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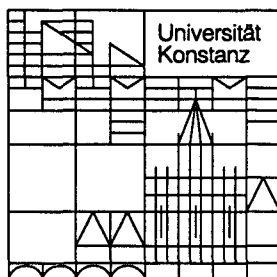
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Max Albert and Jürgen Meckl

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Green Tax Reform and Two-Component Unemployment: Double Dividend or Double Loss?

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Abstract

The double-dividend argument (as used in political debates) addresses worries that a green tax may lead to higher unemployment when wages are inflexible. As protection against this possibility, it is proposed to use the proceeds of the green tax to subsidize employment. In the best case, this protects the environment and reduces unemployment (double dividend). However, even if the main cause of unemployment is a minimum wage, an additional efficiency-wage component (which explains certain stylized facts) can dominate employment effects. In the worst case, this leads to a “double loss”, which is impossible under pure minimum-wage unemployment.

JEL Classification J30, Q28

Keywords double dividend, efficiency wages, green tax reform, unemployment

1 Introduction

Public discussions are often based on the assumption that taxing the use of the environment (green tax) protects the environment at the cost of higher unemployment. Thus, labor and the environment are implicitly viewed as complements. Unemployment is typically attributed to the fact that wages are downward inflexible due to minimum wages or similar institutions (as the German “Tariflöhne”). The most prominent proposal for a solution to the complementarity problem is to use the proceeds of the green tax to subsidize wages or finance a wage-tax cut (revenue recycling). Such a tax reform, it is hoped, yields a double dividend—protection of the environment and reduction of unemployment—while respecting the political constraint of not raising the total tax burden.

The double-dividend argument for the case of minimum-wage unemployment is analyzed by Bovenberg (1998), Bovenberg & van der Ploeg (1996), and Koskela et al. (1998, 1999).¹ The present paper takes a further step in relating the theoretical arguments to the public discussion. (i) It starts from the premises of this discussion: complementarity of labor and the environment, minimum wages as the main cause of unemployment. (ii) It integrates two important stylized facts left unexplained by minimum-wage models: the stability of intersectoral wage differentials over time, and the existence of a (sector-specific) span between minimum wages and effective wages (wage span).² (iii) It shows that such a closer approximation to real-world labor markets is relevant for the issue at hand.

Schlicht (1992) explains German wage spans by assuming that wage setting influences the standard of fairness in the Akerlof-Yellen efficiency-wage model (Akerlof 1982, Akerlof & Yellen 1990). The present paper uses a simplified version of this idea in a multi-sectoral model: If firms pay more relative to the minimum wage, workers reciprocate with more effort. Assuming that the productivity of effort differs across sectors, the model implies sector-specific wage spans and fixed intersectoral wage differentials. Unemployment is involuntary and consists of two

¹Koskela & Schöb (1999) moreover endogenize the minimum wage in a wage-bargaining model. Bovenberg & van der Ploeg (1998) and Schneider (1997) consider search or efficiency-wage unemployment instead. Cf. also Bovenberg (1999) for a survey, which, however, emphasizes issues of optimal taxation and tax incidence that are not relevant for the present argument.

²Cf. Dickens & Katz (1986), Bulow & Summers (1986), Krueger & Summers (1988), Katz & Summers (1989) on wage differentials. Cf. Schlicht (1992) and Franz (1996: 270-274) on German wage spans.

components, a minimum-wage component and an efficiency-wage component. Since repercussions from final-product markets are inessential for our arguments, we consider a small open economy facing given product prices on world markets.

The efficiency-wage component of unemployment changes quite independent from the minimum-wage component. It can dominate the effects of the tax reform *even if minimum wages explain the main part of the observed rate of unemployment*. In the worst case, the efficiency-wage component can lead to a *double loss* (higher use of the environment and higher unemployment), which is impossible with pure minimum-wage unemployment if complementarity holds.

Section 2 summarizes results for pure minimum-wage unemployment. Section 3 presents the two-component model. Section 4 concludes.

2 Pure Minimum-Wage Unemployment

Basic Assumptions. We consider a small open economy using $m + 2$ primary factors to produce $n \leq m$ goods. In this section, we concentrate on minimum-wage unemployment as the only form of involuntary unemployment (*pure* minimum-wage unemployment). We assume that individual and aggregate labor supply is fixed, and that there is a binding minimum wage w determined by some centralized wage-setting process. Corresponding to the argument developed in the introduction, we consider a second fix-price factor: the environment E , the use of which is taxed at rate t .³ The prices of the m other primary factors of production are determined on national factor markets. These flex-price factors are denoted by the vector \mathbf{v} ; their prices are denoted by \mathbf{r} . For the vector product we write $\mathbf{r} \cdot \mathbf{v}$.

Assuming linearly homogeneous production functions f_j , $j = 1, \dots, n$, the cost-minimization problem of a competitive firm in sector j facing given factor prices w , t , and \mathbf{r} then is

$$b_j(w, t, \mathbf{r}) \stackrel{\text{def}}{=} \min_{L_j, E_j, \mathbf{v}^j \geq 0} \left\{ wL_j + tE_j + \mathbf{r} \cdot \mathbf{v}^j : f_j(L_j, E_j, \mathbf{v}^j) \geq 1 \right\}, \quad (1)$$

³Alternatively, one may interpret the factor E as the input of energy which is in perfect elastic supply at a price p_E determined on the world market (cf. Koskela, Schöb & Sinn 1998, 1999). In this case, t is the producer price of energy: $t = p_E(1 + t_E)$, with t_E denoting the *ad valorem* tax rate on energy inputs.

where L_j and E_j are sector j 's inputs of labor and the environment, respectively, and \mathbf{v}^j are sector j 's inputs of the flex-price factors. The envelope theorem implies

$$(a) \frac{\partial b_j}{\partial w} = a_{Lj} \quad (b) \frac{\partial b_j}{\partial t} = a_{Ej} \quad (c) \frac{\partial b_j}{\partial r_h} = a_{hj}, \quad h = 1, \dots, m, \quad (2)$$

where a_{Lj} , a_{Ej} are the input coefficients of labor and the environment, respectively, and a_{hj} is the input coefficient of flex-price factor h .

Equilibrium Conditions Without Revenue Recycling. In order to simplify the exposition, we start with a case where tax revenues are redistributed directly to consumers, which under our assumptions means that revenues have no effect at all.

To describe the equilibrium allocation, we use the GDP function (cf. Dixit and Norman 1980, Woodland 1982)

$$y(\mathbf{p}, L, E, \mathbf{v}) \stackrel{\text{def}}{=} \min_{w, t, \mathbf{r} \geq 0} \{wL + tE + \mathbf{r} \cdot \mathbf{v} : b_j(w, t, \mathbf{r}) \geq p_j \forall j\}. \quad (3)$$

Here \mathbf{p} is a vector of n output prices p_j . Problem (3) describes the equilibrium allocation of given factor endowments of labor L , the environment E , and other factors \mathbf{v} . The solution to the problem are equilibrium factor prices w , t , and \mathbf{r} . The GDP function y is non-decreasing, convex and linearly homogeneous in output prices; non-decreasing, concave and linearly homogeneous in factor endowments; the derivatives w.r.t. output prices are the outputs; the derivatives w.r.t. the factor endowments are the factor prices. Specifically for the first and second derivatives w.r.t. L , E we write y_L , y_E , y_{LE} , and so forth.

In our model, the wage rate w and the price of the environment t are exogenous, while the quantities of labor and environment used in production are endogenous. The equilibrium conditions

$$(a) y_L(\mathbf{p}, L, E, \mathbf{v}) = w \quad (b) y_E(\mathbf{p}, L, E, \mathbf{v}) = t \quad (4)$$

determine the equilibrium demand for labor as $L(\mathbf{p}, w, t, \mathbf{v})$ and for use of the environment as $E(\mathbf{p}, w, t, \mathbf{v})$. Obviously, these functions are homogeneous of degree 1 in the vector of prices (\mathbf{p}, w, t) and homogeneous of degree 0 in flex-price endowments \mathbf{v} . With an aggregate labor supply \bar{L} given exogenously, pure minimum-wage unemployment is $\bar{L} - L(\mathbf{p}, w, t, \mathbf{v})$.

Complementarity. We assume that the GDP function $y(\mathbf{p}, L, E, \mathbf{v})$ is strictly concave and twice continuously differentiable w.r.t. labor and environment. Thus, the matrix A_1 of y 's second derivatives is symmetric and negative definite; the latter implies $|A_1| > 0$ almost everywhere.

According to the standard definition, two factors are said to be substitutes (complements) iff a rise in the price of one leads to an increase (decrease) in the demand for the other. Total differentiation of (4) w.r.t. t and an application of Cramer's rule yield

$$(a) \frac{dL}{dt} = -\frac{y_{LE}}{|A_1|} \quad (b) \frac{dE}{dt} = -\frac{y_{LL}}{|A_1|}. \quad (5)$$

Thus, $y_{LE} > 0$ means that labor and the environment are complements, which implies that introducing a green tax without revenue recycling raises higher unemployment (as usually assumed in public discussions).

Green Tax Reform With Revenue Recycling. We turn to the effects of a green tax under the assumption that its proceeds tE are used to subsidize wages with a subsidization rate s . This implies an additional budget constraint: Let $B(s) = tE(s) - swL$ be the budget surplus of the green tax reform. The reform (as proposed in public discussions) aims at a subsidization rate s with $B(s) = 0$ and therefore $sw = tE/L$. The net wage \bar{w} relevant for the firm is then given by

$$\bar{w} \stackrel{\text{def}}{=} (1 - s)w = w - \frac{tE}{L}. \quad (6)$$

Analogously to (4), the equilibrium conditions are

$$(a) y_L(\mathbf{p}, L, E, \mathbf{v}) = \bar{w} \quad (b) y_E(\mathbf{p}, L, E, \mathbf{v}) = t. \quad (7)$$

Assuming stability (see appendix A), the effects of a green tax reform with revenue recycling can be derived by differentiation of (7) w.r.t. t , which yields the following linear system:

$$\begin{pmatrix} y_{LL} - \frac{tE}{L^2} & y_{LE} + \frac{t}{L} \\ y_{EL} & y_{EE} \end{pmatrix} \begin{pmatrix} \frac{dL}{dt} \\ \frac{dE}{dt} \end{pmatrix} = \begin{pmatrix} -\frac{E}{L} \\ 1 \end{pmatrix} \quad (8)$$

Let us denote the matrix of coefficients by A_2 . We find

$$|A_2| = |A_1| - \frac{t}{L^2} (Ey_{EE} + Ly_{LE}). \quad (9)$$

Thus, the stability condition (23) of appendix A is equivalent to $|A_2| > 0$. Solving according to Cramer's rule and considering percentage changes, we find

$$\begin{aligned} (a) \quad \frac{dL/dt}{L} &= -\frac{1}{|A_2|L} \frac{Ey_{EE} + Ly_{LE} + t}{L} \\ (b) \quad \frac{dE/dt}{E} &= \frac{1}{|A_2|L} \frac{Ly_{LL} + Ey_{LE} - tE/L}{E}. \end{aligned} \tag{10}$$

Concavity and stability are not strong enough to determine any of the signs in (10), esp. if $y_{LE} > 0$ (complementarity). However, complementarity implies at least that a double-loss scenario, where the use of the environment increases and employment falls, is impossible (see appendix B).

More can be said if, initially, $t = 0$ and, thus, $A_2 = A_1$. Equations (10) then reduce to

$$\begin{aligned} (a) \quad \frac{dL}{dt} &= -\frac{1}{|A_1|L} (Ey_{EE} + Ly_{LE}) \\ (b) \quad \frac{dE}{dt} &= \frac{1}{|A_1|L} (Ly_{LL} + Ey_{LE}). \end{aligned} \tag{11}$$

Comparing (11) with (5), we find that a green tax reform with revenue recycling, as compared to the case without revenue recycling, at least initially (i.e., t small) implies (i) higher use of the environment in the case of complementarity and (ii) higher employment in any case. If, on the other hand, t is high enough initially, it is known from the literature (cf. Koskela et al. 1998, 1999) that the tax reform may result in a reduction of employment.

3 A Two-Component Model of Unemployment

Basic Assumptions. We now incorporate efficiency wages as a second source of involuntary unemployment in order to make the model consistent with two important stylized facts: the stability of intersectoral wage differentials over time, and the existence of a positive and sector-specific span between minimum wages and effective wages (wage span).

This section's model is based on Schlicht's (1992) modification of the fair-wage approach of Akerlof (1982) and Akerlof & Yellen (1990). When deciding about their effort, workers respect a fairness norm. The effort required by this norm is assumed to depend on the employer's wage offer w_j and a reference wage w . Specifically, the reference wage is provided by the outcome of the centralized wage-setting process. Effort actually supplied by a worker is then an

increasing function of the relative wage w_j/w . Following a suggestion by Layard, Nickell & Jackman (1994: 37), we explain intersectoral wage differentials by the assumption that the productivity of effort—just like that of any other input—is sector-specific. The two assumptions—effort increasing with the relative wage, productivity increasing with effort—are formalized by the assumption that the sectoral labor input in efficiency units is given by $g_j(w_j/w)L_j$, where L_j is sectoral employment and $g_j(w_j/w)$ is an increasing function describing the sector-specific nexus between relative wages and efficiency of labor.

As usual, we solve the cost-minimization problem of a competitive firm facing a given reference wage w and given prices for other factors of production in two steps. In a first step, the firm chooses a wage rate that minimizes the costs $w_j/g(w_j/w)$ of labor in efficiency units. Under standard assumptions on the shape of the efficiency function g_j , there exists a unique cost-minimizing value of w_j/w . We denote this value by $1 + q_j$. Thus, sectoral wages are determined by a fixed and sector-specific markup q_j on the reference wage: $w_j = (1 + q_j)w$. The sectoral wage span is $w_j - w = q_j w$. We assume that the shape of the efficiency function implies $q_j > 0$. Thus, the model implies positive and sector-specific wage spans. The wage differential between sectors j and i is $(w_j - w_i)/w_j = (q_j - q_i)/q_i$; thus, the model also implies stable intersectoral wage differentials.⁴

The wage actually paid by the firm, the *net wage*, is determined as $\bar{w}_j = (1 - s)w_j = (1 - s)(1 + q_j)w$. Obviously, subsidizing firms at a common rate s is equivalent to changing the reference wage. Thus, the *net reference wage* is $\bar{w} = (1 - s)w$, and $\bar{w}_j/\bar{w} = w_j/w = 1 + q_j$. Given that the markups q_j are fixed and independent of the reference wage or the subsidy, we can analyze the model in terms of the net wage and the net reference wage without referring further to the determinants of effort.

On the basis of the chosen net wage rate $\bar{w}_j = (1 + q_j)\bar{w}$ and corresponding efficiency of labor $\bar{g}_j \equiv g_j(1 + q_j)$, firms solve the standard cost-minimization problem, treating the net reference wage \bar{w} as a parameter. The cost minimization

⁴Different reference wages for different sectors can also be accommodated as long as all reference wages for all sectors always change by the same percentage. This is the case if, e.g., sector-specific minimum wages grow by the same rate as national productivity.

problem in sector j looks as follows:

$$\bar{b}_j(\bar{w}, t, \mathbf{r}) \stackrel{\text{def}}{=} \min_{L_j, E_j, \mathbf{v}^j \geq 0} \{ \bar{w}(1 + q_j)L_j + tE_j + \mathbf{r} \cdot \mathbf{v}^j : f_j(\bar{g}_j L_j, E_j, \mathbf{v}^j) \geq 1 \} \quad (12)$$

This unit-cost function has all the standard properties. The envelope theorem implies

$$(a) \frac{\partial \bar{b}_j}{\partial w} = a_{Lj} \quad (b) \frac{\partial \bar{b}_j}{\partial t} = a_{Ej} \quad (c) \frac{\partial \bar{b}_j}{\partial r_h} = a_{hj}, \quad h = 1, \dots, m, \quad (13)$$

where a_{Lj} and a_{Ej} are the input coefficients of labor and the environment, respectively, and a_{hj} is the input coefficient of the flex-price factor h .

Separating the Components of Unemployment. We introduce a simple and quite natural definition that allows us to separate the two components of unemployment, the minimum-wage component and the efficiency-wage component. Consider the employment L_j by sector j 's representative firm at a reference wage \bar{w} . As shown in appendix C, the quantity $N_j \stackrel{\text{def}}{=} (1 + q_j)L_j$ can be interpreted as the number of workers the representative firm would hire at the same wage in a hypothetical situation where the incentive problem leading to efficiency-wage setting is absent. The incentive problem leads the firm to spend the same amount of money on a smaller number of workers, namely, L_j instead of N_j . Thus, $N_j - L_j > 0$ is sector j 's contribution to efficiency-wage unemployment.

Mainly because we lack a better word, and partly because the term makes at least some intuitive sense, we call N_j sectoral labor *absorption*, in contrast to sectoral labor *employment* L_j . Thus, the sectoral contribution to efficiency-wage unemployment is the difference between sectoral absorption and sectoral employment.

Equilibrium Conditions. The unit-cost functions defined in (1) and (12) have the same properties. We define a production function depending on labor absorption:

$$\bar{f}(N_j, E_j, \mathbf{v}^j) \stackrel{\text{def}}{=} f_j[\bar{g}_j N_j / (1 + q_j), E_j, \mathbf{v}^j] \quad (14)$$

This definition just hides the constants in f . Again using $N_j \stackrel{\text{def}}{=} (1 + q_j)L_j$ and (14), we can rewrite (12) in an equivalent form:

$$\bar{b}_j(\bar{w}, t, \mathbf{r}) \equiv \min_{N_j, E_j, \mathbf{v}^j \geq 0} \left\{ \bar{w}N_j + tE_j + \mathbf{r} \cdot \mathbf{v}^j : \bar{f}_j(N_j, E_j, \mathbf{v}^j) \geq 1 \right\} \quad (15)$$

Thus, we find that the net reference wage \bar{w} is the price of sectoral labor absorption, and that the latter enters the cost minimization problem in the same way as employment does in the standard case. The envelope theorem works as before (see (13)), with the difference that we now interpret

$$\frac{\partial \bar{b}_j(\bar{w}, t, \mathbf{r})}{\partial \bar{w}} = a_{N_j}(\bar{w}, t, \mathbf{r}) \quad (16)$$

as the input coefficient of labor absorption, where of course $a_{N_j} = (1 + q_j)a_{L_j}$.

The equilibrium allocation in the model allowing for two-component unemployment can be described with the help of a GDP function $\bar{y}(\mathbf{p}, N, E, \mathbf{v})$ that is defined in complete analogy to (3); we just have to replace the cost functions by (15) and L by N . The equilibrium conditions are

$$(a) \bar{y}_N(\mathbf{p}, N, E, \mathbf{v}) = \bar{w} \quad (b) \bar{y}_E(\mathbf{p}, N, E, \mathbf{v}) = t. \quad (17)$$

Total subsidization is

$$s \sum w_j L_j = sw \sum (1 + q_j) L_j = swN. \quad (18)$$

Therefore, the tax budget constraint is $B(s) = tE - swN = 0$. Obviously, the complete analysis of section 2 and appendices A (stability) and B (exclusion of double loss) applies if we just substitute absorption N for employment L . Additionally, we have an equation determining total employment L as

$$L = \sum_{j=1}^n L_j = \sum_{j=1}^n \frac{N_j}{1 + q_j}. \quad (19)$$

The results of section 2 and appendices A, B apply to total labor absorption while the effects of a green tax reform on employment must be calculated using (19).

There are now two components of unemployment. On the one hand, we have efficiency-wage unemployment, which is equal to the sum $\sum (N_j - L_j)$ of the sectoral contributions to efficiency-wage unemployment. Total absorption $N = \sum N_j$ is determined in analogy to employment in section 2's model by

the equilibrium conditions (17). Total employment L is determined by (19). Efficiency-wage unemployment is equal to $N - L$. This term is always strictly positive since $N_j - L_j > 0$ for all j .

On the other hand, there is minimum-wage unemployment, which must be equal to the difference between total unemployment $\bar{L} - L$ and efficiency-wage unemployment $N - L$. Thus, we find that minimum-wage unemployment is equal to the difference $\bar{L} - N$ between labor supply and total labor absorption. This difference is positive iff the net wage \bar{w} is higher than some level \bar{w}^* defined by the condition $N = \bar{L}$. The assumption $\bar{w} > \bar{w}^*$ is made throughout the rest of the paper, although an equilibrium where minimum-wage unemployment is negative due to $\bar{w} < \bar{w}^*$ is perfectly possible as long as total unemployment remains positive.

As (19) shows, the sectoral structure of the economy crucially affects aggregate employment once we allow for efficiency-wage unemployment. For a given level of total labor absorption (and, hence, of given pure minimum-wage unemployment), aggregate employment rises with the number of workers employed in the low-wage sectors.

Effects of the Green Tax Reform. We can restate the assumptions discussed in the introduction in the context of the two-component model as follows:

1. The main cause of unemployment is the minimum wage, i.e. minimum-wage unemployment $\bar{L} - N$ is much higher than efficiency-wage unemployment $N - L$.
2. Disregarding the incentive problem, labor and the environment are complements, i.e. $\bar{y}_{NE} > 0$ (since without incentive problem labor demand or employment would be N).
3. As far as minimum-wage unemployment is concerned, there exists a double dividend, i.e. a green tax with revenue recycling protects the environment and leads to a reduction of minimum-wage unemployment $\bar{L} - N$.

When an efficiency-wage component of unemployment exists, the change in aggregate employment is no longer determined by the change in absorption alone. This would only be true for a one-sector model. In a multisectoral model, changes in sectoral absorption are typically accompanied by reductions of absorption in

some and increases in other sectors. Equation (19) shows that the sign of the change $dN = \sum dN_j$ in total labor absorption does not determine the sign of the change $dL = \sum dN_j/(1 + q_j)$ in total employment. If the absorption rises in high-wage sectors (which receive a low weight since for them q_j is rather high) and falls in low-wage sectors (which receive a high weight), efficiency-wage unemployment $N - L$ can rise even if minimum-wage unemployment $\bar{L} - N$ falls due to a rise in total absorption. Appendix D shows that changes in efficiency-wage unemployment can always dominate if sectoral absorptions do not move all in the same direction; it moreover illustrates this result for a special case.

Given the possibility that changes in efficiency-wage unemployment dominate changes in total employment, several conclusions follow immediately. (i) Even if the three assumptions listed above are correct, total employment may fall as a consequence of a green tax reform with revenue recycling. (ii) Assumptions 1 and 2 are not sufficient to ensure that, at least initially ($t = 0$), revenue recycling is always better in terms of employment than no revenue recycling. (iii) Assumptions 1 and 2 are not sufficient to ensure that revenue recycling is necessary for the existence of a double dividend. (iv) Assumption 1 cannot rule out that a green tax reform with revenue recycling leads to a double loss, i.e. a higher use of the environment and lower total employment.

4 Conclusion

To summarize: If a green tax reform favors sectors that motivate employees by high wage spans, a reduction in minimum-wage unemployment can be overcompensated by an increase in efficiency-wage unemployment. Even if (i) minimum wages explain most of the observed level of unemployment, (ii) labor and the environment are complements, and (iii) a green tax reform combined with a wage subsidy actually reduces minimum-wage unemployment, total employment may fall. If, moreover, the first dividend (protection of the environment) is missing, which cannot be excluded theoretically, the tax reform could even lead to a double loss instead of a double dividend.

Our analysis serves to show that a discussion of the possible effects of a green tax reform should more extensively focus on the sectoral structure of the economy since it is sectoral structure together with wage spans and wage differentials that

drives the results. Moreover, it is not sufficient to concentrate on just the main factor explaining unemployment.

The important role of sectoral structure for the level of unemployment has consequences for public-finance employment policies. We find that efficiency-wage unemployment should fall if employment in the low-wage sectors rises. Therefore, a policy of promoting employment in low-wage sectors (e.g., by cutting wage taxes only in low-wage sectors) has better chances of raising total employment. Our analysis rests on a labor-demand-based explanation of wage spans and wage differentials. It therefore supplements the traditional argument in favor of subsidizing low-wage jobs put forward in the literature on heterogeneous labor supply (cf. Sørensen, 1997, for an overview).

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A Stability

The comparative-static analysis of section 2 presupposes that a certain stability condition is fulfilled. The rate s with $B(s) = 0$ cannot be exactly known in advance and will therefore be reached, if at all, in a trial-and-error process where the subsidization is raised if $B(s) > 0$. A simple example of such a process is $\dot{s} = B(s)$. Stability means that a small surplus $B > 0$ does not lead to a cumulative process in which total subsidization swL and tax proceeds tE diverge further and further. Formally, local stability is ensured if $B'(s) < 0$ at $s = tE/wL$, which yields the following stability condition:

$$\frac{dE}{ds} \frac{s}{E} - \frac{dL}{ds} \frac{s}{L} < 1 \text{ at the point } s = tE/wL \quad (20)$$

Since $\bar{w} = (1 - s)w$, differentiating (7) w.r.t. s yields the following result:

$$A_1 \begin{pmatrix} \frac{dL}{ds} \\ \frac{dE}{ds} \end{pmatrix} = \begin{pmatrix} -w \\ 0 \end{pmatrix} \quad (21)$$

As before, our concavity assumption ensures $|A_1| > 0$. Solving for changes in employment and use of the environment, we find

$$(a) \quad \frac{dL}{ds} = -\frac{wy_{EE}}{|A_1|} \quad (b) \quad \frac{dE}{ds} = \frac{wy_{LE}}{|A_1|}. \quad (22)$$

Inserting into the stability condition (20) according to (22) and making use of $s = tE/wL$ yields the condition

$$|A_1| - \frac{t}{L^2} (Ey_{EE} + Ly_{LE}) > 0. \quad (23)$$

For an initial tax level of $t = 0$, stability always holds because $|A_1| > 0$.

B Exclusion of a Double Loss

The range of possible results from (10) is restricted if A_2 is negative definite. Negative definiteness of A_2 implies the same for A_2^{-1} ; hence, $\mathbf{x} \cdot A_2^{-1} \mathbf{x} < 0$ for all non-zero vectors \mathbf{x} if t is small enough. Choosing $\mathbf{x} = (-E, L)$, we find by straightforward computation that $\mathbf{x} \cdot A_2^{-1} \mathbf{x} < 0$ implies

$$\frac{Ey_{EE} + Ly_{LE} + t}{L} + \frac{Ly_{LL} + Ey_{LE} - tE/L}{E} < 0. \quad (24)$$

From eqs. (24) and (10), it follows that the percentage change in employment is higher than the percentage change in the use of the environment:

$$\frac{dL/dt}{L} > \frac{dE/dt}{E}. \quad (25)$$

Thus, a double-loss scenario where the use of the environment increases and employment is reduced is excluded.

Negative definiteness of A_2 means that both eigenvalues are real and negative. The eigenvalues are given by

$$\mu_{1/2} = \frac{\text{tr } A_2}{2} \pm \sqrt{\frac{(\text{tr } A_2)^2}{4} - |A_2|}, \quad (26)$$

where $\text{tr } A_2$ is the trace of A_2 , i.e. the sum of the diagonal elements. Both eigenvalues are real and negative iff the term under the square root is nonnegative.

We have

$$\frac{(\text{tr } A_2)^2}{4} - |A_2| = \frac{1}{4} \left(y_{LL} - \frac{tE}{L^2} - y_{EE} \right)^2 + y_{LE}^2 + \frac{ty_{LE}}{L}; \quad (27)$$

therefore, complementarity ($y_{LE} > 0$) or a small enough value of t are two sufficient but not necessary conditions for negative definiteness and, thus, for the impossibility of a double loss.

C Interpreting Labor Absorption

In section 3, we interpret $N_j \stackrel{\text{def}}{=} (1+q_j)L_j$ as the number of workers the representative firm would hire in a hypothetical situation (situation H) where there exists no incentive problem for the firm. In contrast with the actual situation (situation A) where workers' effort responds to the wage set by the firm, situation H is defined by the condition that workers' effort is fixed at $\bar{g}_j/(1+q_j)$. The net reference wage \bar{w} is equal in both situations.

Fixing effort at the level $\bar{g}_j/(1+q_j)$ means that in both situations a cost-minimizing firm spends the same sum on the same quantity of labor in efficiency units. This can be seen from a comparison of (12) and (15), which obviously are identical once definitions are taken into account. Thus, in situation A the firm buys $\bar{g}_j L_j$ efficiency units at price \bar{w}_j . In situation H, the firm would buy $\bar{g}_j N_j/(1+q_j) = \bar{g}_j L_j$ efficiency units at price \bar{w} . In both situations, wage expenditures are $\bar{w}_j L_j = \bar{w} N_j$.

To summarize: In a hypothetical situation without incentive problem and with a sectoral efficiency of labor fixed at $\bar{g}_j/(1+q_j)$, the firm will hire $N_j = (1+q_j)L_j$ workers at the net reference wage \bar{w} . In the actual situation, the incentive problem forces the firm to spend the same wage sum ($\bar{w}N_j$) on a smaller number of workers ($L_j = N_j/(1+q_j) < N_j$) in order to get the same amount of labor in efficiency units. From the perspective of the firm, both situations are completely equivalent; in both situations, demands for other factors and unit costs are identical.

D Relative Weight of the Two Components

In the general case, the following result holds. If absorption rises in some and falls in other sectors, we can renumber sectors such that $dN_j \geq 0$ for $j \geq k$ and $dN_j < 0$ for $j < k$. We then have $l_0 = \sum_{j \geq k} dN_j < dN < \sum_{j < k} dN_j = l_1$, where $l_0 < 0 < l_1$. As (19) shows, dL can take on any value in the open interval (l_0, l_1) , depending on the values of the q_j . Thus, no matter how small efficiency-wage unemployment $N - L$ is in comparison with minimum-wage unemployment $\bar{L} - N$, it is always possible (depending on the values of the q_j) that the change in efficiency-wage unemployment determines the change in total unemployment. The rest of this appendix illustrates this possibility for a special case where $dN = 0$.

We consider a small open economy producing two final products with world market prices p_1, p_2 . Production can be separated as follows. In a first stage, the economy produces quantities z_1, z_2 of two intermediate inputs with the help of labor (absorption) N and the environment E according to a technology with fixed and strictly positive input coefficients. Thus, we have

$$\begin{pmatrix} z_1 \\ z_2 \end{pmatrix} = \begin{pmatrix} b_{N1} & b_{E1} \\ b_{N2} & b_{E2} \end{pmatrix} \begin{pmatrix} N \\ E \end{pmatrix}, \quad (28)$$

where the matrix is the inverse of a matrix of nonnegative input coefficients:

$$\begin{pmatrix} b_{N1} & b_{E1} \\ b_{N2} & b_{E2} \end{pmatrix} = \frac{1}{a_{N1}a_{E2} - a_{E1}a_{N2}} \begin{pmatrix} a_{E2} & -a_{N2} \\ -a_{E1} & a_{N1} \end{pmatrix}. \quad (29)$$

Note that $b_{Nj}b_{Ej} < 0$, $j = 1, 2$. In a second stage, the intermediate inputs are each combined with other factors to produce quantities x_1, x_2 of the final outputs.

The fact that the other factors are in fixed supply leads to decreasing returns to scale in z_1 and z_2 , respectively. For simplicity, we suppress the other factors and assume a logarithmic production function on the second stage:

$$(a) \ x_1 = \ln z_1 \quad (b) \ x_2 = \ln z_2 \quad (30)$$

This simple two-stage technology allows us to immediately write down the GDP function (where again the flex-price factors in the background are not mentioned):

$$\bar{y}(p_1, p_2, N, E) = p_1 \ln(b_{N1}N + b_{E1}E) + p_2 \ln(b_{N2}N + b_{E2}E) \quad (31)$$

Obviously, this function fulfills all our requirements. Equilibrium is described by

$$\begin{aligned} (a) \quad \bar{y}_N &= \frac{p_1 b_{N1}}{b_{N1}N + b_{E1}E} + \frac{p_2 b_{N2}}{b_{N2}N + b_{E2}E} = \bar{w} \\ (b) \quad \bar{y}_E &= \frac{p_1 b_{E1}}{b_{N1}N + b_{E1}E} + \frac{p_2 b_{E2}}{b_{N2}N + b_{E2}E} = t. \end{aligned} \quad (32)$$

The second derivatives are

$$\begin{aligned} (a) \quad \bar{y}_{NN} &= -\frac{p_1 b_{N1}^2}{(b_{N1}N + b_{E1}E)^2} - \frac{p_2 b_{N2}^2}{(b_{N2}N + b_{E2}E)^2} < 0 \\ (b) \quad \bar{y}_{EE} &= -\frac{p_1 b_{E1}^2}{(b_{N1}N + b_{E1}E)^2} - \frac{p_2 b_{E2}^2}{(b_{N2}N + b_{E2}E)^2} < 0 \\ (c) \quad \bar{y}_{NE} &= -\frac{p_1 b_{N1} b_{E1}}{(b_{N1}N + b_{E1}E)^2} - \frac{p_2 b_{N2} b_{E2}}{(b_{N2}N + b_{E2}E)^2} > 0, \end{aligned} \quad (33)$$

where $\bar{y}_{NE} > 0$ results from $b_{Nj}b_{Ej} < 0$ and means that the technology implies complementarity between labor and the environment.

Comparative-static results are as in (10), where we of course use N instead of L and \bar{y} instead of y , as required by the model of section 3:

$$\begin{aligned} (a) \quad \frac{dN}{dt} &= -\frac{1}{|A_2|N} (E\bar{y}_{EE} + N\bar{y}_{NE} + t) \\ (b) \quad \frac{dE}{dt} &= \frac{1}{|A_2|N} (N\bar{y}_{NN} + E\bar{y}_{NE} - tE/N) \end{aligned} \quad (34)$$

Simple computations yield

$$\begin{aligned} (a) \quad E\bar{y}_{EE} + N\bar{y}_{NE} &= -\bar{y}_E \\ (b) \quad N\bar{y}_{NN} + E\bar{y}_{NE} &= -\bar{y}_N. \end{aligned} \quad (35)$$

Note that (35) and (32) together imply

$$|A_2| = |A_1| - \frac{t}{N^2} (E\bar{y}_{EE} + N\bar{y}_{NE}) = |A_1| + \frac{t^2}{N^2} > 0, \quad (36)$$

which means that the stability condition (23) is fulfilled.

Inserting into (34) according to (35) and using (32) and $\bar{w} = w - tE/N$ yields

$$\begin{aligned} (a) \quad \frac{dN}{dt} &= 0 \\ (b) \quad \frac{dE}{dt} &= \frac{-w}{|A_2|N} < 0. \end{aligned} \quad (37)$$

Let there be a given labor supply $\bar{L} > N$. The example illustrates a case where revenue recycling just suffices to stabilize minimum-wage unemployment $\bar{L} - N$. Whether there is a double dividend or not depends on efficiency-wage unemployment, no matter how small the efficiency-wage contribution to unemployment might be in absolute terms.

Efficiency-wage unemployment is given by $N - L$ where $L = N_1/(1 + q_1) + N_2/(1 + q_2)$. Note that nothing in our example so far depends on the values of the markups q_i . Therefore, any assumption on their magnitude is consistent with the model. We compute sectoral absorptions as

$$\begin{aligned} (a) \quad N_1 &= a_{N1}(b_{N1}N + b_{E1}E) \\ (b) \quad N_2 &= a_{N2}(b_{N2}N + b_{E2}E). \end{aligned} \quad (38)$$

Changes in sectoral absorptions are given by

$$\begin{aligned} (a) \quad \frac{dN_1}{dt} &= \frac{a_{N1}b_{E1}w}{|A_2|N} \\ (b) \quad \frac{dN_2}{dt} &= \frac{a_{N2}b_{E2}w}{|A_2|N}. \end{aligned} \quad (39)$$

Since $b_{E1}b_{E2} < 0$, changes have the opposite sign. If absorption in the low-wage sector (i.e., the sector with a lower markup) goes up, efficiency-wage unemployment and, consequently, total unemployment falls, and there is a double dividend. If absorption in the high-wage sector goes up, unemployment rises.