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THE OPTIMALITY OF A MONETARY UNION WITHOUT A FISCAL UNION

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THE OPTIMALITY OF A MONETARY UNION WITHOUT A FISCAL UNION*

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ABSTRACT:

The paper explores the case for monetary and fiscal unification. Monetary policy suffers from an inflation bias because the monetary authorities are not able to commit. With international risk-sharing in a fiscal union, fiscal discipline suffers from moral hazard. An inflation target alleviates the inflation bias but weakens fiscal discipline. In a monetary union, however, this adverse effect on fiscal discipline is weaker. This advantage of monetary unification may outweigh the disadvantage of not being able to employ monetary policy to stabilise country-specific shocks. While monetary unification may thus be optimal, international risk-sharing may be undesirable because it weakens fiscal discipline.

Keywords: monetary union, fiscal transfer scheme, fiscal discipline, moral hazard, inflation targets.

JEL codes: E52, E58, E61, E62, F42.

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1. Introduction

The process of European monetary unification faces four major institutional issues. The first is that the European Central Bank (ECB) needs to build up credibility for its commitment to price stability. This requires it to adopt an appropriate targeting procedure. Although no formal decisions have been taken in this respect, most likely either money supply or inflation will be targeted (see Persson and Tabellini, 1996, and Svensson, 1997).

The second major issue regarding the process of European monetary unification is that national monetary policies can no longer be used to stabilise country-specific shocks. This is especially serious because empirical work reveals that cross-border ownership of private assets plays only a minor role in dealing with country-specific shocks in Europe (see e.g. Sorensen and Yosha, 1998). The lack of monetary instruments to stabilise country-specific shocks together with inadequate cross-country risk sharing through capital markets lends support to the well-known argument that monetary unification requires fiscal unification: risk sharing through a fiscal transfer scheme (FTS) should take over the task of national monetary policies in stabilising country-specific shocks.

The third major issue facing European monetary unification is that such an FTS may give rise to moral hazard because country-specific shocks are not perfectly observable. International transfers thus cannot be conditioned on these exogenous shocks, but have to be based on fiscal measures that may be affected also by (endogenous) fiscal discipline. By providing additional transfers from the other participants in the scheme, an FTS rewards governments for less fiscal discipline. This induces governments to exert insufficient discipline as some of the costs of lack of discipline can be shifted to the other members of the union.

This relates to the fourth major issue surrounding European monetary unification, namely lack of fiscal discipline. The lack of fiscal discipline produced by international risk-sharing is particularly costly in terms of social welfare because also domestic political distortions are likely to erode fiscal discipline. Accordingly, moral hazard due to international risk-sharing worsens domestic political distortions.

This paper investigates the case for monetary and fiscal unification by exploring the interaction between these four issues involving, respectively, lack of commitment in monetary policy, stabilisation of country-specific shocks, moral hazard due to international risk-sharing, and domestic political distortions producing a lack of fiscal discipline.

As far as the case for fiscal unification is concerned, international risk-sharing through an FTS gives rise to moral hazard. Hence, a trade-off emerges between fiscal discipline and risk-sharing. To protect fiscal discipline, an FTS that provides full insurance against idiosyncratic shocks is no longer optimal. In fact, any international risk sharing may be undesirable if labour market distortions and public spending requirements are large relative to the variance of the country-specific shocks. With large spending requirements and serious labour-market distortions, fiscal discipline is particularly beneficial in terms of alleviating tax distortions and the inflation bias due to lack of commitment. At the same time, with small country-specific shocks, international risk-sharing is only of minor importance. Hence, in trading off substantial gains from more fiscal discipline with only small gains from risk-sharing, the union optimally refrains from using an FTS. Domestic political distortions further strengthen the case against an FTS; lower fiscal discipline hurts social welfare by exacerbating not only the distortions due to lack of commitment (i.e. the inflation bias) but also domestic political distortions.

The case for monetary unification at first sight appears to become weaker if moral hazard prevents international risk-sharing (i.e. fiscal unification). In a fiscal union with full international risk sharing, national monetary policy is not needed to stabilise country-specific shocks because the FTS would pool these shocks. In the absence of full risk-sharing, however, giving up national monetary authority is costly in terms of less effective stabilisation of country-specific shocks.

This paper defies this common wisdom about the link between monetary and fiscal unification. It shows that monetary unification may be desirable even if moral hazard makes fiscal unification (i.e. full international risk-sharing) unattractive so that monetary unification is costly in terms of providing less effective stabilisation of country-specific shocks. In fact, even if moral hazard is so serious that no international risk sharing is optimal, a monetary union may be preferable to decentralised monetary policy.

The key to understanding the benefits from monetary unification is that institutional measures aimed at promoting the credibility of monetary policy, namely inflation targets for a central bank, weaken fiscal discipline but less so in a monetary union. In particular, imposing a tighter inflation target on the central bank implies that the inflation preferences of governments and the central bank diverge more. This induces governments to cut back on fiscal discipline so as to encourage the central bank to raise inflation to a level that is more in line with the governments' preferred rate. However, the effect of a unilateral reduction in fiscal discipline on the inflation rate is weaker in a monetary union than with national monetary policy because fiscal policy of each individual country exerts only a relatively small effect on union-wide monetary policy. The incentive to reduce fiscal discipline so as to undo the effects of the inflation target by forcing the central bank to produce higher inflation is thus weaker in a monetary union.[1] Accordingly, the trade-off between enhancing the credibility of monetary policy (by imposing an inflation target) and encouraging fiscal discipline is less sharp in a monetary union. On balance, a monetary union yields lower inflation, higher output and more fiscal discipline.

The lack of fiscal discipline due to domestic political distortions and international risk-sharing together with the inflation bias due to lack of commitment gives rise to a trade-off when considering the case for monetary unification. This trade-off is between, on the one hand, strengthening commitment and encouraging fiscal discipline and, on the other hand, giving up an instrument for facilitating the stabilisation of country-specific shocks. Monetary unification is optimal if the problems of lack of commitment and fiscal discipline dominate the need for stabilising country-specific shocks. Numerical results show that this is the case for a wide range of parameter values. In fact, for any of the parameter combinations we have investigated, monetary union outperforms national monetary policymaking. Monetary unification becomes relatively more desirable if country-specific shocks are small, if serious domestic political distortions weaken fiscal discipline, and if large government spending requirements and output distortions raise the temptation of the central bank to employ a surprise inflation as a way to alleviate distortions in the output market.

The conditions that make a monetary union relatively more desirable contribute to a fiscal union being undesirable. In particular, for a monetary union without a fiscal union to be optimal, lack of both commitment in monetary policy and discipline in fiscal policy need to be serious while country-specific stabilisation should only be of minor importance due to small country-specific shocks. Commitment problems are important if monetary authorities are tempted to boost output in view of both large non-tax distortions and large spending requirements producing serious tax distortions. These output distortions exacerbate also the problem of lack of fiscal discipline.

To explore the interaction between the credibility of monetary policy, fiscal discipline, international risk-sharing, and country-specific shock stabilisation, we extend the Barro and Gordon (1983a,b) model of discretionary monetary policymaking by including fiscal policy, unobservable

[1] A similar mechanism is explored in Beetsma and Bovenberg (1998). In particular, in setting the tax rate, the fiscal authority acts as a Stackelberg leader against the central bank. If the central bank prefers lower inflation than the fiscal authority does (e.g., because it is more conservative in the sense of Rogoff (1985) or because of the presence of an inflation target), the fiscal authority faces an incentive to raise taxes so as to induce the central bank to raise inflation. Since the effect of a unilateral change in taxes on the common inflation rate is weaker in a monetary union than with national monetary policymaking, the incentive to raise taxes in order to force the common central bank to produce higher inflation is weaker.

exogenous shocks, fiscal discipline, domestic political distortions, multiple countries, and international risk-sharing. In this way, we can study the interaction between three distortions, namely lack of commitment in monetary policy,[2] moral hazard due to international risk-sharing in the presence of asymmetric information about fiscal discipline, and domestic political distortions producing a lack of fiscal discipline. Domestic political distortions are present if the costs of exerting fiscal discipline are larger for the government than for society at large. This is the case if the costs of fiscal discipline fall mainly on the government's own constituency while the benefits accrue to society at large. Indeed, fiscal discipline may be especially costly to the government because it harms its own constituency and, therefore, erodes its political support.

Monetary and fiscal policy are modelled as follows. While monetary policy may be set at the central, union level by a common central bank (CCB), taxes are selected at a decentralised level by the national governments of the member countries of the union. Before taxes and monetary policy are selected, the national governments determine fiscal discipline. In choosing discipline, the governments thus act as Stackelberg leaders against the CCB. Fiscal discipline is modelled as suggested by Illing (1995). In particular, both random exogenous shocks and fiscal discipline affect the spending requirements of the government but outsiders (including the authorities at the supranational level who are responsible for the FTS) cannot separately observe these two effects on the government budget.

The traditional optimum currency area literature emphasises reductions in transaction costs,[3] the relative importance of monetary versus real shocks, and misalignments of nominal exchange rates as possible arguments in favour of monetary unification.[4] More recent work, in contrast, suggests that monetary unification may change the strategic interactions among the monetary and fiscal authorities in a welfare-enhancing way (for example, see Beetsma and Bovenberg, 1998). The present paper belongs to the latter category. To our knowledge, it is one of the first to explicitly model the interaction between fiscal discipline, political distortions, and moral hazard due to international risk-sharing in the context of a monetary union. Sibert (1997) studies a two-stage game of monetary unification, in which in the first period governments select the efficiency of the tax

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[2] The welfare losses due to lack of commitment originate in distortions in the output market. In particular, the monetary authorities are tempted to employ surprise inflation as a way to alleviate the output-market distortions by boosting output and employment.

[3] The classical contribution of Mundell (1961) employs this as the main argument in favour of monetary unification.

[4] See Obstfeld and Rogoff (1996), Chapter 9, for a comprehensive overview of the arguments in favour and against monetary unification.

system. However, her model differs from ours in two major respects. First, moral hazard due to asymmetric information about fiscal discipline is absent. Second, the model does not deal with stabilisation issues because it abstracts from random shocks. In models without fiscal discipline, Jensen (1997) and Kletzer (1997) explore the case for an FTS in a monetary union in which wages and prices are sticky.

The remainder of this paper is structured as follows. Section 2 presents the model. As a benchmark for the analysis, Section 3 studies the case with commitment for monetary policymaking (both at the national and at the union level). Discretion is analysed in Section 4. To highlight how the presence of an inflation target may affect the case for monetary unification, Section 5.1 explores welfare losses and optimal institutions in the absence of an inflation target, while Section 5.2 provides a similar analysis under the assumption that the inflation target is set optimally. Finally, Section 6 concludes.

2. The model

There are n countries. Consider some country i. Following, among others, Alesina and Tabellini (1987), Debelle (1993), Debelle and Fischer (1994) and Jensen (1994), we assume that workers in country i are represented by trade unions whose sole objective is to achieve a target expected real wage rate, the logarithm of which we normalise to zero. Therefore, the (log) of the nominal wage rate is set equal to the expected (log of the) price level, $E(p_i)$. Expectations are rational. Hence, the subjective price expectation of wage setters, p_i^e, equals the mathematical expectation that follows from the model, i.e. $p_i^e = E(p_i)$.

Output of a representative firm in country i is given by:

$$Y_i = L_i^{\eta},\ 0<\eta<1, \tag{1}$$

where L_i is labour.

Revenues in country i are taxed at a rate τ_i. The firm maximises profits $(1-\tau)P_i L_i^{\eta} - W_i L_i$ where P_i and W_i represent, respectively, the price level and the wage rate. Hence, (log) output is given by $y_i = (\eta/(1-\eta))(\pi_i - \pi_i^e - \tau_i + \log\eta)$, where π_i denotes the inflation rate, π_i^e represents the expected (by wage setters) inflation rate and $\log(1-\tau_i)$ has been approximated by $-\tau_i$. For convenience, we normalise output by subtracting the constant $(\eta/(1-\eta))\log\eta$ from y_i. Moreover, we assume that $\eta = ½$. Hence, normalised output, x_i, amounts to

$$x_i = \pi_i - \pi_i^e - \tau_i. \tag{2}$$

Society i's welfare loss is given by

$$V_{S,i} = \tfrac{1}{2}\beta_s e_i^2 + \tfrac{1}{2}\mathrm{E}[\alpha\pi_i^2 + (x_i - \tilde{x})^2],\ 0 \leq \beta_s \leq 1,\ \alpha > 0, \tag{3}$$

where e_i is the amount of fiscal discipline (or "effort") exerted by the government and where E[.] denotes the expectations operator. Society i's losses are increasing in deviations of both inflation, π_i, from its optimum (for convenience assumed to be zero, which corresponds to price stability) and (log) output, x_i, from its optimum, $\tilde{x} > 0$. The positive value for $\tilde{x}$ reflects product or labour-market distortions that cause the natural level of output (i.e., the level of output in the absence of taxes and inflation surprises, which has been normalised to zero) to be too low from a social perspective. The parameter α measures the relative weight attached to inflation stabilisation versus output stabilisation. If $\beta_s > 0$, society i's losses are also increasing in fiscal discipline. Fiscal discipline may involve, among other things, enhancing public sector efficiency and cutting subsidies to special interest groups. Discipline, $e_i > 0$, may be costly because it creates social tensions and unrest. This way of modelling fiscal discipline is due to Illing (1995).

The government of country i features the following loss function

$$V_{G,i} = \tfrac{1}{2}e_i^2 + \tfrac{1}{2}\mathrm{E}[\alpha\pi_i^2 + (x_i - \tilde{x})^2]. \tag{4}$$

The government's loss function coincides with society's loss function, except that the weight attached to fiscal discipline may be larger. In particular, if exerting more fiscal discipline implies cutting favours for its own constituence, the government may suffer more losses from more fiscal discipline than society at large does.

The government of country i selects its policies under the following budget constraint:

$$\tilde{g} + \epsilon_i - e_i = \tau_i + \gamma(\epsilon_i - e_i) - \gamma(\hat{\epsilon} - \hat{e}),\ 0 \leq \gamma \leq 1, \tag{5}$$

where $\tilde{g}$ is an exogenously given, fixed component of government spending and ϵ_i is a mean-zero unexpected shock with variance σ^2 which, if positive, expands the government's need for revenues (i.e., it worsens the fiscal situation). For convenience (and without any consequences for the main insights from the ensuing analysis), we assume that the shocks are uncorrelated across the countries. More discipline, e_i, reduces the government's need for resources, for example, because it reduces benefits to special interest groups. For analytical convenience, we assume that discipline affects the government budget constraint linearly. The government's budget has to be balanced by tax revenues, τ_i, and a net fiscal transfer $\gamma(\epsilon_i-e_i)-\gamma(\hat{\epsilon}-\hat{e})$. A hat above a variable denotes the average over all countries. Hence, $\hat{\epsilon}=(1/n)\sum_{j=1}^{n}\epsilon_j$ and $\hat{e}=(1/n)\sum_{j=1}^{n}e_j$. The sum of the net transfers over all countries, $\sum_{j=1}^{n}[\gamma(\epsilon_j-e_j)-\gamma(\hat{\epsilon}-\hat{e})]$, is zero. Hence, the budget is balanced at the federal or supranational level.

We assume that e_i and ϵ_i are separately observable only by government i. Other authorities only observe the combination ϵ_i-e_i. An example of such a combination is an increase in unemployment benefits. While such an increase may be observable to outsiders, it would be much harder for them to infer which part of the increase is due to a truly exogenous shock and which part is due to a lack of effort of the government to stem the increase in unemployment benefits. Another example is an observable fall in total tax revenues. It may be difficult to figure out which share of the fall is due to circumstances beyond the control of the government and which share is the result of too little effort in collecting revenues. e_i will be particularly hard to infer if a higher e_i captures a reduction in special favours to interest groups or the government's own constituency. By their nature, these tend to be hidden from the general public.

With only the combination ϵ_i-e_i being observable, international transfer payments can not be conditioned on the random shocks ϵ_i but only on the observable combinations ϵ_i-e_i.[5] Accordingly, if the government of country i finds itself in a precarious fiscal situation, this might be due either to fiscal mismanagement or to an unfavourable shock beyond its control. Of course, in order to extract more international transfers, the government would claim that its fiscal problems were due to a bad exogenous shock rather than fiscal mismanagement.

The fiscal transfer scheme is assumed to be linear. Such a simple transfer scheme may not be too different from what we could expect in reality. As we will see below, the optimal linear scheme depends only on the variances of the shocks (and the model parameters) and therefore requires very little information about the features of the distribution of the shocks.

Equation (5) implies that a share γ of country i's "unluckiness" is transfered to the other participants and vice versa. Therefore, γ will be termed the *degree of risk sharing* among the participants of the scheme. If $\gamma=0$, risk sharing is absent, while $\gamma=1$ implies full risk sharing. This

5 The authorities at the supranational level who are responsible for operating the system of international transfer payments face a "signal extraction problem". Based on the observations ϵ_i-e_i, $i=1,..,n$, they form an estimate of the e_i or, equivalently, of the ϵ_i, $i=1,..,n$. Appendix G shows that a linear transfer scheme based on these estimates of ϵ_i, $i=1,..,n$, effectively reduces to the transfer scheme imbedded in (5).

latter case will be referred to as *fiscal unification*. If $0<\gamma<1$, the countries participate in a *partial fiscal union*. We exclude negative risk sharing ($\gamma<0$), which would amount to transferring even more resources to countries that already experience a relatively favourable fiscal situation, as being politically infeasible.[6]

For future use, we rewrite (5) into a more convenient format:

$$\tilde{g} + (1-\gamma)(\epsilon_i - e_i) + \gamma(\hat{\epsilon} - \hat{e}) = \tau_i \tag{5'}$$

Below it will become clear that, in equilibrium, the tax rate τ_i depends on ϵ_i. This suggests that a (linear) fiscal transfer scheme based on tax rates (which are directly observable) would dominate a scheme based on the observable combinations $\epsilon_i - e_i$, $i=1,..,n$. However, this is not true as we will show here. Suppose that,

$$\tilde{g} + \epsilon_i - e_i = \tau_i + \theta(\tau_i - \hat{\tau}),\ \theta \geq 0, \tag{5''}$$

where $\theta(\tau_i - \hat{\tau})$ is a fiscal transfer. The idea is that, if country i is hit by a relatively bad shock, i.e. $\epsilon_i > \hat{\epsilon}$, it has to set a relatively high tax rate, i.e. $\tau_i > \hat{\tau}$. The transfer is a way to compensate country i indirectly for its "bad luck". Take the cross-country average of (5″), $\hat{\tau} = \tilde{g} + \hat{\epsilon} - \hat{e}$, and use it to substitute for $\hat{\tau}$ in (5″). Then, by redefining $\gamma = \theta/(1+\theta)$, we arrive at an equation that reduces to (5′). Hence, a transfer scheme based on realised tax rates is equivalent to a scheme based on the combinations $\epsilon_i - e_i$, $i=1,..,n$.

As far as monetary policymaking is concerned, we consider two cases, namely national monetary policymaking within each country and central monetary policy within a monetary union. The first case involves monetary policy being selected at the national level by an instrument-independent central bank (see Fischer, 1995). This seems the most appropriate benchmark for comparing national and central monetary policies because the prospective participants of the European Monetary Union (EMU) feature independent central banks by now.

With national monetary policy, the central bank of country i selects country i's inflation rate (which it can control directly) in order to minimise the following loss function:

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[6] Without this constraint, it may be optimal to reduce γ below zero in order to enhance fiscal discipline. As will become clear below, even at $\gamma=0$, discipline may be too low from a social perspective because the government does not fully internalise the costs of lack of discipline (e.g. due to domestic political distortions or lack of commitment). The first-order welfare gains on account of more fiscal discipline may offset the welfare losses arising from further destabilising the economy in the face of country-specific shocks.

$$V_{NCB,i} = \tfrac{1}{2}[\alpha(\pi_i-\pi_i^*)^2 + (x_i-\tilde{x})^2], \tag{6}$$

where π_i^* represents the inflation target (see Svensson, 1997, and Beetsma and Jensen, 1998) imposed on the central bank.[7]

In a monetary union, fiscal policy and fiscal discipline are selected at the national level, but monetary policy is selected at the union level by the common central bank (CCB), which chooses the common inflation rate so as to minimise:

$$V_{CCB} = \tfrac{1}{2}[\alpha(\pi-\pi^*)^2 + (1/n)\textstyle\sum_{i=1}^{n}(x_i-\tilde{x})^2]. \tag{7}$$

The timing of events in each country is as follows. The first stage is the institutional design stage, in which the inflation target, π^*, and the degree of risk sharing, γ, are chosen. Subsequently, inflation expectations are formed and nominal wages are signed, followed by the choice of (unobservable) fiscal discipline.[8] After this, the shocks to the government budgets materialise. Finally, inflation and taxes are selected and international transfers occur. At this stage, nominal wages are taken as given.

The model allows for three distortions. The first is that the central bank is not able to commit to a low inflation rate before inflation expectations as formed. Hence, the central bank takes inflation expectations as given when setting inflation. This tempts the central bank to produce inflation surprises to alleviate output distortions by boosting output and employment. The inflation bias due to lack of commitment thus originates in distortions on the output market. The second distortion is the presence of moral hazard, because shocks are not directly observable. Indeed, governments do not fully internalise the costs of lack of fiscal discipline if international fiscal transfers allow governments to shift some of the costs to other countries. The third distortion is that fiscal discipline is more costly for the government than for society at large. In this case, the government can shift the cost of lack of discipline to other domestic groups. The second distortion is present only if there is international risk sharing ($\gamma>0$), while the third distortion requires that $\beta_s<1$.

[7] Including discipline in the loss function of the central bank would not affect the outcomes. The reason is that, when the central bank selects inflation, fiscal discipline has already been set by the government.

[8] The timing of wage setting relative to the choice of fiscal discipline is irrelevant for the outcomes, due to the unobservability of fiscal discipline.

3. Monetary policy commitment

As a benchmark for the more realistic case of discretionary monetary policy, we first explore the hypothetical case in which the independent central bank is able to commit to some inflation rule. With commitment, there is no need to impose an inflation target on the central bank to alleviate an inflation bias. This section therefore assumes that $\pi^*=0$. The inflation rule is announced after γ is chosen, but before inflation expectations are formed. The rule is assumed to be completely credible.

The commitment case should be treated mainly as a stepping stone to aid the interpretation of the discretionary case, because the rule announced by the central bank depends on the fiscal shocks, which were assumed to be private information of the respective governments.

3.1. National monetary policy

Table 1 contains the outcomes (derived in Appendix A) for the case in which monetary policy is conducted at the national level. Inflation is zero on average, but it responds to a weighted average of the idiosyncratic shock and the average of the shocks across the countries so as to provide the optimal trade-off between inflation and output variability. The *output gap*, defined as $\tilde{x}$-x_i, is the sum of a deterministic component (i.e., the term involving $\tilde{g}+\tilde{x}$) and a stochastic component (i.e., the term involving the realisation of the random shocks). The latter component arises because the output gap depends on the tax rate, which absorbs part of the shocks to the government budget constraint. Finally, because fiscal discipline is selected before the shocks occur, it consists only of a deterministic component.

Discipline does not affect average inflation, because the inflation rule is selected before discipline is determined. However, the output gap is reduced by an increase in discipline. A higher degree of risk sharing, γ, or a larger number of participants in the FTS weakens fiscal discipline and thus raises the output gap. This is the result of a typical moral hazard problem: an increase in γ or n implies that a larger share of the increase in resources resulting from exerting fiscal discipline accrues to other countries through the FTS. Hence, the incentive to exert fiscal discipline is weakened.

The moral hazard problem does not affect the stabilisation of the *effective* shock, $(1-\gamma)\epsilon_i+\gamma\hat{\epsilon}$, i.e., the remaining part of the shock when the transfer payment is taken into account. For a *given* FTS, stabilisation policy is efficient. However, an increase in n or γ reduces the variance of the effective shock itself.

3.2. Monetary union

Table 1 displays also the outcomes for commitment under monetary union. On average, inflation, output and discipline are the same as with national monetary policy. Hence, the moral hazard problem is present in the same way as with national monetary policy. However, inflation responds only to the average union shock, while with national monetary policymaking inflation reacts also to the country-specific shocks.

3.3. Welfare losses

Table 3 contains the expressions for the equilibrium welfare losses in the absence of an inflation target ($\pi^*=0$). These expressions consist of a term involving $(\bar{g}+\bar{x})^2$ (the so-called *deterministic welfare loss*) and a term involving σ^2 (the so-called *stochastic welfare loss*). The deterministic welfare loss arises also in the absence of stochastic shocks. It originates in non-tax distortions that reduce the equilibrium level of output below its optimal level and the need to finance government spending through distortionary taxes. The stochastic welfare loss is due to the inability to simultaneously stabilise inflation and the output gap in the face of a quadratic loss function.

Under commitment, two distortions contribute to a lack of fiscal discipline and raise the deterministic welfare loss. The first distortion, which originates in international risk-sharing and fiscal discipline not being directly observable, is moral hazard in exerting fiscal discipline. The second, domestic political, distortion is the government attaching a larger loss than society to a given level of fiscal discipline. The first distortion vanishes if international risk-sharing is absent (i.e. if $\gamma=0$) while the second distortion is not present if the weights that the government and society attach to fiscal discipline coincide (i.e. if $\beta_s=1$). Hence, without domestic political distortions (i.e. if $\beta_s=1$), the deterministic welfare loss achieves its minimum at $\gamma=0$. The introduction of international risk-sharing (i.e. starting from $\gamma=0$) thus does not produce any first-order deterministic welfare losses in the absence of other distortions (due to lack of commitment or domestic political distortions). If $\gamma=0$ and $\beta_s<1$, however, the introduction of international risk-sharing yields a first-order deterministic welfare loss by worsening political distortions. Intuitively, less fiscal discipline due to more international risk-sharing worsens the political distortion.

The comparison of the welfare losses with decentralised and centralised monetary policies (see Table 3) indicates that monetary unification is not attractive. The creation of a monetary union does not affect the deterministic welfare losses but raises the stochastic welfare losses. Stochastic losses are larger in a monetary union because inflation can no longer be used to stabilise the country-specific shock components, ϵ_i-$\hat{\epsilon}$. The stabilisation role of national monetary policy is especially valuable if shocks are large (i.e. σ is large) and international risk sharing is small (i.e. both γ and n are small). With full international risk-sharing (i.e. $\gamma = 1$), all country-specific shocks are completely absorbed by the FTS so that national monetary policy does not play any role in stabilising these shocks. In that case, therefore, giving up national monetary policy in a monetary union does not yield any welfare loss.

4. Discretionary monetary policy with an FTS

4.1. National monetary policy

The policy outcomes (for given π^* and γ) are contained in Table 2A. They are derived in Appendix B through backwards induction. Inflation is selected taking inflation expectations and taxes as given. Taxes are set taking fiscal discipline as given. The resulting system can then be solved for inflation and taxes as a function of inflation expectations and fiscal discipline. When choosing fiscal discipline, the government takes these "reaction functions" into account and, thus, acts as a Stackelberg leader against the central bank.[9] When forming inflation expectations, the private sector takes proper account of the government's optimal choice of fiscal discipline and the consequences of this for average inflation.

In order to interpret the results, we first assume that an inflation target is absent ($\pi^*=0$) and fiscal discipline is fixed. In that case, the model corresponds to the one in Beetsma and Bovenberg (1997). Monetary policy suffers from an inflationary bias; with the same level of fiscal discipline, inflation exceeds that under commitment. The inflationary bias originates in the, in equilibrium, futile incentive to raise output through surprise inflation (see also Barro and Gordon, 1983a,b).

Both average inflation and the output gap fall with fiscal discipline (this can be seen when deriving these variables -- see Appendix B). Due to moral hazard, fiscal discipline decreases in the degree of risk sharing, γ, and the number of countries participating in the FTS, n. Hence, an increase in γ or n raises average inflation and widens the average output gap.

We now turn to the case with an inflation target. A tighter inflation target (i.e., a lower

[9] The timing of events is important here. If inflation, taxes and discipline would all be simultaneously selected after the shocks had occurred, the government would no longer act as a Stackelberg leader against the central bank when choosing discipline. Accordingly, the inflation target would no longer feature in the outcomes for discipline and the output gap. Moreover, fiscal discipline would respond to the shocks. With the timing assumed in this paper, discipline can be interpreted as being a structural phenomenon rather than a short-term response to a shock.

value for π^*) reduces inflation. In fact, an inflation target affects the average inflation rate through two channels. As in Svensson (1997), a tighter inflation target raises the marginal cost of inflation, thereby inducing the central bank to select a lower inflation rate. In our model, however, it also raises inflation indirectly through its impact on fiscal discipline. In particular, a lower inflation target weakens fiscal discipline (see below). This, in turn, boosts inflation.

The indirect effect of the inflation target on discipline gives rise to a trade-off in setting the optimal inflation target. In particular, in order to alleviate the lack of commitment in monetary policy, the inflation target should be negative. However, imposing such a tight inflation target weakens fiscal discipline, thereby worsening moral hazard and domestic political distortions. Hence, in selecting the inflation target, society faces a trade-off between fighting the inflation bias due to a lack of commitment and combatting the lack of discipline due to political distortions or moral hazard.

To obtain more intuition for the impact of the inflation target on fiscal discipline, we first inspect the reaction function of the central bank:

$$\pi_i = [1/(1+\alpha)](\alpha\pi^* + \pi_i^e + \tau_i + \tilde{x}). \tag{8}$$

Hence, both a tighter (i.e., lower) inflation target or a lower tax rate reduce the inflation rate. Imposing a tight inflation target ($\pi^* < 0$) on the central bank drives a wedge between the inflation preferences of the fiscal authority (which features an inflation target of zero (see (3)) and those of the central bank. To bring inflation more in line with its own preferred rate, the fiscal authority exploits its leadership position and reduces discipline. Hence, for the government's budget to remain in balance, the tax rate needs to be raised, which, in turn, forces the central bank to produce higher inflation in order to protect employment. If the relative weight in the loss function attached to inflation stabilisation, α, goes to zero, the effect of the inflation target on fiscal discipline vanishes. Intuitively, the fiscal authority no longer cares about inflation and, hence, perceives no reason to use fiscal discipline as an instrument to bring inflation closer to its own preferred rate.

The adverse effect on fiscal discipline of a tighter inflation target is reduced if the degree of risk sharing increases or if the number of participants in the FTS increases.[10] The reason is as follows. A tighter inflation target leads to less discipline and, hence, higher taxes. The larger the degree of risk sharing and the larger the number of participants in the FTS, the smaller the need to raise taxes. A reduction in fiscal discipline is therefore less effective as an indirect instrument to

[10] In mathematical terms, $\partial e/\partial\pi^*$ is decreasing in both γ and n.

force the central bank to raise the inflation rate.

4.2. Monetary Union

We turn now to the case of a monetary union. Hence, monetary policy is decided at the supranational level by a CCB that is independent from the governments of the participating countries (which is what the Maastricht Treaty envisages for EMU).

The policy outcomes are derived in Appendix C and contained in Table 2B. In the absence of an inflation target, $\pi^*=0$, fiscal discipline is again weakened by a moral hazard problem, which is exacerbated if γ or n increases (i.e. $\partial e_i/\partial\gamma<0$ and $\partial e_i/\partial n<0$).

To interpret the effect of a non-zero inflation target, we inspect again the reaction function of the CCB:

$$\pi = [1/(1+\alpha)][\alpha\pi^* + \pi^e + (1/n)\textstyle\sum_{j=1}^{n}(\tau_j + \tilde{x})]. \tag{9}$$

As before, a strict inflation target ($\pi^*<0$) drives a wedge between the fiscal authorities' inflation preferences and the central bank's inflation preferences. In a monetary union, however, a unilateral weakening of fiscal discipline is much less effective in raising the inflation rate than with national monetary policies. In particular, the tax increase that results from less fiscal discipline exerts only a "1 over n" effect on inflation. This weakens the incentive of the fiscal authority to weaken fiscal discipline as an instrument to raise the inflation rate set by the CCB. Indeed, Table 2B shows that the "1 over n" term features also in the effect of the inflation target on fiscal discipline. Hence, although a strict inflation target ($\pi^*<0$) weakens discipline, it does so only by a factor "1 over n". In other words, in terms of its effect on fiscal discipline, a strict inflation target is less harmful in a monetary union than with an independent national central bank.[11]

4.3. Welfare losses

Welfare losses under discretion (assuming that$\pi^*=0$) are reported in Table 3, both for national monetary policy and monetary union. The inability to commit introduces a third distortion in

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[11] In a fiscal union (i.e. $\gamma=1$), the effect of the inflation target on fiscal discipline is the same with national monetary policies as in a monetary union. In that case, the effect is "1 over n" also with national monetary policies. Intuitively, with full international risk-sharing, country-specific variations in discipline are fully absorbed through the FTS, thereby reducing the effect on the country-specific tax rate.

addition to moral hazard associated with international risk sharing (if $n>1$ and $\gamma>0$) and domestic political distortions (if $\beta_s<1$). In contrast to the commitment case, introducing international risk-sharing (i.e. increasing γ at $\gamma=0$) yields a first-order loss in deterministic welfare even in the absence of political distortions (i.e. if $\beta_s=1$). The reason is that international risk-sharing worsens a third distortion, namely the inflation bias due to the combination of a lack of commitment and output distortions. In particular, more risk-sharing weakens fiscal discipline. This raises inflation expectations, which still need to be formed when the degree of risk-sharing γ is selected, and thus worsens the inflation bias.

The impact of the degree of risk sharing on the two components of the welfare loss reveals a trade-off between reducing the deterministic and stochastic losses. In particular, more risk-sharing raises the deterministic welfare loss by weakening fiscal discipline. The stochastic welfare loss, in contrast, declines with international risk-sharing because more risk-sharing facilitates the stabilisation of country-specific shocks.

Comparing the welfare losses under commitment with those under discretion (see Table 3), we observe that the latter losses are strictly higher for any degree of risk sharing. This is because commitment eliminates the inflation bias, which serves no socially useful purpose. Hence, commitment is socially valuable.

Under the assumption of a zero inflation target, Table 4 summarises the discussion of the effects of the various distortions by reporting the derivative, evaluated at $\gamma=0$, of the deterministic component of the social losses with respect to γ. The results apply to national monetary policymaking and monetary union.

5. Optimal institutional design

This section explores the optimal institutional design of both fiscal and monetary policy, namely the degree of risk-sharing by an FTS and the inflation target of the central bank.[12] First, sub-section 5.1 explores the case in which only international risk sharing can be set optimally at a fixed zero inflation target. Subsequently, sub-section 5.2 allows also the inflation target to be set optimally. This step-wise analysis clearly reveals that the case for monetary unification depends importantly on whether a non-zero inflation target can be imposed on the central bank. Indeed, a monetary union

[12] A third aspect of institutional design concerns the optimal number of participants in the FTS or in the monetary union. However, we assume that the size of the union is determined by considerations outside the model.

can dominate national monetary policymaking in terms of social welfare only in sub-section 5.2.

5.1. No inflation target ($\pi^*=0$)

The optimal degree of international risk sharing trades off the costs of less fiscal discipline (in terms of worsening moral hazard, the inflation bias due to lack of commitment, and domestic political distortions) and the benefits of more stabilisation of country-specific shocks. The costs of weaker fiscal discipline rise with the revenue needs of the government, which worsens commitment problems and raises the value of fiscal discipline in terms of reducing tax distortions. At the same time, the benefits of stabilisation increase with the variance of the country-specific shocks. Accordingly, if $(\tilde{g}+\tilde{x})^2/\sigma^2$ is large, enhancing fiscal discipline is relatively more important than facilitating international risk sharing. This yields the following proposition, which is formally established in Appendix D:

Proposition 1: For any of the four possible regimes (commitment or discretion and national monetary policy or monetary union) and in the absence of an inflation target ($\pi^*=0$):

a. For large values of $(\tilde{g}+\tilde{x})^2/\sigma^2$,[13] the optimal degree of risk sharing is zero, unless $\beta_s=1$ and there is commitment. For other values of $(\tilde{g}+\tilde{x})^2/\sigma^2$, the optimal degree of risk sharing is incomplete ($0<\gamma^{opt}<1$) and decreasing in $(\tilde{g}+\tilde{x})^2/\sigma^2$.

b. With initial international risk-sharing (i.e. if $0<\gamma^{opt}<1$), more participating countries, n, reduces the optimal degree of risk sharing ($\partial\gamma^{opt}/\partial n<0$). At the same time, a higher value for β_s raises the optimal degree of risk sharing ($\partial\gamma^{opt}/\partial\beta_s>0$).

Complete risk sharing is never optimal (*Proposition 1a*). Intuitively, marginally reducing risk-sharing from full risk-sharing yields a first-order gain in deterministic welfare by strengthening fiscal discipline but exerts only second-order effects on stochastic welfare (i.e. the derivative of the stochastic welfare loss with respect to γ is zero at $\gamma=1$).

A larger union reduces the optimal degree of risk-sharing. On the one hand, a larger number of participants in the FTS exacerbates the moral hazard problem by weakening fiscal discipline. On the other hand, it facilitates international risk-sharing as shocks can be smoothed out

[13] The exact conditions are the following. Commitment with national monetary policy: $(\tilde{g}+\tilde{x})^2/\sigma^2\geq 8/[(1+1/\alpha)(1-\beta_s)]$. Commitment with monetary union: $(\tilde{g}+\tilde{x})^2/\sigma^2\geq 8/(1-\beta_s)$. Discretion and national monetary policy: $(\tilde{g}+\tilde{x})^2/\sigma^2\geq 8/[(1+1/\alpha)(1+1/\alpha-\beta_s)]$. Discretion with monetary union: $(\tilde{g}+\tilde{x})^2/\sigma^2\geq 8/(1+1/\alpha-\beta_s)$. Note that the range of values for $(\tilde{g}+\tilde{x})^2/\sigma^2$ for which $\gamma=0$ is optimal is smaller with monetary union than with national monetary policy.

over more countries. Whereas the costs of additional risk-sharing thus rise, the benefits fall. Hence, the optimal degree of international risk-sharing declines.

An increase in β_s implies that the domestic political distortions associated with a lack of fiscal discipline become less important. The weakening of fiscal discipline associated with moral hazard is thus less harmful in terms of worsening political distortions. The associated smaller costs of moral hazard allow for an increase in the optimal degree of international risk sharing.

The following proposition compares a monetary union and a system of independent national central banks. It also compares the optimal degree of international risk sharing under commitment and discretion.

Proposition 2: Suppose that $\pi^*=0$.

a. Both under commitment and discretion a system of independent national central banks is strictly preferable to a monetary union.

b. If, under commitment, $(\tilde{g}+\tilde{x})^2/\sigma^2<8/(1-\beta_s)$, or, under discretion, $(\tilde{g}+\tilde{x})^2/\sigma^2<8/(1+1/\alpha-\beta_s)$, the optimal degree of international risk sharing is strictly higher under a monetary union.

c. If $(\tilde{g}+\tilde{x})^2/\sigma^2<8/(1+1/\alpha)(1-\beta_s)$ for a system of independent national central banks or $(\tilde{g}+\tilde{x})^2/\sigma^2<8/(1-\beta_s)$ for a monetary union, then the optimal degree of risk sharing is higher under commitment than under discretion.

The proof of *Proposition 2* is given in Appendix E. *Proposition 2a* can be interpreted as follows. For a given degree of international risk sharing, monetary unification does not affect deterministic welfare. Stochastic losses, in contrast, rise because national monetary policy can no longer be employed to stabilise the idiosyncratic shock components, ϵ_i-$\hat{\epsilon}$. Hence, for a given degree of risk sharing (and, therefore, also for the degree of risk sharing that is optimal under a monetary union), welfare losses are higher under a monetary union than with national policymaking. Only under complete internationational risk-sharing (i.e. $\gamma=1$) would national monetary policy not add any stabilisation benefits. *Proposition 1a* established, however, that complete risk sharing cannot be optimal because of moral hazard.

The intuition behind *Proposition 2b* is that in a monetary union the FTS has to take over part of the role of national monetary policies in stabilising country-specific shock components. Hence, in accordance with common wisdom, monetary unification should be accompanied by larger international transfers. However, the welfare losses from weaker fiscal discipline may be so large that no international risk sharing may actually be optimal not only under national but also centralised monetary policymaking. This is the case if $(\tilde{g}+\tilde{x})^2/\sigma^2$ is sufficiently high while either commitment is absent or political distortions are present (i.e. $\beta_s < 1$). In that case, weaker fiscal discipline due to moral hazard worsens existing domestic political distortions or the inflation bias due to lack of commitment. Hence, it is optimal to refrain from international risk sharing despite its stabilisation benefits.

The reason behind *Proposition 2c* is that moral hazard is less costly under commitment because the associated weakening of fiscal discipline does not exacerbate the inflation bias due to lack of commitment.

5.2. An inflation target

This sub-section explores the optimal institutional design if in addition to the degree of international risk sharing also the inflation target can be freely set to minimise society's welfare losses. A non-zero inflation target is optimal only if the central bank cannot commit to an inflation rule. In that case, the inflation target plays a socially useful rule in fighting the inflation bias.

This sub-section shows that an optimal non-zero inflation target may overturn the result from the previous sub-section that monetary unification is never optimal. Since a non-zero inflation target can be optimal only under discretion, the case for monetary union thus requires a lack of commitment. This sub-section focusses on the case with discretion.

The inflation target affects only the deterministic components of the policy outcomes. Hence, the optimal inflation target follows from the first-order condition:[14]

$$\beta_s\, e_i\, \partial e_i/\partial \pi_i^* + \alpha\, \mathrm{E}[\pi_i]\, \partial \pi_i/\partial \pi_i^* + \mathrm{E}[\tilde{x}\text{-}x_i]\, \partial(\tilde{x}\text{-}x_i)/\partial \pi_i^* = 0, \tag{10}$$

where, in the case of a monetary union, π_i is the common inflation rate and π_i^* the inflation target imposed on the CCB. Using the outcomes in Table 2, we can solve (10) for the optimal inflation targets to be imposed on the national central banks or the CCB. The expressions for these targets as a function of international risk-sharing, γ, are presented in Table 5. They give rise to the following proposition:

Proposition 3: Both with and without monetary unification, the optimal inflation target is negative and is decreasing in β_s in the presence of discretionary monetary policy.

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[14] The quadratic nature of the loss function ensures that the second-order condition for a minimum is met.

Under both monetary arrangements, it is optimal to impose an inflation target below the socially optimal inflation rate of zero. This is in line with the findings of Svensson (1997). Intuitively, the negative inflation target helps to offset the inflation bias due to discretionary monetary policy.

The optimal inflation target is stricter (i.e. more negative) if society attaches substantial costs to fiscal discipline so that domestic political distortions are smaller (i.e. β_s is large). The reason is that a stricter (i.e. lower) inflation target weakens fiscal discipline. The indirect costs of a stricter inflation target in terms of weaker fiscal discipline are smaller if society experiences substantial losses for exerting fiscal discipline.

The expressions for the optimal inflation target are rather complicated and uninformative. For the case of $\beta_s=0$, however, we can establish the following proposition:

Proposition 4: Suppose that $\beta_s=0$ and that international risk sharing is not necessarily set optimally. Both with and without monetary unification, a higher degree of international risk sharing, γ, tightens the optimal inflation target.

The intuition behind Proposition 4 is that, by worsening the moral hazard problem, a higher γ weakens fiscal discipline and thus raises the tax level. To protect employment in the face of a higher tax rate, the central bank is more tempted to produce an inflation surprise, thereby worsening the inflation bias. To offset the stronger incentive for a surprise inflation, society finds it optimal to tighten the inflation target.

By substituting the expressions for the optimal inflation target (Table 5) into the expressions for inflation and the output gap, we can express society's equilibrium welfare loss under an optimal inflation target as a function of γ. These functions are in general complicated and will be investigated numerically (see below). However, for the special case of $\beta_s=0$, Table 6 provides analytical expressions for the welfare losses. This gives rise to the following proposition:

Proposition 5: Let $n>1$ and $\beta_s=0$ and suppose that the optimal inflation target (given γ) is imposed. Both for a system of independent national central banks and for a monetary union, the optimal degree of international risk sharing is zero for relatively large values of $(\tilde{g}+\tilde{x})^2/\sigma^2$. For lower values of $(\tilde{g}+\tilde{x})^2/\sigma^2$, partial risk sharing is optimal (i.e., $0<\gamma^{opt}<1$), with the optimal degree of risk sharing being decreasing in $(\tilde{g}+\tilde{x})^2/\sigma^2$.[15]

[15] For the case of independent national central banks (and $\beta_s=0$), zero risk sharing is optimal if and only if $(\tilde{g}+\tilde{x})^2/\sigma^2 \geq (4+1/\alpha)^2/2(1+1/\alpha)^2$.

This proposition (which is proven in Appendix F) shows that, for $\beta_s=0$, the basic trade off in the choice of γ between weakening fiscal discipline and facilitating risk sharing survives if the inflation target is set optimally. As before, the deterministic welfare loss is increasing in γ, while the stochastic welfare loss (which is the same as before) is decreasing in γ ($\gamma<1$).

We now turn to the question whether monetary unification can be optimal. A tight inflation target (i.e. $\pi^*<0$) weakens fiscal discipline (see sub-section 4.1), but less so in a monetary union (see sub-section 4.2). Indeed, for a given target $\pi^*<0$ and γ, more fiscal discipline under a monetary union produces lower average inflation and a lower average output gap than under national monetary policymaking. In this way, the possibility of imposing a strict inflation target aimed at alleviating the inflation bias due to discretionary monetary policy makes a monetary union more attractive. However, while a monetary union may be preferable in terms of average inflation and output, it performs worse in terms of stabilisation policy.

To illustrate this trade-off between decentralised and centralised monetary policy, we resort to numerical computations and take any possible combination of β_s, α, n and $(\tilde{g}+\tilde{x})^2/\sigma^2$, where $\beta_s \in \{0,0.25,0.5,0.75,1\}$, $\alpha \in \{0.1,0.5,1,2,10\}$, $n \in \{1,2,5,11,15\}$ and $(\tilde{g}+\tilde{x})^2/\sigma^2 \in \{0.01,0.1,1,10,100\}$. The case with $n=11$ corresponds to the initial number of EMU participants, while $n=15$ is the total number of countries currently in the European Union.

Table 7 reports, for a number of parameter combinations, the optimal value of γ and the associated welfare loss (divided by σ^2), both for monetary union and a system of independent national central banks. For the case of monetary union, the table also reports the optimal inflation target, the averages of inflation, the output gap and discipline (all divided by $\tilde{g}+\tilde{x}$), the deterministic and stochastic welfare losses (all divided by σ^2), and the ratio of the welfare loss under monetary union divided by the welfare loss under national monetary policy. The table presents results for the two extreme values of β_s (i.e. $\beta_s=0$ and $\beta_s=1$).

Table 7 assumes that $\alpha=1$ so that society attaches an equal loss to a one-percent deviation in either inflation or output from its socially optimal level. Moreover, we vary the number of countries from 2 (a "mini-union") to 15 and we vary $(\tilde{g}+\tilde{x})^2/\sigma^2$ from 0.01 to 100. Table 7a assumes that $\beta_s=0$, when society always prefers more fiscal discipline. Table 7b, in contrast, assumes that $\beta_s=1$, when fiscal discipline affects society's loss to the same extent as it affects the government's loss.

The results of the numerical exercise can be summarised as follows:

Result 1: Summary of numerical results. For any of the parameter combinations that we investigate we find that:

a. The social welfare loss is lower under monetary union than under a system of independent national central banks.

b. Unless it is already equal to zero, the optimal degree of risk sharing is decreasing in $(\bar{g}+\bar{x})^2/\sigma^2$.

c. The optimal degree of risk sharing is as high or higher under a monetary union than under a system of independent national central banks.

d. Under national monetary policy, welfare losses are decreasing in *n*, if $(\bar{g}+\bar{x})^2/\sigma^2$ is not too large. Under a monetary union, welfare losses are always decreasing in *n*, ceteris paribus.

Hence, for any of the investigated parameter combinations, monetary unification outperforms a system of independent national central banks. In particular, monetary union dominates decentralised monetary policy even if $\beta_s=1$. The reason is that monetary unification allows for a stricter inflation target without substantially weakening fiscal discipline. As a result, fiscal discipline is stronger and the average inflation and output gap smaller in a monetary union. Accordingly, a monetary union benefits from smaller deterministic losses on account of a smaller inflation bias, less moral hazard, and less domestic political distortions. A larger value of $(\bar{g}+\bar{x})^2/\sigma^2$ raises the losses from the inability to commit, the presence of moral hazard, and (if $\beta_s<1$) domestic political distortions. This makes not only international risk-sharing less attractive but also makes monetary unification more attractive. Accordingly, if labour markets distortions and spending requirements are sufficiently important compared to the variance of the shocks, then monetary union without an FTS is the optimal arrangement.[16] Table 7 shows some cases, for $\beta_s=0$ as well as $\beta_s=1$ in which monetary union without an FTS is the optimal arrangement. In all of these cases, $(\bar{g}+\bar{x})^2/\sigma^2$ is relatively large.

As already mentioned, the numerical results show that monetary unification dominates an arrangement with independent national central banks even if $(\bar{g}+\bar{x})^2/\sigma^2$ is small. The intuition is that in that case it is optimal to have substantial fiscal risk-sharing (i.e. γ is high) and, hence, the loss in terms of less efficient stabilisation from giving up an independent monetary policy is only small.

Result 1b extends *Proposition 1a* to the case when the inflation target is optimally chosen. *Result 1c* confirms the result for the case $\pi^*=0$ contained in *Proposition 2b*. As before, the FTS appropriates part of the stabilisation task originally performed by national monetary policy. Another

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[16] Note, however, that if we *restrict* γ to zero, it is easy to see that monetary unification can be dominated by national monetary policymaking. This is the case if $(\bar{g}+\bar{x})^2/\sigma^2$ is sufficiently small.

reason why the optimal degree of risk sharing is higher under a monetary union is that imposing a negative inflation target is less costly in terms of lower discipline. This provides scope for additional risk sharing. The intuition behind *Result 1d* is as follows. If $(\bar{g}+\bar{x})^2/\sigma^2$ is not too large and, hence, the optimal degree of risk sharing is positive, a larger group of participants implies that the same stabilisation gains can be obtained with a reduction in γ, which, in turn, reduces the deterministic welfare loss. In the case of a monetary union, the welfare enhancing effect of a larger union is supported also by a weakening of the adverse effect of a tight inflation target on fiscal discipline. This effect remains present also if $(\bar{g}+\bar{x})^2/\sigma^2$ is relatively large and the optimal degree of risk sharing is zero.

6. Conclusions

Common wisdom about the link between monetary and fiscal unification focusses on stabilisation considerations. These considerations imply that a monetary union can be optimal only in the presence of a fiscal union in which international transfers substitute for national monetary policies in stabilising country-specific shocks. Indeed, stabilisation considerations would generally argue in favour of both international transfers and national monetary policies (i.e. a fiscal union without a monetary union). This paper establishes that lack of both commitment and fiscal discipline provide arguments that go exactly the other way by providing a case in favour of monetary unification but against fiscal unification.[17]

The case for monetary union without a fiscal union depends on the combination of a lack of fiscal discipline due to moral hazard, a lack of commitment, and the presence of distortions in the output market. Without moral hazard, full risk-sharing would not impose any costs. Hence, a fiscal union would be optimal. With commitment or in the absence of output distortions, monetary unification would not provide any benefits because an inflation target would be unnecessary as an instrument to fight the inflation bias. Accordingly, the benefits of monetary union in terms of weakening the adverse consequences of an inflation target on fiscal discipline would be absent.

A monetary union without a fiscal union is optimal if both lack of commitment of monetary

[17] Two additional considerations strengthen the case for monetary unification further. First, we have compared monetary unification with the best-available alternative based on national monetary policymaking. However, setting up an FTS may well be (politically) easier if it is accompanied by monetary unification. Hence, if (partial) risk sharing is optimal, this would constitute another advantage in favour of monetary unification. Second, it may be easier to impose a (credible) inflation target in the case of a monetary union than with national monetary policymaking. The reason is that in a monetary union the central bank is removed further from the direct influence of the national governments.

policy and lack of discipline of fiscal policy are serious. Commitment problems are important if monetary authorities are tempted to boost output in view of large non-tax distortions and large spending requirements producing serious tax distortions. These output distortions exacerbate also the problem of lack of fiscal discipline, which is also worsened by domestic political distortions.

These conditions for a monetary union but against a fiscal union are likely to be met in Europe. In particular, European economies suffer from serious distortions in labour markets while high public spending gives rise to substantial tax distortions. Moreover, lack of risk-sharing through private capital markets in Europe may be due to the same reason why international public transfers may be unattractive in Europe, namely lack of transparency and asymmetric information (see also Gordon and Bovenberg, 1996). Indeed, moral hazard due to international transfers seems to be a potentially important issue because of lack of transparancy of budgeting processes. This lack of transparancy contributes also to political distortions weakening fiscal discipline.

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Appendices

A: Derivations of commitment outcomes.

First, the central bank announces an inflation rule (to which it will stick). Then, inflation expectations are formed. Third, discipline is chosen. Fourth, the shocks occur. Finally, taxes and inflation are selected and transfer payments take place.

A.1. System of independent national central banks

The central bank of country i announces an inflation rule of the following format:

$$\pi_i = \delta_1\epsilon_i + \delta_2\hat{\epsilon}. \tag{A.1}$$

Hence, $\pi_i^e=0$. Combining (A.1), (2) and (5), we have:

$$\tilde{x}\text{-}x_i = \tilde{g} + \tilde{x} - (1-\gamma)e_i - \gamma\hat{e} + (1-\gamma-\delta_1)\epsilon_i + (\gamma-\delta_2)\hat{\epsilon}. \tag{A.2}$$

The government minimises $\frac{1}{2}e_i^2 + \frac{1}{2}E[\alpha\pi_i^2+(x_i-\tilde{x})^2]$ over e_i, taking π_i as given by (A.1). This yields,

$$e_i = \left[\frac{1-\gamma(n-1)/n}{2-\gamma(n-1)/n}\right](\tilde{g}+\tilde{x}), \tag{A.3}$$

where we have used that, in equilibrium, all governments choose the same level of fiscal discipline (this is easy to show [1]).

Because the inflation rule does not affect discipline, the central bank, in selecting the inflation rule, chooses δ_1 and δ_2 so as to minimise:

$$\tfrac{1}{2}\, E\,[\,\alpha(\delta_1\epsilon_i+\delta_2\hat{\epsilon})^2 + ((1-\gamma-\delta_1)\epsilon_i+(\gamma-\delta_2)\hat{\epsilon})^2\,].$$

[1] Some manipulation shows that the first-order condition for the choice of e_i can be written as $\{1-[1-\gamma(n-1)/n](1-\gamma)\}\ e_i = [\gamma\hat{e}-(\tilde{g}+\tilde{x})][1-\gamma(n-1)/n]$. As this equation holds for all $i=1,..,n$, it follows immediately that $e_j=e_i$, $j=1,..,n$. A similar reasoning can be used to show that the equilibria for the other cases considered in the paper (and which are derived below) are symmetric in the sense that each government selects the same amount of fiscal discipline.

The first-order conditions are:

$$E\,[\ \alpha(\delta_1\epsilon_i+\delta_2\hat{\epsilon})\epsilon_i - ((1-\gamma-\delta_1)\epsilon_i+(\gamma-\delta_2)\hat{\epsilon})\epsilon_i\ ] = 0,$$
$$E\,[\ \alpha(\delta_1\epsilon_i+\delta_2\hat{\epsilon})\hat{\epsilon} - ((1-\gamma-\delta_1)\epsilon_i+(\gamma-\delta_2)\hat{\epsilon})\hat{\epsilon}\ ] = 0.$$

Using that $E[\hat{\epsilon}\epsilon_i] = E[\hat{\epsilon}^2] = \sigma^2/n$, it is easy to show that $\delta_1=(1-\gamma)/(1+\alpha)$ and $\delta_2=\gamma/(1+\alpha)$. Using (A.3), it is also easy to check that the outcomes for inflation and the output gap are those that are given in Table 1.

A.2. Monetary union

Completely analogous.

B: Derivation of outcomes for a system of national central banks combined with FTS

The central bank minimises $\frac{1}{2}[\alpha(\pi_i-\pi_i^*)^2+(x_i-\tilde{x})^2]$ over π_i, subject to (2). The first-order condition can be written as:

$$\pi_i = [1/(1+\alpha)](\alpha\pi_i^*+\tau_i+\tilde{x}+\pi_i^e), \tag{B.1}$$

Rewrite the government budget constraint (5′) as:

$$\tau_i+\tilde{x} = \tilde{g}+\tilde{x} + (1-\gamma)(\epsilon_i-e_i) + \gamma(\hat{\epsilon}-\hat{e}). \tag{B.2}$$

Substitute (B.2) into (B.1) and rewrite to give:

$$\pi_i = \left(\frac{1/\alpha}{1+1/\alpha}\right)\left((\tilde{g}+\tilde{x}+\pi_i^e)+(1-\gamma)(\epsilon_i-e_i)+\gamma(\hat{\epsilon}-\hat{e})\right) + \left(\frac{1}{1+1/\alpha}\right)\pi_i^*. \tag{B.3}$$

Hence,

$$\frac{\partial\pi_i}{\partial e_i} = \left(\frac{1/\alpha}{1+1/\alpha}\right)\left(\left(\frac{n-1}{n}\right)\gamma-1\right). \tag{B.4}$$

Substitute the right-hand sides of (B.2) and (B.3) for $(\tau_i+\tilde{x})$ and π_i, respectively, into the equation $\tilde{x}-x_i=(\tau_i+\tilde{x})-(\pi_i-\pi_i^e)$, which we can then rewrite to give:

$$\tilde{x}-x_i = \left(\frac{1}{1+1/\alpha}\right)\left((\tilde{g}+\tilde{x}+\pi_i^e)+(1-\gamma)(\epsilon_i-e_i)+\gamma(\hat{\epsilon}-\hat{e})\right) - \left(\frac{1}{1+1/\alpha}\right)\pi_i^*. \tag{B.5}$$

Hence,

$$\frac{\partial(\tilde{x}-x_i)}{\partial e_i} = -\left(\frac{1}{1+1/\alpha}\right)\left(1-\left(\frac{n-1}{n}\right)\gamma\right). \tag{B.6}$$

Going back along the game tree, the government minimises $\frac{1}{2}e_i^2 + \frac{1}{2}\mathrm{E}[\alpha\pi_i^2+(\tilde{x}-x)^2]$ over e_i, subject to (B.3) - (B.6), taking π_i^e as given. The first-order condition can be written as:

$$e_i + \alpha\mathrm{E}[\pi_i](\partial\pi_i/\partial e_i) - \mathrm{E}[\tilde{x}-x_i](\partial x_i/\partial e_i)] = 0, \tag{B.7}$$

It is easy to show that, in equilibrium, each government selects the same amount of fiscal discipline. Hence, from (B.3) and (B.5) we have, respectively:

$$E[\pi_i] = \left(\frac{1/\alpha}{1+1/\alpha}\right)\left(\tilde{g}+\tilde{x}+\pi_i^e-e_i\right) + \left(\frac{1}{1+1/\alpha}\right)\pi_i^*, \tag{B.8}$$

$$E[\tilde{x}-x_i] = \left(\frac{1}{1+1/\alpha}\right)\left(\tilde{g}+\tilde{x}+\pi_i^e-e_i\right) - \left(\frac{1}{1+1/\alpha}\right)\pi_i^*, \tag{B.9}$$

where we have made use of the assumption that expectations formed about discipline are rational ($e_i^e=e_i$). Substitute (B.4), (B.6), (B.8) and (B.9) into (B.7) and rewrite to give:

$$e_i = \left(\frac{1-\gamma(n-1)/n}{1+1/\alpha}\right)\left(\tilde{g}+\tilde{x}-e_i+\pi_i^e\right). \tag{B.10}$$

Take expectations of (B.3) and solve to give:

$$\pi_i^e = (1/\alpha)\left(\tilde{g}+\tilde{x}-e_i\right) + \pi_i^*, \tag{B.11}$$

where we have again used that expectations are rational (hence, wage setters anticipate correctly the level of fiscal discipline) and that the equilibrium is symmetric. Substitute (B.11) into (B.10). Some algebra then yields:

$$e_i = \left(1-\gamma(n-1)/n\right)\left(\tilde{g}+\tilde{x}-e_i\right) + \left(\frac{1-\gamma(n-1)/n}{1+1/\alpha}\right)\pi_i^*. \tag{B.12}$$

Hence,

$$e_i = \left(\frac{1-\gamma(n-1)/n}{D_2}\right)\pi_i^* + \left(\frac{1-\gamma(n-1)/n}{2-\gamma(n-1)/n}\right)(\tilde{g}+\tilde{x}), \tag{B.13}$$

where

$$D \equiv (1+1/\alpha)(2-\gamma(n-1)/n). \tag{B.14}$$

which is the solution for e_i as given in Table 2A.

Substitute the right-hand side of (B.11) into (B.3). Next, substitute into the resulting equation the right-hand side of (B.13) for e_i and $\hat{e}$. Solving yields the solution for π_i as given in Table 2A. Finally, rewrite (B.2) as:

$$\tau_i + \tilde{x} + \pi_i^e = \tilde{g} + \tilde{x} + \pi_i^e + (1-\gamma)(\epsilon_i - e_i) + \gamma(\hat{\epsilon} - \hat{e}).$$

Subtract this expression from (B.3) and use that $\tilde{x}-x_i=(\tau_i+\tilde{x}+\pi_i^e)-\pi_i$ (from (2)) in order to give:

$$\tilde{x}-x_i = -\left(\frac{1}{1+1/\alpha}\right)\left(\tilde{g}+\tilde{x}+\pi_i^e - e_i + (1-\gamma)\epsilon_i + \gamma\hat{\epsilon}\right) + \left(\frac{1}{1+1/\alpha}\right)\pi_i^*,$$

where we have used the cross-country symmetry in terms of the choice of fiscal discipline. Substitute into this equation the right-hand side of (B.11) for π_i^e. Next, eliminate e_i from the resulting equation by substituting the right-hand side of (B.13).

Set $\pi_i^*=0$. Society's welfare loss as given in Table 3 then follows upon substitution of the solutions for e_i, π_i and $\tilde{x}-x_i$ into $\frac{1}{2}\beta_s e_i^2 + \frac{1}{2}E[\alpha\pi_i^2 + (\tilde{x}-x_i)^2]$. The deterministic welfare loss is easy to derive. The stochastic welfare loss involves working out:

$$\left(\frac{1}{1+1/\alpha}\right) E\left((1-\gamma)\epsilon_i + \gamma\hat{\epsilon}\right)^2 =$$

$$\left(\frac{1}{1+1/\alpha}\right) E\left((1-\gamma)^2\epsilon_i^2 + 2(\gamma(1-\gamma)/n)\epsilon_i^2 + \gamma^2\left(\sum_j \epsilon_j/n\right)^2\right) =$$

$$\left(\frac{1}{1+1/\alpha}\right)\left((1-\gamma)^2\sigma^2 + 2(\gamma(1-\gamma)/n)\sigma^2 + \gamma^2\sigma^2/n\right) =$$

$$\left(\frac{1}{1+1/\alpha}\right)\left((1-\gamma)^2\left(\frac{n-1}{n}\right) + \frac{1}{n}\right)\sigma^2.$$

C: Derivation of the outcomes for a monetary union with FTS

The common central bank (CCB) minimises over π (the union-wide inflation rate) and subject to (2), $i=1,..,n$, the following objective function:

$$\frac{1}{2}E[\alpha(\pi-\pi^*)^2 + (1/n)\sum_{i=1}^{n}(x_i-\tilde{x})^2]. \qquad \text{(C.1)}$$

The first-order condition is:

$$\alpha(\pi-\pi^*) + (\pi-\pi^e) = (1/n)\sum_{i=1}^{n}(\tau_i+\tilde{x}) = \hat{\tau}+\tilde{x}, \tag{C.2}$$

where $\hat{\tau}\equiv(1/n)\sum_{i=1}^{n}\tau_i$. Combine this with the government budget constraint,

$$\tilde{g} + (1-\gamma)(\epsilon_i-e_i) + \gamma(\hat{\epsilon}-\hat{e}) = \tau_i, \tag{5'}$$

in order to eliminate π and rewrite the result to give

$$(1+\alpha)(\tau_i+\tilde{x}) + \kappa(\hat{\tau}+\tilde{x})= (1+\alpha)[(\tilde{g}+\tilde{x}) + (1-\gamma)(\epsilon_i-e_i) + \gamma(\hat{\epsilon}-\hat{e})]. \tag{C.3}$$

Take averages of the left- and right-hand sides of (C.3) and rewrite the result to give:

$$\hat{\tau}+\tilde{x} = \tilde{g}+\tilde{x}+\hat{\epsilon}-\hat{e}. \tag{C.4}$$

Substitute the (C.4) into (C.2) and rewrite to give:

$$\pi = \left(\frac{1}{1+1/\alpha}\right)\pi^* + \left(\frac{1/\alpha}{1+1/\alpha}\right)(\tilde{g}+\tilde{x}+\pi^e+\hat{\epsilon}-\hat{e}). \tag{C.5}$$

Hence,

$$\frac{\partial\pi}{\partial e_i} = -\frac{1}{n}\left(\frac{1/\alpha}{1+1/\alpha}\right). \tag{C.6}$$

From the government budget constraint we have

$$\tau_i+\tilde{x} = (\tilde{g}+\tilde{x}) + (1-\gamma)(\epsilon_i-e_i) + \gamma(\hat{\epsilon}-\hat{e}) .$$

Substitute this into the right-hand side of $\tilde{x}-x_i=(\tau_i+\tilde{x})-(\pi-\pi^e)$ to give:

$$\tilde{x}-x_i = \pi^e - \pi + (\tilde{g}+\tilde{x}) + (1-\gamma)(\epsilon_i-e_i) + \gamma(\hat{\epsilon}-\hat{e}). \tag{C.7}$$

Substitute (C.5) for π into (C.7) and manipulate to give:

$$x_i-\tilde{x} = \left(\frac{1}{1+1/\alpha}\right)\left(\tilde{g}+\tilde{x}+\pi^e-\pi^*\right) + (1-\gamma)(\epsilon_i-e_i) + \left(\gamma-\frac{1/\alpha}{1+1/\alpha}\right)(\hat{\epsilon}-\hat{e}). \tag{C.8}$$

Hence,

$$\frac{\partial(\tilde{x}-x_i)}{\partial e_i} = \left(\frac{n-1}{n}\right)\gamma - \left(\frac{1+((n-1)/n)/\alpha}{1+1/\alpha}\right). \tag{C.9}$$

Going back along the game tree, the government minimises $\frac{1}{2}e_i^2 + \frac{1}{2}E[\alpha\pi^2+(x_i-\bar{x})^2]$ over e_i, subject to (C.5), (C.6), (C.8) and (C.9), taking π^e as given. The first-order condition can be written as:

$$e_i + \alpha E[\pi_i](\partial\pi/\partial e_i) + E[x_i-\bar{x}](\partial x_i/\partial e_i) = 0, \tag{C.10}$$

Substitute from (C.5), (C.6), (C.8) and (C.9) into (C.10). Work out the expectations and use rationality ($e_i^e=e_i$) and that $e_j=e_i$, for all $j=1,..,n$ (again, this is easy to show). Some manipulation then yields:

$$e_i = \left(\frac{(\gamma-1)(n-1)/n}{1+1/\alpha}\right)\pi^* + \left(\frac{1-\gamma(n-1)/n}{1+1/\alpha}\right)\left(\tilde{g}+\tilde{x}+\pi^e-e_i\right). \tag{C.11}$$

Take expectations of the left- and right-hand side of (C.5). Using the assumption that wage setters' expectations are rational and the result that $e_j=e_i$, for all $j=1,..,n$, we have:

$$\pi^e = \pi^* + (1/\alpha)(\tilde{g}+\tilde{x}-e_i). \tag{C.12}$$

Substitute (C.12) into (C.11) and solve to give the solution for e_i as contained in Table 2B. The solutions for π and $\bar{x}-x_i$ are equally straightforward (although cumbersome): to obtain the solution for inflation, substitute the right-hand side of (C.12) into (C.5). Into this result substitute the solution for e_i, where we make use of the result that $e_j=e_i$, for all $j=1,..,n$. To obtain the solution of $\bar{x}-x_i$, substitute the right-hand side of (C.12) into (C.8). Using again that $e_j=e_i$, for all $j=1,..,n$, and substituting the solution for e_i into the resulting equation we obtain (after some algebra) the solution for $\bar{x}-x_i$.

Set $\pi^*=0$. Society's welfare loss as given in Table 3 follows upon substitution of the solutions for π and $\bar{x}-x_i$ into $\frac{1}{2}\beta_s e_i^2+\frac{1}{2}E[\alpha\pi^2+(x_i-\bar{x})^2]$. The deterministic welfare loss is easy to derive. The stochastic term involves working out

$$E\left(\left(\frac{1/\alpha}{(1+1/\alpha)^2}\right)\hat{\epsilon}^2 + \left(\left(\frac{1/\alpha}{1+1/\alpha}-\gamma\right)\hat{\epsilon}-(1-\gamma)\epsilon_i\right)^2\right). \tag{C.13}$$

This is straightforward, but somewhat cumbersome.

D. Proof of Proposition 1

We introduce the following notation. V_S^{IC} is society's equilibrium loss under an independent national central bank which is able to commit. V_S^{ID} is the corresponding loss under discretion. V_S^{UC} is society's loss under monetary union and commitment, while V_S^{UD} is society's loss under monetary union with discretion. The corresponding expressions are given in Table 3. Assume that $\pi^*=0$ and, for the case of commitment, that $\beta_s<1$.

One has:

$$\frac{\partial V_S^{IC}}{\partial\gamma} = \left[\frac{[1-\beta_s(1-\gamma(n-1)/n)](n-1)/n}{(2-\gamma(n-1)/n)^3}\right](\tilde{g}+\tilde{x})^2 - \left[\frac{(1-\gamma)(n-1)/n}{1+1/\alpha}\right]\sigma^2, \tag{D.1}$$

$$\frac{\partial V_S^{UC}}{\partial\gamma} = \left[\frac{[1-\beta_s(1-\gamma(n-1)/n)](n-1)/n}{(2-\gamma(n-1)/n)^3}\right](\tilde{g}+\tilde{x})^2 - [(1-\gamma)(n-1)/n]\sigma^2, \tag{D.2}$$

$$\frac{\partial V_S^{ID}}{\partial\gamma} = \left[\frac{[1+1/\alpha-\beta_s(1-\gamma(n-1)/n)](n-1)/n}{(2-\gamma(n-1)/n)^3}\right](\tilde{g}+\tilde{x})^2 - \left[\frac{(1-\gamma)(n-1)/n}{1+1/\alpha}\right]\sigma^2, \tag{D.3}$$

$$\frac{\partial V_S^{UD}}{\partial\gamma} = \left[\frac{[1+1/\alpha-\beta_s(1-\gamma(n-1)/n)](n-1)/n}{(2-\gamma(n-1)/n)^3}\right](\tilde{g}+\tilde{x})^2 - [(1-\gamma)(n-1)/n]\sigma^2, \tag{D.4}$$

$$\frac{\partial^2 V_S^{IC}}{\partial^2\gamma} = \left[\frac{[(n-1)/n]^2[3+\beta_s(-1+2\gamma(n-1)/n)]}{(2-\gamma(n-1)/n)^4}\right](\tilde{g}+\tilde{x})^2 + \left[\frac{(n-1)/n}{1+1/\alpha}\right]\sigma^2 > 0, \tag{D.5}$$

$$\frac{\partial^2 V_S^{UC}}{\partial^2\gamma} = \left[\frac{[(n-1)/n]^2[3+\beta_s(-1+2\gamma(n-1)/n)]}{(2-\gamma(n-1)/n)^4}\right](\tilde{g}+\tilde{x})^2 + [(n-1)/n]\sigma^2 > 0, \tag{D.6}$$

$$\frac{\partial^2 V_S^{ID}}{\partial^2\gamma} = \left[\frac{[(n-1)/n]^2[3(1+1/\alpha)+\beta_s(-1+2\gamma(n-1)/n)]}{(2-\gamma(n-1)/n)^4}\right](\tilde{g}+\tilde{x})^2 + \left[\frac{(n-1)/n}{1+1/\alpha}\right]\sigma^2 > 0, \tag{D.7}$$

$$\frac{\partial^2 V_S^{UD}}{\partial^2\gamma} = \left[\frac{[(n-1)/n]^2[3(1+1/\alpha)+\beta_s(-1+2\gamma(n-1)/n)]}{(2-\gamma(n-1)/n)^4}\right](\tilde{g}+\tilde{x})^2 + [(n-1)/n]\sigma^2 > 0. \tag{D.8}$$

Hence, the derivatives of V_S^{IC}, V_S^{UC}, V_S^{ID} and V_S^{UD} with respect to γ are all strictly increasing for the range $0\leq\gamma\leq 1$.

Hence, if $\partial V_S^*/\partial\gamma_{|\gamma=0}\geq 0$ (where the "*" denotes any of the regimes IC, UC, ID or UD), we have $\gamma^{opt}=0$. From (D.1) - (D.4) we see immediately that this condition reduces to $(\tilde{g}+\tilde{x})^2/\sigma^2\geq 8/[(1+1/\alpha)(1-\beta_s)]$ for IC, to $(\tilde{g}+\tilde{x})^2/\sigma^2\geq 8/(1-\beta_s)$ for UC, to $(\tilde{g}+\tilde{x})^2/\sigma^2\geq 8/[(1+1/\alpha)(1+1/\alpha-\beta_s)]$ for ID, and to $(\tilde{g}+\tilde{x})^2/\sigma^2\geq 8/(1+1/\alpha-\beta_s)$ for UD.

If this condition does not hold, we have $\partial V_S^*/\partial\gamma_{|\gamma=0}<0$. Moreover, from (D.2) we have that $\partial V_S^* / \partial \gamma_{|\gamma=1} > 0$. Hence, if the above condition does not hold, then $0 < \gamma^{opt} < 1$.

From (D.1), if $(\tilde{g}+\tilde{x})^2/\sigma^2 < 8/[(1+1/\alpha)(1-\beta_s)]$, then, for IC, γ^{opt} is implicitly defined by:

$$\left[\frac{1-\beta_s\left(1-\gamma^{opt}(n-1)/n\right)}{\left(2-\gamma^{opt}(n-1)/n\right)^3}\right]\frac{(\tilde{g}+\tilde{x})^2}{\sigma^2} = \frac{1-\gamma^{opt}}{1+1/\alpha}. \tag{D.9}$$

From (D.2), if $(\tilde{g}+\tilde{x})^2/\sigma^2 < 8/(1-\beta_s)$, then, for UC, γ^{opt} is implicitly defined by:

$$\left[\frac{1-\beta_s\left(1-\gamma^{opt}(n-1)/n\right)}{\left(2-\gamma^{opt}(n-1)/n\right)^3}\right]\frac{(\tilde{g}+\tilde{x})^2}{\sigma^2} = 1-\gamma^{opt}. \tag{D.10}$$

From (D.3), if $(\tilde{g}+\tilde{x})^2/\sigma^2 < 8/(1+1/\alpha)(1+1/\alpha-\beta_s)$, then, for ID, γ^{opt} is implicitly defined by:

$$\left[\frac{1+1/\alpha-\beta_s\left(1-\gamma^{opt}(n-1)/n\right)}{\left(2-\gamma^{opt}(n-1)/n\right)^3}\right]\frac{(\tilde{g}+\tilde{x})^2}{\sigma^2} = \frac{1-\gamma^{opt}}{1+1/\alpha}. \tag{D.11}$$

From (D.4), if $(\tilde{g}+\tilde{x})^2/\sigma^2 < 8/(1+1/\alpha-\beta_s)$, then, for UD, γ^{opt} is implicitly defined by:

$$\left[\frac{1+1/\alpha-\beta_s\left(1-\gamma^{opt}(n-1)/n\right)}{\left(2-\gamma^{opt}(n-1)/n\right)^3}\right]\frac{(\tilde{g}+\tilde{x})^2}{\sigma^2} = 1-\gamma^{opt}. \tag{D.12}$$

We see immediately that, for (D.9) - (D.12) to continue to hold, an increase in $(\tilde{g}+\tilde{x})^2/\sigma^2$ or an increase in n requires a fall in γ^{opt}, while an increase in β_s requires a rise in γ^{opt}.

E. Proof of Proposition 2

Assume that $\pi^*=0$ and, for the case of commitment, that $\beta_s<1$.

Part a: Explained in the text.

Part b: From the proof of Proposition 1 it follows immediately that, if $8/[(1+1/\alpha)(1-\beta_s)] \leq (\tilde{g}+\tilde{x})^2/\sigma^2 < 8/(1-\beta_s)$ for commitment and if $8/[(1+1/\alpha)(1+1/\alpha-\beta_s)] \leq (\tilde{g}+\tilde{x})^2/\sigma^2 < 8/(1+1/\alpha-\beta_s)$ for discretion, γ^{opt} is higher under monetary union than with an independent, national central bank.

If $(\tilde{g}+\tilde{x})^2/\sigma^2 < 8/(1+1/\alpha)(1-\beta_s)$, γ^{opt} under an IC is determined by (D.9) and γ^{opt} under UC is determined by (D.10). Take the value for γ which is optimal under IC. That is, (D.9) holds. Hence, for this value of γ the left-hand side of (D.10) would be smaller than the right-hand side of (D.10). For (D.10) to hold, γ has to increase further. A similar reasoning holds for discretion.

Part c: For example, for the case of independent national central banks, if $(\tilde{g}+\tilde{x})^2/\sigma^2 \geq 8/[(1+1/\alpha)(1-\beta_s)]$ the optimal degree of risk sharing is zero both under commitment and discretion. If $8/[(1+1/\alpha)(1+1/\alpha-\beta_s)] \leq (\tilde{g}+\tilde{x})^2/\sigma^2 < 8/[(1+1/\alpha)(1-\beta_s)]$, the optimal degree of risk sharing is zero under discretion and positive under commitment. Otherwise, we need to compare (D.9) and (D.11). Suppose that (D.9) holds. Then, the left-hand side of (D.11) exceeds its right-hand side. Hence, the optimal degree of risk sharing under discretion is lower than under commitment. For the case of monetary union, the proof is similar.

F. Proof of Proposition 5

Consider first the case of a national, independent central bank. Using the expression for society's loss in Table 6, we have:

$$\frac{\partial V_S^I}{\partial \gamma} = \left(\frac{(1+1/\alpha)(1+y)(n-1)/n}{((1+y)^2+1/\alpha)^2}\right)(\tilde{g}+\tilde{x})^2 - \left(\frac{n-1}{n}\right)\left(\frac{1}{1+1/\alpha}\right)(1-\gamma)\sigma^2, \tag{F.1}$$

$$\frac{\partial^2 V_S^I}{\partial^2 \gamma} = \left(\frac{n-1}{n}\right)^2\left(\frac{(1+1/\alpha)(3(1+y)^2-1/\alpha)}{((1+y)^2+1/\alpha)^3}\right)(\tilde{g}+\tilde{x})^2 + \left(\frac{n-1}{n}\right)\left(\frac{1}{1+1/\alpha}\right)\sigma^2, \tag{F.2}$$

where $y \equiv 1-\gamma(n-1)/n > 0$.

An internal optimum for γ requires that the right-hand side of (F.1) be zero:

$$\left(\frac{(1+1/\alpha)(1+y)}{((1+y)^2+1/\alpha)^2}\right)(\tilde{g}+\tilde{x})^2 = \left(\frac{1}{1+1/\alpha}\right)(1-\gamma)\sigma^2, \tag{F.3}$$

hence,

$$(\tilde{g}+\tilde{x})^2 = \left(\frac{((1+y)^2+1/\alpha)^2}{(1+1/\alpha)^2(1+y)}\right)(1-\gamma)\sigma^2, \tag{F.4}$$

Substitute this into the right-hand side of (F.2) to give an expression which can be written as $((n-1)/n)\sigma^2$ times:

$$\left(\frac{(3(1+y)^2-1/\alpha)(1-\gamma)(n-1)/n}{((1+y)^2+1/\alpha)(1+1/\alpha)(1+y)}\right) + \left(\frac{1}{1+1/\alpha}\right) =$$

$$\frac{(3(1+y)^2-1/\alpha)(1-\gamma)(n-1)/n + ((1+y)^2+1/\alpha)(1+y)}{((1+y)^2+1/\alpha)(1+1/\alpha)(1+y)} > 0.$$

Hence, for any $0<\gamma<1$ for which V_S^I is flat we have a minimum. By continuity of $\partial V_S^I/\partial\gamma$, there can only be one such point on the interval $0<\gamma<1$. Note, furthermore, that $\partial V_S^I/\partial\gamma_{|\gamma=1}>0$. Hence, $\gamma^{opt}=0$ if $\partial V_S^I/\partial\gamma_{|\gamma=0}\geq 0$, which is equivalent to $(\tilde{g}+\tilde{x})^2/\sigma^2 \geq (4+1/\alpha)^2/[2(1+1/\alpha)^2]$, or $0<\gamma^{opt}<1$, otherwise.

Note that

$$W[(\tilde{g}+\tilde{x})^2/\sigma^2,\gamma] \equiv \left(\frac{(1+1/\alpha)(1+y)}{((1+y)^2+1/\alpha)^2}\right)\frac{(\tilde{g}+\tilde{x})^2}{\sigma^2} - \left(\frac{1}{1+1/\alpha}\right)(1-\gamma) = 0,$$

when evaluated at an internal optimum, $0<\gamma^{opt}<1$. Hence, at an internal optimum we have that

$$\partial\gamma/\partial[(\tilde{g}+\tilde{x})^2/\sigma^2]_{|\gamma=\gamma opt} = -\{\partial W/\partial[(\tilde{g}+\tilde{x})^2/\sigma^2]\}/\{\partial W/\partial\gamma\}_{|\gamma=\gamma opt} > 0,$$

because $\partial W/\partial[(\tilde{g}+\tilde{x})^2]/\sigma^2>0$ and $\partial W/\partial\gamma_{|\gamma=\gamma opt}>0$.

Now, consider the case of a monetary union. Using the expression for society's loss in Table 6, we have:

$$\frac{\partial V_S^U}{\partial\gamma} = \left(\frac{(1+1/\alpha)(1/n+(1+1/\alpha)z)(n-1)/n}{(1/n^2+(2/n)z+(1+1/\alpha)z^2)^2}\right)(\tilde{g}+\tilde{x})^2 - \left(\frac{n-1}{n}\right)(1-\gamma)\sigma^2, \tag{F.5}$$

$$\frac{\partial^2 V_S^U}{\partial^2\gamma} = \left(\frac{(1+1/\alpha)((n-1)/n)^2 w}{(1/n^2+(2/n)z+(1+1/\alpha)z^2)^3}\right)(\tilde{g}+\tilde{x})^2 + \left(\frac{n-1}{n}\right)\sigma^2 > 0, \tag{F.6}$$

where $z \equiv 1+(1-\gamma)(n-1)/n \geq 1$ and $w \equiv (3-1/\alpha)/n^2 + 6(1+1/\alpha)z/n + 3(1+1/\alpha)^2z^2 > 0$. If $(\tilde{g}+\tilde{x})^2/\sigma^2$ is sufficiently large, $\partial V_S^U/\partial\gamma_{|\gamma=0} \geq 0$. Hence, combining with (F.6), we have that $\gamma^{opt}=0$ if $(\tilde{g}+\tilde{x})^2/\sigma^2$ is sufficiently large. Otherwise, $0<\gamma^{opt}<1$ with γ^{opt} determined by the first-order condition:

$$\left(\frac{(1+1/\alpha)(1/n+(1+1/\alpha)z^{opt})}{(1/n^2+(2/n)z^{opt}+(1+1/\alpha)(z^{opt})^2)^2}\right)(\tilde{g}+\tilde{x})^2 = (1-\gamma^{opt})\sigma^2, \tag{F.7}$$

where $z^{opt} \equiv z_{|\gamma=\gamma opt}$. An increase in γ raises the left-hand side of (F.7) and reduces its right-hand side. Hence, an increase in $(\tilde{g}+\tilde{x})^2/\sigma^2$ implies a fall in the optimal degree of risk sharing, γ^{opt}.

G: Explicit treatment of the signal extraction problem at the supranational level:

Because of the unobservability of the shocks the federal authorities responsible for the federal transfers face a signal extraction problem: on the basis of the observations $c_i \equiv \epsilon_i - e_i$, they form an estimate e_i^c of e_i, or, alternatively, an estimate $\epsilon_i^c = c_i + e_i^c = \epsilon_i - e_i + e_i^c$ of ϵ_i. Transfers then take place on the basis of the estimates ϵ_i^c, $i=1,..,n$. The budget constraint of government i is given by:

$$\tilde{g} + \epsilon_i - e_i = \tau_i + \gamma(\epsilon_i^c - \hat{\epsilon}^c), \tag{G.1}$$

where a hat above a variable again denotes the cross-country average.

Because e_i is selected before ϵ_i occurs, we *conjecture* that the federal authorities estimate e_i to be the same constant k for all i, i.e. $e_i^c=k$. This conjecture needs to be confirmed, i.e., we need to show that, in equilibrium, the fiscal authorities behave in such a way that e_i is a constant k.

Substituting $\epsilon_i^c=\epsilon_i-e_i+k$ and $\tilde{\epsilon}^c=\tilde{\epsilon}-\tilde{e}+k$ into (G.1), the government budget constraint reduces to (5) or (5′) in the text (because k drops out). Hence, for each of the relevant cases considered in the paper (i.e., discretion with national monetary policy or with monetary unification), the outcomes are unchanged. Because we found that for each of these cases the outcome for e_i was a constant (see Tables 1 and 2), our conjecture was correct: the federal authorities simply estimate e_i to be equal to the solution given in Table 1 or 2 (depending on the specific case being considered) in the paper. This is their best estimate and it is exactly correct in equilibrium.

Table 1: Equilibrium policy outcomes under commitment ($\pi^{*}=0$).

Variable:	No union	Monetary union
π_i	$\left(\frac{1/\alpha}{1+1/\alpha}\right)\left[(1-\gamma)\epsilon_i+\gamma\hat{\epsilon}\right]$	$\left(\frac{1/\alpha}{1+1/\alpha}\right)\hat{\epsilon}$
$\tilde{x}$-x_i	$\left(\frac{1}{2-\gamma(n-1)/n}\right)(\tilde{g}+\tilde{x}) + \left(\frac{1}{1+1/\alpha}\right)\left[(1-\gamma)\epsilon_i+\gamma\hat{\epsilon}\right]$	$\left(\frac{1}{2-\gamma(n-1)/n}\right)(\tilde{g}+\tilde{x}) - \left(\frac{1/\alpha}{1+1/\alpha}-\gamma\right)\hat{\epsilon}+(1-\gamma)\epsilon_i$
e_i	$\left(\frac{1-\gamma(n-1)/n}{2-\gamma(n-1)/n}\right)(\tilde{g}+\tilde{x})$	$\left(\frac{1-\gamma(n-1)/n}{2-\gamma(n-1)/n}\right)(\tilde{g}+\tilde{x})$

Table 2: Equilibrium policy outcomes under discretion

A. National monetary policymaking with independent central banks:

Variable:	
π_i	$\left(\frac{(1+1/\alpha)+(1-\gamma(n-1)/n)}{D}\right)\pi^* + \left(\frac{1/\alpha}{2-\gamma(n-1)/n}\right)(\tilde{g}+\tilde{x}) + \left(\frac{1/\alpha}{1+1/\alpha}\right)\left[(1-\gamma)\epsilon_i+\gamma\hat{\epsilon}\right]$
$\tilde{x}$-x_i	$-\left(\frac{1-\gamma(n-1)/n}{D}\right)\pi^* + \left(\frac{1}{2-\gamma(n-1)/n}\right)(\tilde{g}+\tilde{x}) + \left(\frac{1}{1+1/\alpha}\right)\left[(1-\gamma)\epsilon_i+\gamma\hat{\epsilon}\right]$
e_i	$\left(\frac{1-\gamma(n-1)/n}{D}\right)\pi^* + \left(\frac{1-\gamma(n-1)/n}{2-\gamma(n-1)/n}\right)(\tilde{g}+\tilde{x})$

Note: $D \equiv [1+1/\alpha][2-\gamma(n-1)/n]$.

B. monetary union:

Variable:	
π	$\left(\frac{1/n+(1+(1-\gamma)(n-1)/n)(1+1/\alpha)}{D}\right)\pi^{*} + \left(\frac{1/\alpha}{2-\gamma(n-1)/n}\right)(\tilde{g}+\tilde{x}) + \left(\frac{1/\alpha}{1+1/\alpha}\right)\hat{\epsilon}$
$\tilde{x}\text{-}x_i$	$-\left(\frac{1/n}{D}\right)\pi^{*} + \left(\frac{1}{2-\gamma(n-1)/n}\right)(\tilde{g}+\tilde{x}) - \left(\frac{1/\alpha}{1+1/\alpha}-\gamma\right)\hat{\epsilon} + (1-\gamma)\epsilon_i$
e_i	$\left(\frac{1/n}{D}\right)\pi^{*} + \left(\frac{1-\gamma(n-1)/n}{2-\gamma(n-1)/n}\right)(\tilde{g}+\tilde{x})$

Table 3: Equilibrium social welfare losses ($\pi^*=0$).

Independent national central bank, commitment:
$\left[\frac{\beta_s(1-\gamma(n-1)/n)^2+1}{2(2-\gamma(n-1)/n)^2}\right](\tilde{g}+\tilde{x})^2 + \left[\frac{1}{2(1+1/\alpha)}\right]\left[(1-\gamma)^2\left(\frac{n-1}{n}\right)+\frac{1}{n}\right]\sigma^2$
Monetary union, commitment:
$\left[\frac{\beta_s(1-\gamma(n-1)/n)^2+1}{2(2-\gamma(n-1)/n)^2}\right](\tilde{g}+\tilde{x})^2 + \left[\frac{1}{2(1+1/\alpha)}\right]\frac{\sigma^2}{n}+(1-\gamma)^2\left[\frac{n-1}{2n}\right]\sigma^2$
Independent national central bank, discretion:
$\left[\frac{\beta_s(1-\gamma(n-1)/n)^2+(1+1/\alpha)}{2(2-\gamma(n-1)/n)^2}\right](\tilde{g}+\tilde{x})^2 + \left[\frac{1}{2(1+1/\alpha)}\right]\left[(1-\gamma)^2\left(\frac{n-1}{n}\right)+\frac{1}{n}\right]\sigma^2$
Monetary union, discretion:
$\left[\frac{\beta_s(1-\gamma(n-1)/n)^2+(1+1/\alpha)}{2(2-\gamma(n-1)/n)^2}\right](\tilde{g}+\tilde{x})^2 + \left[\frac{1}{2(1+1/\alpha)}\right]\frac{\sigma^2}{n}+(1-\gamma)^2\left[\frac{n-1}{2n}\right]\sigma^2$

Table 4: Evaluation of $\partial V_{s,i}/\partial\gamma$ at $\gamma=0$ (national monetary policy and monetary union).

	Commitment	Discretion
$0\leq\beta_s<1$	>0	>0
$\beta_s=1$	0	>0

Table 5: Optimal inflation targets ($0\leq\beta_s\leq1$).

National mon. policy	$-\left[\frac{(1+1/\alpha)\left[1+1/\alpha+\beta_s(1-\gamma(n-1)/n)^2\right]}{(1+\beta_s)(1-\gamma(n-1)/n)^2+\alpha(1/\alpha+2-\gamma(n-1)/n)^2}\right](\tilde{g}+\tilde{x})$
Monetary union	$-\left[\frac{\beta_s(1+1/\alpha)(1-\gamma(n-1)/n)/n+(1+1/\alpha)^2(1+(1-\gamma)(n-1)/n)}{(1+\beta_s)/n^2+\alpha[1/n+(1+(1-\gamma)(n-1)/n)(1+1/\alpha)]^2}\right](\tilde{g}+\tilde{x})$

Table 6: Equilibrium social loss under optimal inflation targets ($\beta_s=0$).

National mon. policy	$\frac{1}{2}\left(\frac{1+1/\alpha}{(2-\gamma(n-1)/n)^2+1/\alpha}\right)(\tilde{g}+\tilde{x})^2+\left(\frac{1}{2(1+1/\alpha)}\right)\left((1-\gamma)^2\left(\frac{n-1}{n}\right)+\frac{1}{n}\right)\sigma^2$
Monetary union	$\frac{1}{2}\left(\frac{1+1/\alpha}{(2-\gamma(n-1)/n)^2+(1/\alpha)(1+(1-\gamma)(n-1)/n)^2}\right)(\tilde{g}+\tilde{x})^2+\left(\frac{1}{2(1+1/\alpha)}\right)\frac{\sigma^2}{n}+(1-\gamma)^2\left(\frac{n-1}{2n}\right)\sigma^2$

Table 7: Numerical comparison national monetary policy and monetary union for various parameter combinations ($\alpha = 1$).

a: $\beta_s=0$

		No union		Monetary union								
n	$(\bar{g}+\bar{x})^2/\sigma^2$	γ^{opt}	$V^N_{S,i}/\sigma^2$	γ^{opt}	$\pi^{*,opt}/(\bar{g}+\bar{x})$	$E[\pi]/(\bar{g}+\bar{x})$	$E[\bar{x}-x_i]/(\bar{g}+\bar{x})$	$E[e_i]/(\bar{g}+\bar{x})$	det.loss/σ^2	stoch.loss/σ^2	$V^U_{S,i}/\sigma^2$	$V^N_{S,i}/V^U_{S,i}$
2	0.01	0.994	0.128	0.995	-0.615	0.153	0.768	0.232	0.0031	0.125	0.128	1.00
2	0.1	0.945	0.155	0.955	-0.615	0.149	0.757	0.243	0.0297	0.126	0.155	0.999
2	1	0.561	0.402	0.669	-0.615	0.121	0.685	0.315	0.242	0.152	0.394	0.981
2	10	0.000	2.25	0.000	-0.615	0.080	0.560	0.440	1.60	0.375	1.98	0.878
2	100	0.000	20.25	0.000	-0.615	0.080	0.560	0.440	16.0	0.375	16.4	0.809
5	0.01	0.992	0.0541	0.993	-0.820	0.081	0.897	0.103	0.0041	0.0500	0.0541	1.00
5	0.1	0.925	0.0898	0.935	-0.820	0.075	0.862	0.138	0.0374	0.0517	0.0891	0.992
5	1	0.497	0.381	0.634	-0.820	0.051	0.714	0.286	0.256	0.104	0.360	0.945
5	10	0.000	2.25	0.000	-0.820	0.028	0.525	0.475	1.38	0.450	1.83	0.814
5	100	0.000	20.25	0.000	-0.820	0.028	0.525	0.475	13.8	0.450	14.3	0.704
11	0.01	0.991	0.0273	0.991	-0.913	0.041	0.947	0.053	0.0045	0.0228	0.0273	1.00
11	0.1	0.916	0.0667	0.927	-0.913	0.037	0.898	0.102	0.0404	0.0252	0.0655	0.983
11	1	0.467	0.374	0.625	-0.913	0.024	0.721	0.279	0.260	0.0867	0.347	0.925
11	10	0.000	2.25	0.000	-0.913	0.012	0.511	0.489	1.31	0.477	1.79	0.794
11	100	0.000	20.25	0.000	-0.913	0.012	0.511	0.489	13.1	0.477	13.6	0.670
15	0.01	0.991	0.0213	0.991	-0.936	0.031	0.959	0.041	0.0046	0.0167	0.0213	1.00
15	0.1	0.914	0.0616	0.926	-0.936	0.027	0.906	0.094	0.0411	0.0192	0.0603	0.980
15	1	0.471	0.373	0.624	-0.936	0.017	0.722	0.278	0.261	0.0826	0.343	0.920
15	10	0.000	2.25	0.000	-0.936	0.009	0.508	0.492	1.29	0.483	1.78	0.789
15	100	0.000	20.25	0.000	-0.936	0.009	0.508	0.492	12.9	0.483	13.4	0.662

Note: γ^{opt} = optimal degree of risk sharing, $V^N_{S,i}$ = society's welfare loss at $\gamma=\gamma^{opt}$ under national monetary policymaking. $V^U_{S,i}$ = society's welfare loss at $\gamma=\gamma^{opt}$ under a monetary union, "det.loss" = deterministic welfare loss, "stoch.loss" = stochastic welfare loss.

b: $\beta_s = 1$.

		No union		Monetary union									
n	$(\bar{g}+\bar{x})^2/\sigma^2$	γ^{opt}	$V^N_{S,i}/\sigma^2$	γ^{opt}	$\pi^{*,opt}/(\bar{g}+\bar{x})$	$E[\pi]/(\bar{g}+\bar{x})$	$E[\bar{x}-x_i]/(\bar{g}+\bar{x})$	$E[e_i]/(\bar{g}+\bar{x})$	det.loss/σ^2	stoch.loss/σ^2	$V^U_{S,i}/\sigma^2$	$V^N_{S,i}/V^U_{S,i}$
2	0.01	0.996	0.128	0.997	-0.667	0.111	0.777	0.223	0.0033	0.125	0.128	1.00
2	0.1	0.962	0.158	0.967	-0.667	0.106	0.769	0.231	0.0328	0.125	0.158	0.999
2	1	0.709	0.444	0.770	-0.667	0.080	0.718	0.282	0.301	0.138	0.439	0.988
2	10	0.000	2.98	0.222	-0.667	0.032	0.605	0.395	2.62	0.276	2.89	0.971
2	100	0.000	27.52	0.000	-0.667	0.020	0.569	0.431	25.49	0.375	25.86	0.940
5	0.01	0.993	0.0541	0.994	-0.829	0.072	0.899	0.101	0.0041	0.0500	0.0541	1.00
5	0.1	0.935	0.0906	0.944	-0.829	0.064	0.868	0.132	0.0387	0.0512	0.0900	0.994
5	1	0.613	0.411	0.716	-0.829	0.038	0.751	0.249	0.314	0.082	0.396	0.962
5	10	0.000	2.98	0.290	-0.829	0.012	0.599	0.401	2.60	0.252	2.85	0.957
5	100	0.000	27.52	0.000	-0.829	0.003	0.526	0.474	25.07	0.450	25.52	0.927
11	0.01	0.991	0.0273	0.992	-0.915	0.039	0.948	0.052	0.0045	0.0228	0.0273	1.00
11	0.1	0.923	0.0670	0.934	-0.915	0.033	0.903	0.097	0.0413	0.0247	0.0660	0.986
11	1	0.581	0.402	0.702	-0.915	0.018	0.759	0.241	0.317	0.0631	0.380	0.947
11	10	0.000	2.97	0.308	-0.915	0.005	0.597	0.403	2.59	0.240	2.83	0.952
11	100	0.000	27.52	0.027	-0.915	0.001	0.518	0.482	25.03	0.453	25.49	0.926
15	0.01	0.991	0.0213	0.992	-0.937	0.029	0.960	0.040	0.0046	0.0167	0.0213	1.00
15	0.1	0.921	0.0618	0.932	-0.937	0.025	0.911	0.089	0.0419	0.0188	0.0608	0.982
15	1	0.574	0.400	0.699	-0.937	0.013	0.761	0.239	0.318	0.0590	0.377	0.943
15	10	0.000	2.98	0.312	-0.937	0.004	0.597	0.403	2.59	0.238	2.83	0.951
15	100	0.000	27.52	0.038	-0.937	0.001	0.518	0.482	25.03	0.449	25.48	0.926

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