11.27	6.78
	NCO	7.33	4.91	6.44	8.03	7.66	7.51	9.42	5.89
	NB	7.47	7.08	8.40	9.95	10.00	8.96	10.89	6.89
	CCO	8.17	8.67	8.66	9.31	10.30	9.67	10.08	7.89
G	NC	15.099	14.149	13.135	15.124	12.410	9.389	13.620	12.655
	NCO	15.108	14.146	13.134	15.117	12.414	9.389	13.610	12.663
	NB	15.112	14.132	13.136	15.095	12.412	9.389	13.623	12.669
	CCO	15.121	14.129	13.124	15.078	12.410	9.389	13.594	12.674

[a] $\Delta Y, \Delta P_y, \Delta P_c, \Delta W, \Delta N$ in % growth per annum. RL and RS in % and G in logaritmic of the real level government expenditure values.

expenditure and lower levels of the short (and long term) interest rates than during the period 1981-1990. The results are in accordance with the broad economic policy guidelines of the EU in which a reduction of short and long term interest rates is proposed in the short to medium term and budgetary consolidation should be achieved by reducing government expenditure and by an improvement of the efficiency of the fiscal system (see, e.g., the 1994 broad economic guidelines [11]).

Studying some results more specifically we observe that for all countries the cooperative outcomes show lower inflation rates than the noncooperative outcomes. These outcomes are generated, on average, by reductions in government expenditure and an increase in the long term interest rates. As can be seen in table 5, both policies hamper growth in the SLIM-model. This property suggests that countries should use a higher interest rate policy in order to prevent inflationary growth [14].

For Germany we observe that in the cooperative setting it has to reduce domestic inflation in order to reduce foreign inflation. Because GDP-growth is strongly inflationary in the SLIM-model, this policy leads to lower GDP growth rates. Since Germany plays a leading role due to its large spillovers, we find in the cooperative game that Germany likes to prevent negative effects for other EU-economies, which is ultimately profitable for Germany itself. Important to note is the accumulation of inflation over time in the SLIM-model. A relatively high inflationary policy in Germany generates higher inflations abroad. In the next period this high inflation is transported back to Germany which, in the next period again, is transported back abroad and so on. The longer the planning period the more important this inflationary accumulation effect drives the final results. Remarkable is the policy change that occurs in Germany if the cooperative setting is replaced by a noncooperative one. In the cooperative solution Germany increases the short term interest rate and uses a contractionary fiscal policy in order to reduce inflation (and, thus, also inflation abroad) whereas in the noncooperative setting it does not care about the foreign effects and chooses a contractionary monetary and expansionary fiscal policy. This noncooperative behaviour leads to more growth in Germany but also to higher domestic and foreign inflation and lower domestic employment.

To understand most of the results we have to discuss the impact of the two policy instruments in the SLIM-model, the short term interest rate and government expenditure. We take Germany as an example. An increase in the German short term interest rate leads in general to an increase in the domestic long term interest rate. This results in a decline in domestic output, inflation and wages. There is, however, through the channel of the long term interest rate a stabilising effect, since the decline of inflation leads to lower interest rates. The initial increase in the long term interest rate in Germany has, furthermore, an increasing effect on the foreign long term interest rates and, hence, a negative effect on

[14] The same assesment was made by the monetary authorities in 1989: in a period of inflationary pressures, where the rate of growth exceded the level required to stabilize employment, nominal short-term interest rates increased in every EU-country (see Drèze en Malinvaud [9]).

foreign growth. This effect can be valuable for these countries in order to fight against inflation. On the other hand, a contractionary fiscal policy in Germany leads also to a decline in growth and inflation as well in Germany as in the foreign countries; but this decrease in inflation leads, through the interest rate channel, to a decline of the long term interest rate in Germany and also abroad. This last effect has again some increasing impact on growth and inflation. It is exactly this opposite functioning in policy behaviour between the short term interest rate and government expenditure which should be kept in mind when interpreting the results.

If we again compare the noncooperative and cooperative outcomes we see, on average, that the noncooperative outcomes yield higher growth rates and to a lesser extent higher employment rates but also to higher inflation and wage rates. This effect is mainly created by the four larger economies, in particular we see a substantial reduction in the short term interest rate in Germany and the UK and a substantial expansionary fiscal policy in Germany and France.

Another interesting aspect is that the *CCO*-outcome suggests that countries with traditionally low interest rates, such as Germany, Belgium and the Netherlands should adjust their interest rates to higher levels in order to achieve global convergence. Our model suggests that it is less costly for the EU as a whole to reach convergence if these three countries adjust their interest rate levels upwards, since this would make it easier for the other five countries, which have traditionally higher interest rates, to achieve these lowest three rates. The noncooperative outcome, however, suggests that Germany, the Netherlands, and to a lesser extent Belgium, should follow more the policy they advocated during the eighties where the interest rates were, for at least Germany and the Netherlands, substantially lower than for the other five countries. This raises the important question: 'who should converge to who?'. It is clear that in a Treaty with *fixed* policy targets this question would not exist but in this case, where we have *flexible* policy targets, this is a serious issue. One could argue that this is one of the reasons why Germany is such an advocate of a more speed EU, since, in that case, they could follow, more or less, their noncooperative strategy with low interest rates and, hence, leaving the other countries the option to follow or not. It is clear that such a noncooperative strategy of Germany saddles up most other countries with more costs than if a cooperative strategy was adopted by Germany. These increasing costs in the foreign countries are, partly, transferred back to Germany which in the end yields higher costs for Germany as well in the noncooperative case. This argument may also explain why Germany uses this threat-argument of a two speed Europe in its negotiations with the other EU-economies. On the other hand, the low gains the model predicts for the UK, if they play cooperatively, suggests that the UK can put heavy pressure on the negotiations since they can not gain much during Stage Two. This may be an explanation why it threatens, once in a while, with leaving the EU. Remark, that we disregard the possible profits for each country which it expects to gain in Stage Three of EMU [15]. Before

[15]If the Member States would consider the possible positive gains of Stage Three, then it is likely that each Member State is willing to accept more costs during Stage Two. In our context, this means that

proceeding with our analyses we first give the dynamic game results in the tight exchange rate regime.

5.2 Empirical results in a tight exchange rate regime

We present for this regime the same tables as shown in the previous subsection. In table 6 we present the implications for welfare for the four game outcomes. The figures can be

Table 6: The objective function values, convergence values and weights in a tight exchange rate regime

	Countries								
	Belgium	Denmark	Germ.	France	Ireland	Italy	Netherl.	U.K.	Conv.
NC	1.05	1.01	2.96	1.93	1.12	2.34	1.08	1.27	8.76
NCO	0.88	1.15	1.99	1.63	1.18	2.82	0.94	1.27	8.32
NB	0.34	0.73	1.19	1.21	0.92	1.48	0.72	1.01	6.63
CCO	1.05	1.01	2.96	1.93	1.12	2.34	1.08	1.27	2.53
	Weights								
	Belgium	Denmark	Germ.	France	Ireland	Italy	Netherl.	U.K.	Conv.
α^{NB}	0.07	0.18	0.03	0.07	0.25	0.06	0.14	0.20	-
α^{CCO}	0.10	0.04	0.06	0.12	0.06	0.19	0.26	0.17	0.44

compared to the outcomes presented in table 4. If in the tight exchange rate regime it would be optimal that no country uses the possibility of managing its exchange rate with the dollar, i.e. $\Delta E = 0$ for the whole planning period, then we would obtain exactly the same outcomes as in the fixed exchange rate regime which we considered in the previous subsection.

If we compare the two noncooperative outcomes we see that in a tight exchange rate regime the *NCO* outcome is profitable for four countries (Belgium, Germany, France, the Netherlands), malicious for three countries (Denmark, Ireland, Italy) and makes no difference for the UK. Furthermore, these results suggest a small increase in global welfare since the total gains of the four countries seem to be higher than the total losses of the three countries. Concerning individual welfare in the *NCO*-solution we noticed that increasing λ yielded substantial gains for the four mentioned countries and the UK, whereas for the other three countries we found that the objective function values remained almost the same as shown in table 6, with $\lambda = 0.2$. The implications for total welfare depend, of course, on the weights one assigns to the individual welfare functions, but with equal weights we found that total welfare substantially increased when increasing λ. These experiments suggest

Member States are willing to consider outcomes outside the negotiation area where even more convergence would be possible.

that the outcomes severely depend on the specification of the convergence conditions in a noncooperative world and that it even may be possible that a particular convergence function could be constructed in which each individual Member State would be better off than in the *NC*-solution. Comparing tables 5 and 7, we observe that managing the exchange rate in the SLIM-model is profitable for the five traditionally higher inflationary countries but malicious for Belgium, Germany and the Netherlands. This observation holds for any of the four game outcomes.

Remarkable are the differences in welfare outcomes in the noncooperative case for Germany and France between the tight and the fixed exchange rate regime. A great deal of burden, associated with the various exchange rate policies in the tight exchange rate regime, is covered by Germany. This observation follows from the fact that Germany has a substantially lower welfare value in the fixed exchange rate regime than in the tight exchange rate regime, whereas for France it is the other way around. The reason for this finding is that in the SLIM-model, French output is strongly positively affected by an appreciation of the nominal exchange rate between the French Franc against the Dollar and a depreciation of the nominal exchange rate between the German mark against the Dollar.

The overall results of table 6 are in line with those of table 4. We observe also that the weights α^{NB} and α^{NC} are (very) similar in both dynamic games experiments. Again Germany, France and Italy have the lowest weight values in the *NB*-solution. The four smaller dependent countries and the more isolated country UK gain less in a cooperative strategy. In the cooperative solutions, the fixed exchange rate regime can be seen as a restricted form of the tight exchange rate regime and should therefore by definition lead to lower total welfare values. If we, as an example, multiply all individual weights with the corresponding individual welfares then we find that total welfare increases from 0.89 in the tight exchange rate regime to 0.98 in the fixed exchange rate regime. If we use the same α^{NB}-weights then we find that in the *NC* case (and, thus, also in the *CCO* case) that total welfare is 1.30 in the tight exchange rate regime and 1.36 in the fixed exchange rate regime. For the *CCO*-solution this observation implies that in the tight exchange rate regime 1.30-0.89=0.41 of total welfare is used for minimizing convergence and in the fixed exchange rate regime 1.36-0.98=0.38 of total welfare. It is clear that the *CCO*-solution chosen in this example does not guarantee that the convergence criteria are reached. It is, however, possible to search for strategies which satisfy the convergence criteria and a 'rough measure' of convergence costs, in terms of welfare, could then be constructed as shown by the example above.

In table 7 we present the averages of the target and instrumental values for each country seperately. A first glance shows that the qualitative outcomes of the fixed exchange rate regime are similar to the tight exchange rate regime. For all countries we see again that inflation is reduced in the cooperative case. We observe the strongest adjustments in the exchange rates in the *CCO* outcome. For this outcome, we observe that the traditionally higher inflationary countries, such as France, Ireland and Italy, appreciate their currency

Table 7: The average target- and instrumental values (1992-1999)[a]

		Bel.	Germ.	Denm.	France	U.K.	Irel.	Italy	Neth.
	Target values								
ΔY	NC	1.86	2.52	1.41	2.35	2.65	4.64	2.46	1.49
	NCO	1.97	2.58	1.48	2.59	2.68	4.69	2.51	1.50
	NB	1.87	2.47	1.57	2.20	2.56	4.59	2.48	1.63
	CCO	1.74	2.20	1.43	1.90	2.52	4.49	2.23	1.17
ΔPy	NC	3.33	4.11	5.25	5.56	4.92	5.91	8.25	3.64
	NCO	3.54	4.09	5.32	5.76	4.94	5.92	8.61	3.80
	NB	3.08	3.68	4.92	4.52	4.63	5.71	7.48	3.39
	CCO	3.09	3.75	4.76	4.11	4.45	5.54	5.96	3.45
ΔPc	NC	3.48	3.66	5.39	5.54	4.78	5.03	8.75	3.60
	NCO	3.69	3.65	5.45	5.74	4.81	5.04	9.15	3.75
	NB	2.99	3.36	5.04	4.52	4.48	4.77	7.89	3.22
	CCO	2.96	3.39	4.88	4.12	4.31	4.57	6.25	3.28
ΔW	NC	5.23	5.37	6.82	7.06	7.50	9.06	9.85	4.65
	NCO	5.54	5.41	6.96	7.39	7.54	9.08	10.26	4.92
	NB	4.79	4.82	6.44	5.81	7.11	8.82	8.98	4.28
	CCO	4.76	4.72	6.18	5.22	6.86	8.61	7.23	4.25
ΔN	NC	0.03	0.39	0.36	0.38	-0.32	0.70	0.81	0.09
	NCO	0.07	0.43	0.37	0.50	-0.29	0.72	0.83	0.16
	NB	0.04	0.56	0.45	0.30	-0.41	0.66	0.79	0.10
	CCO	-0.03	0.46	0.42	0.15	-0.49	0.60	0.70	-0.07
RL	NC	8.07	7.07	9.56	10.05	8.72	8.69	11.30	8.03
	NCO	8.11	7.07	8.66	9.28	8.59	8.25	10.49	7.74
	NB	8.46	8.34	9.39	10.09	9.42	8.71	11.09	8.17
	CCO	8.93	8.91	9.50	9.91	9.60	9.33	10.69	8.78
	Instrumental values								
		Bel.	Germ.	Denm.	France	U.K.	Irel.	Italy	Neth.
RS	NC	6.84	4.92	8.36	9.36	8.29	8.48	10.62	6.82
	NCO	6.96	4.89	7.27	8.25	8.09	7.78	9.68	6.40
	NB	7.44	7.43	8.38	9.59	9.77	8.49	10.36	6.89
	CCO	8.28	8.67	8.58	9.23	10.13	9.51	9.88	8.00
G	NC	15.091	14.147	13.136	15.119	12.410	9.389	13.620	12.655
	NCO	15.095	14.144	13.135	15.110	12.412	9.389	13.615	12.658
	NB	15.112	14.125	13.136	15.099	12.414	9.389	13.623	12.669
	CCO	15.126	14.128	13.128	15.086	12.411	9.388	13.598	12.675
ΔE	NC	-0.02	0.00	0.00	-0.02	0.00	-0.06	-0.07	0.00
	NCO	0.00	0.00	0.00	-0.03	0.00	-0.06	-0.09	0.00
	NB	-0.02	0.13	0.00	-0.01	0.06	-0.05	-0.06	0.00
	CCO	0.15	0.54	0.00	-0.09	0.01	-0.14	-0.20	0.02

[a] $\Delta Y, \Delta P_y, \Delta P_c, \Delta W, \Delta N, \Delta E$ in % growth per annum. RL and RS in % and G in logaritmic of the real level government expenditure values.

against the dollar and that the traditionally low inflationary countries, such as Belgium, Germany and the Netherlands depreciate their currency, in order to fulfil the convergence requirements (of especially convergence in consumer price inflation).

Now let us take a closer look at the four convergence criteria. Since we have only one fiscal policy instrument, government expenditure, the experiments are less useful for checking the budget criteria. We did, however, construct the desired government expenditure paths such that all Member States substantially reduced government expenditure in order to be able to restore their budget. In comparison with the other game outcomes, for most countries the *CCO*-outcome yielded lower levels of government expenditure. This was not the case for Belgium and the Netherlands. Comparing the noncooperative and the cooperative outcomes we see that both countries changed their policy behaviour in both experiments. In the noncooperative game they follow a contractionary fiscal policy and a low interest rate policy. However, in especially the *CCO*-case, they have to follow the higher interest rates of the other countries and, therefore, both countries have to increase interest rates. This policy has, however, a negative impact on output growth and in order to offset some of this negative impact both countries react with an increase in government expenditure. Through the high priority of 10 on the exchange rates we obviously find that the exchange rates are kept very tight around the 1991 values. In table 7 one observes that most values of ΔE are close to zero; we only find a substantial depreciation of the German mark against the Dollar in the case of the *CCO*-outcome. It is clear that such a policy is very unlikely in reality. However, in the cooperative *CCO*-outcome studied here, Germany is very much concerned about convergence of *all* the EU-Member States and, therefore, reacts with a depreciation policy.

In order to check the two central criteria of convergence in consumer price inflation and nominal long term interest rates we will present some graphs. In figure 5, we present the consumer price deflator responses for three different game outcomes in the tight exchange rate regime[16]. In figure 6 we present the long term interest rates for the same game outcomes. The graphs show some interesting facts. First of all, the graphs suggest that it seems to be much harder to converge for consumer price inflation than for the long term interest rates. This fact is, however, more a property of the model and is related to the fact that long term interest rates in the SLIM-model can directly be manipulated by the short term interest rates, whereas the consumer price deflator can only indirectly be influenced [17]. As already indicated by the convergence values of table 6, we see in all figures that the degree of convergence increases from the *NC*, *NB* to the *CCO*-outcome. The long term interest rate criterion is fulfilled by all the Member States in the *CCO*-outcome with an average long term interest of 8.5%. For the consumer price deflator we find less convergence. If we consider the three Member States with the lowest inflation (Belgium, Germany and

[16]The similarity between the graphs of the *NC* and *NCO* outcome was large, so we decided to include the graph of the *NC* outcome only

[17]For instance, if we would follow the same strategy as used in Brandsa and Italianer [3], who consider wages as an instrumental variable, then it would be much easier to obtain convergence in (lower) consumer price inflation rates.

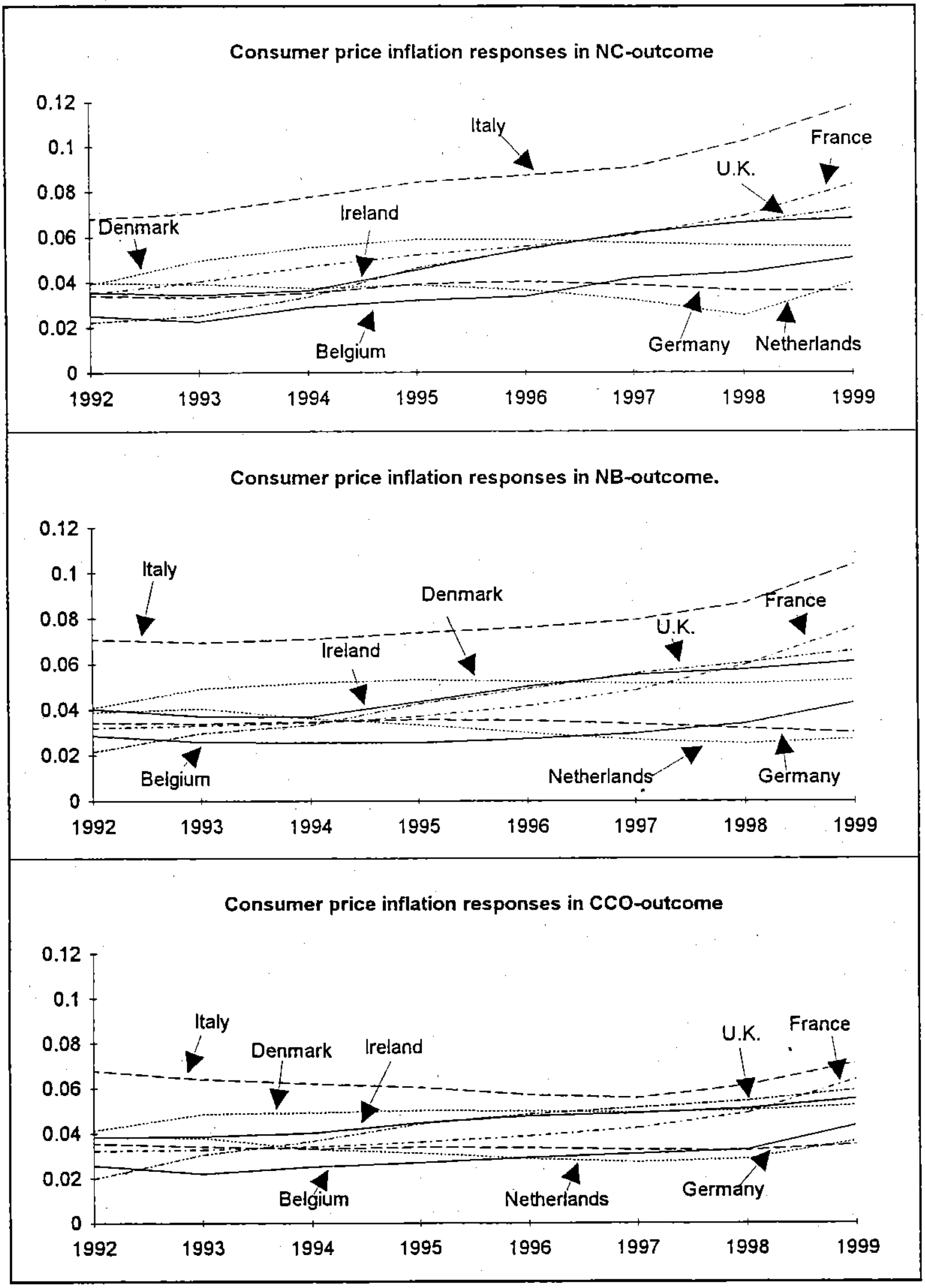

Figure 5: Consumer price inflation responses in various game outcomes

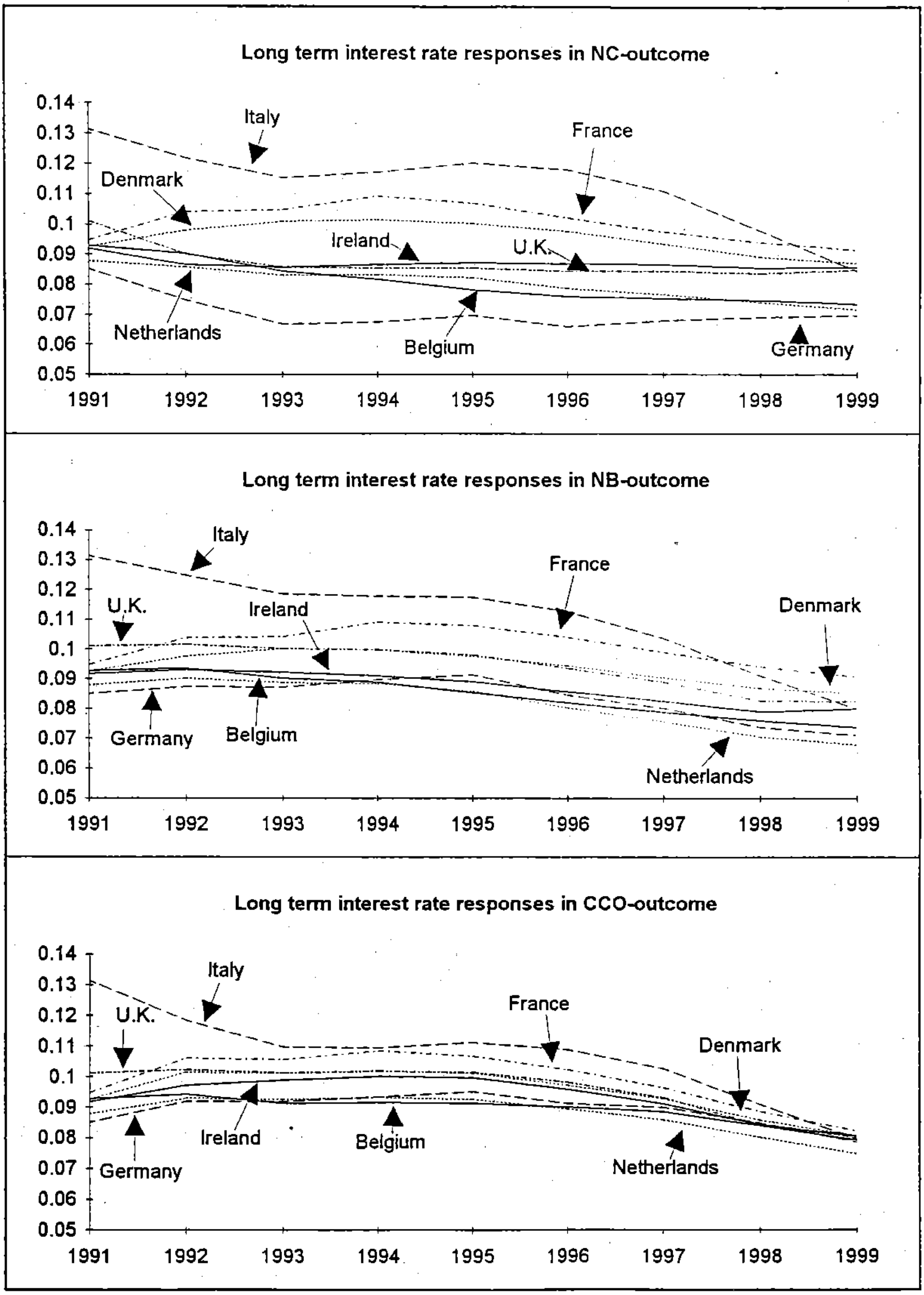

Figure 6: Long term interest rate responses in various game outcomes

the Netherlands), then we find a consumer price deflator of around 4%. Since, the Maastricht Treaty allows only for consumer price inflation rates which are no more than 1.5% points above the average for the three countries with the lowest inflation rates we see that three of the other five Member States fulfil this rule and that Italy and France come very close to the 5.5% norm. The results of the graphs are in accordance with the empirical results of Brandsma and Italianer [3] who state that, with appropriate coordination, all the eight Member State should be able to fulfil the convergence criteria. In that study the authors used the European Commission's Quest model, which contains all the EU-Member States and they allowed sometimes, in order to fulfil the criteria, for drastic measures such as dismissing government employees or using the wage rate of the government employees as a policy variable. Remark, however, that in that research the broad economic policy guidelines [11] were followed which propose inflation rates of 2-3%. It is important to stress that these inflation rates are low if one compares them with the average inflation rates during the eighties. Therefore, it is important to realise that during the 1990-1994 period average output was rather low in the EU, so that several countries fighted successfully against inflation. A property of the SLIM-model, and also of most other EU-models (see, e.g. Douven and Plasmans [6]), is that growth is strongly inflationary (in the long run on average 1% GDP-growth yields about 2% inflation). This relationship between growth and inflation in most models may be somewhat exaggerated, but also may suggest that countries will get a hard time if overall growth in the EU substantially increases. Concerning employment, tables 5 and 7 suggest also that in order to reach the convergence criteria employment will decline in most countries, except for Denmark and Germany. For these two countries the decline in wages, which stimulates employment, was large enough to offset the decrease in output, which hampers employment. In all experiments the impact on employment is rather low which suggests that the policy measures used in the SLIM-model are not adequate enough to fight for substantial increases in employment. It suggests that more structural changes are needed in order to promote employment in several EU-economies.

6 Conclusions

In this paper we carried out a dynamic game analysis with the SLIM-model. In the dynamic game we compare four (hypothetical) scenarios. First, a noncooperative scenario which is represented by the feedback Nash solution (*NC*) in which each country minimises its own welfare and, second, a feedback Nash solution (*NCO*) in which each country minimises its own welfare, but additionally tries to fulfil the two convergence criteria of convergence in the long term interest rates and convergence in consumer price inflation rates. Third, a purely cooperative scenario, which is represented by the Nash bargaining solution (NB) and, fourth, a cooperative convergence scenario (CCO). In this last scenario the EU-Member States play in a cooperative mode, but face a dynamic constraint of convergence in consumer price inflation and long term interest rates. These two convergence conditions are elaborated at the Maastricht Treaty (1991). The third condition in this Treaty is that each Member State should strive for a sustainable government financial position. This aspect is modelled by means of the individual welfare functions of each country. In our experiments we assumed that each country substantially lowers its government expenditure, in order to restore its government deficit. The fourth Maastricht convergence condition, no exchange rate realignments for at least two years, is modelled by keeping in one experiment the (dollar) exchange rate fixed at the initial 1991 levels and in a second experiment by allowing only for very small movements around these 1991 levels. For the *CCO*-solution we assume that countries do not accept 'welfare losses' which are higher than the 'welfare costs' obtained in the noncooperative solution. This assumption makes it possible to prove that the maximum convergence that can be reached is limited. Furthermore, one can obtain a unique cooperative convergence solution in this case.

The first important observation is that we found some evidence that convergence does not occur if the EU-Member States do not coordinate their policies (see also Brandsma and Italianer [3]).

Furthermore, our theoretical study suggests that one should design (optimal) convergence criteria in the sense that the impact of the convergence criteria is profitable in the noncooperative case and remains close to Pareto optimal solutions in the cooperative case. Since, in reality, we observe a mix of cooperative and noncooperative policy behaviour this study suggests that the European Commission should strive for restrictions on national policies in which negative spillovers diminish in the noncooperative game but still keep almost all the gains in the cooperative game. Our first empirical results give some evidence to the fact that the Maastricht criteria at least do not harm much in a noncooperative setting and are indeed close to Pareto optimal solutions in the cooperative setting.

The model 'predicts' a nominal long term interest rate of around 8.5% and a consumer price deflator of around 4% as optimal in 1999. Optimal growth will in all countries be moderate.

Country specific remarks are that the SLIM-model predicts that the two largest EU-Member States, Germany and France gain most when comparing the noncooperative outcome with the purely cooperative outcome. This gives some evidence to the fact that strong (more independent) countries gain more, by playing cooperatively, than small (more dependent) countries. The main intuition behind this result is that the gains of the strongly interdependent countries are mainly due to a more effective use of their instrumental variables in order to produce, more or less, the same target variables, whereas the generated spillovers to the dependent countries are only produced by the target variables.

The two convergence conditions of the long term interest rate and the consumer price inflation are examples of flexible shared targets, since it is beforehand not clear what the ideal target values in 1999 will be. This raises an important question: Who converges to who? Should countries strive for the low targets advocated by Germany or should Germany adjust its interest rate and inflation targets to higher values and, thus, giving the other countries more room (and, hence, less welfare loss) for achieving the criteria. Our model predicts that it would be less costly for the EU as a whole if the traditionally low interest rate countries Belgium, Germany and the Netherlands converge towards the higher interest rates of the five other EU-economies, instead of using as convergence target a fixed low nominal interest rate level. Inflation targets can, more or less, be fixed on the initial 1991 values of around 2-4%. We have to emphasize that this result hinges decisively on the assumption that all countries (including Italy) should converge. Excluding, e.g., an inflationary country like Italy from a cooperative dynamic game experiment would lead to lower inflation target rates for the other players in that game.

It is important to stress that the results obtained in this paper are, of course, model dependent. Further research, such as robustness and sensitivity analyses, is desirable in order to obtain a better understanding of the different game outcomes. In particular the following aspects should be elaborated:
(1) In our research we assumed exogenous behaviour of the two foreign countries, USA and Japan. How will the dynamic game outcomes change if we endogenise their behaviour?
(2) Since it is extremely difficult to model the exact specifications of the convergence conditions of the Maastricht Treaty we modelled convergence in this paper by assuming that the EU-Member States converge to the average long term interest rate level and average consumer price inflation of the larger three EU-Member States, Germany, France and U.K. This aspect of the model should be elaborated more and it may be interesting to look for 'optimal' convergence functions.

A Appendix

In this appendix we give derive the formula for computing cooperative convergence outcomes (CCO). To that end the convergence problem is rewritten into a standard optimal control problem. First, however, we will formulate the description of the dynamic behaviour of each country in the SLIM-model:

Assumption A.1 *The economic behaviour of the individual countries can be described by (for $i = 1, \ldots, N$) :*

$$y_i(t) = A_i y_i(t-1) + \sum_{j \neq i}^{N} A_{ij} y_j(t-1) + B_i u_i(t) + D_i d_i(t) \tag{7}$$

where $y_i(t) \in I\!R^{n_i}$ is the state of the i-th country (endogenous variables), $u_i(t) \in I\!R^{m_i}$ is the control vector (instrumental variables) and the vector $d_i(t) \in I\!R^{\ell_i}$ is the purely exogenous data-vector. For all i, A_i, A_{ij}, B_i and D_i are real matrices of appropriate dimensions.

Assumption A.2 *Every country solves the problem:*

$$\min_{u_i} J_i := \min_{u_i} \sum_{t=t_0}^{t_f} \left\{ \|y_i(t) - y_i^*(t)\|^2_{Q_i(t)} + \|u_i(t) - u_i^*(t)\|^2_{R_i(t)} \right\}$$

subject to (7).

Using the stacked forms $u(t) = (u_1'(t), ..., u_N'(t))'$ and $y(t) = (y_1'(t), ..., y_N'(t))'$ the aspect of convergence can be described as follows:

Assumption A.3 *The minimization problem with respect to the convergence function is defined as:*

$$\min_u C(u) := \min_u \sum_{t=t_0}^{t_f} \|L(t)y(t)\|^2_{Q_0(t)}$$

Remark. The matrices $L(t), Q_0(t)$ can be chosen dependent on the problem. For instance if we want to investigate convergence to the average of the endogenous variables, the matrices L can be specified as follows (for $t = t_0, ..., t_f$):

$$L = \begin{pmatrix} \frac{N-1}{N}I & -\frac{1}{N}I & . & . & . & -\frac{1}{N}I \\ -\frac{1}{N}I & \frac{N-1}{N}I & -\frac{1}{N}I & & & -\frac{1}{N}I \\ . & & . & & & . \\ . & & & . & & . \\ . & & & & . & . \\ -\frac{1}{N}I & . & . & . & -\frac{1}{N}I & \frac{N-1}{N}I \end{pmatrix}$$

or if we want to investigate convergence to endogenous variables of a specific country, say country i, we get

$$L = \begin{pmatrix} -I & 0 & ... & 0 & I & 0 & ... & 0 \\ 0 & -I & 0 & ... & I & 0 & ... & 0 \\ . & & . & & . & & & . \\ . & & & . & I & & & . \\ 0 & . & . & 0 & 0 & 0 & ... & 0 \\ . & & & & I & . & & . \\ . & & & & . & & . & . \\ 0 & . & . & . & I & . & . & -I \end{pmatrix}$$

The matrices $Q_0(t)$ give the weights that each country wants to assign to the convergence function in each time period. Remark, that in the paper we choose L such that it satisfies the convergence function as presented in the paper.

Assumption A.4 (cooperative convergence problem) *Given*

$$0 \leq \alpha_i \leq 1, \quad i = 1, ..., N, \quad \sum_{i=1}^{N} \alpha_i = 1, \quad 0 \leq \lambda \leq 1,$$

the problem to be solved is:

$$\min_{u_i} \quad (1-\lambda)\sum_{i=1}^{N} \alpha_i J_i \quad + \quad \lambda C$$

subject to (7) *for (i=1,...,N).*

The solution of the above stated control problem can be derived by reformulating it as a standard LQ problem. We first introduce the overall system vectors:

$$\begin{aligned}
y(t) &= (y_1'(t), y_2'(t), ..., y_N'(t))' \\
y^*(t) &= (y_1'^*(t), y_2'^*(t), ..., y_N'^*(t))' \\
u(t) &= (u_1'(t), u_2'(t), ..., u_N'(t))' \\
u^*(t) &= (u_1'^*(t), u_2'^*(t), ..., u_N'^*(t))' \\
d(t) &= (d_1'(t), d_2'(t), ..., d_N'(t))'
\end{aligned}$$

Next introduce matrices $Q(t), R(t), Q^*(t), A, B$ and D in the following way:

$$\begin{aligned}
Q(t) &= (1-\lambda)\text{diag}(\alpha_1 Q_1(t), \alpha_2 Q_2(t), ..., \alpha_N Q_N(t)) \\
R(t) &= (1-\lambda)\text{diag}(\alpha_1 R_1(t), \alpha_2 R_2(t), ..., \alpha_N R_N(t)) \\
Q^*(t) &= \lambda L'(t) Q_0(t) L(t) \\
A &= \begin{pmatrix} A_1 & A_{12} & . & . & . & A_{1N} \\ A_{21} & A_2 & & & & . \\ . & & . & & & . \\ . & & & . & & . \\ . & & & & . & . \\ A_{N1} & . & . & . & . & A_{NN} \end{pmatrix} \\
B &= \begin{pmatrix} B_1 & 0 & . & . & . & 0 \\ 0 & B_2 & & & & . \\ . & & . & & & . \\ . & & & . & & . \\ . & & & & . & 0 \\ 0 & . & . & . & 0 & B_N \end{pmatrix} \\
D &= \begin{pmatrix} D_1 & 0 & . & . & . & 0 \\ 0 & D_2 & & & & . \\ . & & . & & & . \\ . & & & . & & . \\ . & & & & . & 0 \\ 0 & . & . & . & 0 & D_N \end{pmatrix}
\end{aligned}$$

The above problem is equivalent with the optimal control problem:

$$\min_{\bar{u}} \sum_{t=t_0}^{t_f} \left\{ \|\bar{y}(t) - \bar{y}^*(t)\|^2_{\bar{Q}(t)} + \|\bar{u}(t) - \bar{u}^*(t)\|^2_{\bar{R}(t)} \right\}$$

subject to

$$\bar{y}(t) = \bar{A}\bar{y}(t-1) + \bar{B}\bar{u}(t) + \bar{D}\bar{d}(t),$$

with

$$\begin{aligned}
\bar{A} &= \begin{pmatrix} A & 0 \\ 0 & A \end{pmatrix} \\
\bar{B} &= \begin{pmatrix} B \\ B \end{pmatrix} \\
\bar{D} &= \begin{pmatrix} D \\ D \end{pmatrix} \\
\bar{Q}(t) &= \begin{pmatrix} Q(t) & 0 \\ 0 & Q^*(t) \end{pmatrix} \\
\bar{R}(t) &= R(t) \\
\bar{y}(t) &= \begin{pmatrix} y(t) \\ y(t) \end{pmatrix} \\
\bar{u}(t) &= \begin{pmatrix} u(t) \end{pmatrix} \\
\bar{y}^*(t) &= \begin{pmatrix} y^*(t) \\ 0 \end{pmatrix} \\
\bar{u}^*(t) &= \begin{pmatrix} u^*(t) \end{pmatrix} \\
\bar{d}(t) &= \begin{pmatrix} d(t) \end{pmatrix}
\end{aligned}$$

Theorem A.5 *The solution for the cooperative convergence problem is than given, for $t = t_0, \ldots, t_f$, by :*

$$\hat{u}(t) = E(t+1)^{-1} \left(\bar{R}(t)\bar{u}^*(t) - \frac{1}{2}\bar{B}^T K(t+1) \left[\bar{A}\bar{y}(t-1) + \bar{D}\bar{d}(t) \right] - \frac{1}{2}\bar{B}^T g(t+1) \right)$$

where $K(t)$ satisfies, for $t = t_0, \ldots, t_f + 1$, the following backward Riccati difference equation :

$$\begin{cases} K(t) &= 2\bar{Q}(t-1) + \bar{A}^T K(t+1) \left(I - \frac{1}{2}\bar{B}E^{-1}(t+1)\bar{B}^T K(t+1) \right) \bar{A} \\ K(t_f+1) &= 2\bar{Q}(t_f) \end{cases}$$

$E(t+1)$ is defined, for $t = t_0, \ldots, t_f$, by :

$$E(t+1) := \bar{R}(t) + \frac{1}{2}\bar{B}^T K(t+1)\bar{B}$$

$g(t)$ satisfies, for $t = t_0, \ldots, t_f + 1$, the following backward difference equation :

$$\begin{cases} g(t) & = & -2\bar{Q}(t-1)y^*(t-1) + \bar{A}^T K(t+1)\bar{B}E^{-1}(t+1)\bar{R}(t)\bar{u}^*(t) \\ & & +\bar{A}^T K(t+1)\bar{D}d(t) - \frac{1}{2}\bar{A}K(t+1)\bar{B}E^{-1}(t+1)\bar{B}^T K(t+1)\bar{D}d(t) \\ & & +\bar{A}^T g(t+1) - \frac{1}{2}\bar{A}K(t+1)\bar{B}E^{-1}(t+1)\bar{B}^T g(t+1) \\ g(t_f+1) & = & -2\bar{Q}(t_f)\bar{y}^*(t_f) \end{cases}$$

Remark, that the standard cooperative problem, without convergence, can be computed by substituting $L = 0$.

The CCO solution is now represented by a particular choice of the weights $\alpha^{CCO} = (\alpha_1, ..., \alpha_N, \lambda)$. To find this set we have to use a constraint optimization procedure. These procedures are available in existing computer packages. Since, in section 3.3 it is shown that the CCO outcome coincides in the $J_1, ..., J_N$-plane with the NC outcome, the stopping criterium of the numerical optimization algorithm can be implemented as follows. Stop, if for all $i, i = 1, ..., N$, J_i is 'close' to J_i^{NC}.

B Appendix

In this appendix we describe our choices for the exogenous values. For the two foreign countries, USA and Japan, we used as starting values, the true 1991 values. From thereon we constructed the exogenous values for 1992-1999, using linear interpolation. Since, links between countries in the SLIM-model are of three types: first, financial variables such as interest rates and exchange rates; second, GDP inflation; and third foreign output, we present in table 8 just the (growth) rates for these values. Remark, that we assumed that the nominal long term interest rate, RL, is constant for the planning period 1992-1999. For

Table 8: The exogenous (growth) rates for USA and Japan in 1999.

	rates for endogenous values		
Countries	ΔY	ΔP_y	RL
USA	2.00	3.00	8.00
Japan	3.00	2.00	6.00

the other exogenous variables in the model, the nominal exchange rate and the labour force we constructed the exogenous paths as follows. We used the actual 1991 values and from thereon we assumed for the labour force the average historical growth rates over the last ten years 1982-1991 and for the nominal exchange rates we assumed zero growth rates.

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