Journal of Public Economics 87 (2003) 1123–1136
JOURNAL OF PUBLIC ECONOMICS
www.elsevier.com/locate/econbase

The role of taxes as automatic destabilizers in New Keynesian economics

Henrik Jacobsen Kleven*, Claus Thustrup Kreiner

Institute of Economics, University of Copenhagen and EPRU[1], Studiestræde 6, DK-1455 Copenhagen K, Denmark

Received 11 January 2001; accepted 28 February 2001

Abstract

This paper analyses the effects of taxation in New Keynesian economics. The results show that taxes contribute to price and wage stickiness and, moreover, that the resulting fluctuations in welfare are magnified by the presence of taxes. These results are at odds with the old Keynesian idea of automatic stabilizers.

Keywords: New Keynesian economics; Taxation; Automatic stabilizers

JEL classification: E32; E62

1. Introduction

How do taxes influence business cycles? An old insight due to traditional Keynesian theory is that taxes, which depend positively on income, serve as automatic stabilizers by reducing effective demand in upturns and increasing effective demand in downturns. The result is intuitively appealing but, as argued forcefully by Lucas and his collaborators, the whole framework builds on a

*Corresponding author. Tel.: +45-35-324-413; fax: +45-35-324-444.
E-mail address: henrik.kleven@econ.ku.dk (H.J. Kleven).
[1]The activities of EPRU (Economic Policy Research Unit) are financed through a grant from The Danish National Research Foundation.

0047-2727/01/$ – see front matter
PII: S0047-2727(01)00139-6

theoretically unfounded assumption of rigid prices. As a response to this critique, New Keynesian theory has shown that price rigidity may arise because of small price adjustment costs and empirical research has shown that these so-called menu costs are within realistic limits (Levy et al., 1997; Dutta et al., 1999). Consequently, the theory resurrects many of the traditional Keynesian results, for example that nominal demand disturbances may give rise to inefficiently large fluctuations in output (see, e.g., Romer, 1993). In this paper we ask if the old Keynesian idea of automatic stabilizers also carries over to New Keynesian theory.

To our knowledge, only one previous paper, Agell and Dillén (1994), has analyzed this issue. They show that the inefficiencies present in New Keynesian models can be remedied by Pigouvian taxes and subsidies, and conclude moreover that

> "The derived policy rules are kindred in spirit to standard Keynesian policy prescriptions: progressive taxes may serve a useful purpose in combating wasteful economic fluctuations." (Agell and Dillén, 1994, abstract, p. 111).

However, in their normative analysis the optimal marginal and average income tax rates are negative, so that income is effectively subsidized, and these subsidies are then financed in a lump sum fashion. Consequently, progressive taxation in the Agell and Dillén terminology really means subsidizing income at a decreasing marginal rate.[2] Accordingly, their results do not give any indication on how real-world tax systems affect the business cycle. This paper aims at doing so by undertaking a positive analysis of the impact of taxes in New Keynesian theory. To broaden the scope we move the analysis from a simple farmer economy to a more realistic setting with both firms and workers and, in addition, we examine the impact of different types of taxes such as profit taxes, sales taxes, payroll taxes, wage income taxes, and value-added taxes.

In general, our results are opposite to those of Agell and Dillén (1994): taxes contribute to price and wage stickiness and, furthermore, the welfare consequences of nominal disturbances are magnified by the presence of taxes. The impact of the various kinds of taxes differs, however. Profit taxes, sales taxes, and value-added taxes contribute to price rigidity, while wage income taxes and value-added taxes contribute to wage rigidity. Payroll taxes are neutral for the occurrence of price

[2] In order to see this, note from their Eqs. (12) and (16) that the two optimal tax parameters are characterized by $\tau_0 > 1$ and $\tau_1 < 1$. As real income is always below one in equilibrium, this implies from Eq. (7) that each individual receives a subsidy as a function of real income. In fact, it is quite misleading that the authors call τ_0 and τ_1 tax parameters and T lump-sum transfers from the government, as the τ parameters determine the shape of a subsidy function while T in equilibrium is a lump-sum tax.

and wage rigidity but, like the other types of taxes, they contribute to an enlargement of the welfare fluctuations.

A corollary on these conclusions is that the traditional equivalence results of tax theory do not, in general, carry over to the New Keynesian paradigm. According to the conventional theory of taxation, whether a tax is levied on the demand side or the supply side of a market has no consequences for the equilibrium resource allocation. For example, a wage tax on households is equivalent to a payroll tax on firms and, likewise, the effect of a sales tax is identical to the effects of a general income tax or a value-added tax. By contrast, we show that these taxes are no longer equivalent as they have different implications for the degree of nominal rigidity and, accordingly, for macroeconomic fluctuations.

The next section sets up a model of imperfect competition in goods and labor markets. Apart from the introduction of a tax system, the model is essentially similar to the standard frameworks of Blanchard and Kiyotaki (1987) and Ball and Romer (1989, 1990, 1991). The third and fourth sections derive our main results while the fifth section concludes.

2. The model

The economy is populated by a continuum of households indexed by i and distributed uniformly on [0,1]. There is a continuum of goods indexed by $j \in [0,1]$. The utility level of household i is given by

$$u_i = \left(\int_{j=0}^{1} c_{ij}^{1-\mu} \, \mathrm{d}j \right)^{1/(1-\mu)} - \frac{\gamma}{\gamma+1} l_i^{(\gamma+1)/\gamma}, \; 0 < \mu < 1, \, \gamma > 0, \tag{1}$$

where c_{ij} is consumption of good j, l_i is the number of working hours, μ is the reciprocal of the elasticity of substitution between any two goods (or, equivalently, the Lerner index), and γ is the reciprocal of the elasticity of marginal disutility of work, which, in this formulation, corresponds to the labor supply elasticity.

The budget constraint of household i is given by

$$\int_{j=0}^{1} p_j c_{ij} \, \mathrm{d}j \le w_i l_i - T_{\mathrm{w}}(w_i l_i) + \int_{j=0}^{1} \pi_{ij} \, \mathrm{d}j + S_i \equiv I_i, \tag{2}$$

where p_j denotes the price of good j, w_i denotes the wage rate, $T_{\mathrm{w}}(\cdot)$ is a differentiable and increasing wage tax function, π_{ij} is lump-sum dividends net of tax obtained on shares in firm j, and S_i are lump-sum transfers which are adjusted to balance the government budget.[3]

[3] Rather than using lump-sum transfers to balance the budget, we could obtain similar results by including government purchases.

The type of labor supplied by any given worker is imperfectly substitutable for the labor supply of other workers, leaving each worker with some monopoly power in the labor market. Accordingly, household i maximizes (1) with respect to c_{ij}, l_i, and w_i subject to Eq. (2) and the downward sloping labor demand schedule of firms.

To analyze the effects of nominal disturbances, we introduce money into the model. Following Ball and Romer (1989, 1990, 1991), we assume that some transactions technology, for example a cash-in-advance constraint, determines the relation between aggregate spending and money balances:

$$\int_{i=0}^{1} I_i \,\mathrm{d}i = m. \tag{3}$$

On the production side of the economy, we have a continuum of firms indexed by j and distributed uniformly on [0,1]. The technology of firm j is described by the production function

$$y_j = \frac{1}{\alpha}\left(\int_{i=0}^{1} (l_{ij})^{1-\rho}\,\mathrm{d}i\right)^{\alpha/(1-\rho)}, \quad 0<\alpha<1,\, 0<\rho<1, \tag{4}$$

where l_{ij} is input of labor of type i, ρ is the reciprocal of the elasticity of substitution between any two types of labor (i.e. the Lerner index), and α determines the homogeneity of the production function. Profits of firm j are given by

$$\pi_j = p_j y_j - \int_{i=0}^{1} w_i l_{ij}\,\mathrm{d}i - T_{\mathrm{p}}\left(p_j y_j - \int_{i=0}^{1} w_i l_{ij}\,\mathrm{d}i\right) - T_{\mathrm{pr}}\left(\int_{i=0}^{1} w_i l_{ij}\,\mathrm{d}i\right), \tag{5}$$

where $T_{\mathrm{p}}(\cdot)$ and $T_{\mathrm{pr}}(\cdot)$ are differentiable and increasing functions, denoting profit and payroll taxes, respectively. Each firm is selling a product which is an imperfect substitute for the output of other firms, implying that each firm has some monopoly power in the goods market. Thus, firm j maximizes (5) with respect to p_j, y_j, and l_{ij} subject to Eq. (4) and the goods demand function of households.

From the first-order conditions of the wage and price setters as well as the symmetry of the model, implying that $p_j = p\ \forall j$ and $w_i = w\ \forall i$, we obtain the following equation for aggregate production (see Appendix A):

$$y \equiv \int_{j=0}^{1} y_j\,\mathrm{d}j = \frac{1}{\alpha}\left(\frac{(1-t_{\mathrm{w}})(1-t_{\mathrm{p}})}{1-t_{\mathrm{p}}+t_{\mathrm{pr}}}(1-\mu)(1-\rho)\right)^{\gamma\alpha/[1+\gamma(1-\alpha)]} \leq \frac{1}{\alpha}, \tag{6}$$

where $t_{\mathrm{w}} \equiv T'_{\mathrm{w}}(\cdot)$, $t_{\mathrm{p}} \equiv T'_{\mathrm{p}}(\cdot)$, and $t_{\mathrm{pr}} \equiv T'_{\mathrm{pr}}(\cdot)$ denote marginal tax rates. The first best level of production $1/\alpha$ is obtained as the Lerner indices, μ and ρ, and the tax rates go to zero. As in standard New Keynesian models, aggregate production is below its first best level due to imperfect competition in goods and labor markets. In the present model, the existence of distortionary taxation also hampers the incentives to participate in economic activity, thereby moving output further below the first best level.

Although prices are fully flexible, the model does not feature money neutrality unless we impose additional constraints on the tax system. This is because tax payments depend on nominal income. If, for instance, marginal tax rates are increasing functions of nominal tax bases, positive monetary disturbances will move agents up in higher tax brackets, thereby reducing economic incentives and aggregate output. In the following section we avoid such effects by assuming that the tax system is linear in the neighborhood of the initial equilibrium, i.e. t_w, t_p, and t_{pr} are treated as constants. While this assumption excludes the possibility of continuously increasing marginal tax rates, it does not exclude tax progressivity as marginal tax rates may very well be higher than average tax rates. We will return to the implications of a general non-linear tax system in Section 4 but, as we shall see, this extension will not change the qualitative conclusions of the analysis.

3. Taxation, nominal rigidities and fluctuations

Now, we introduce lump-sum costs associated with the adjustment of prices and wages. In the presence of such adjustment costs, so-called menu costs, the equilibrium may involve rigidity of prices and wages, implying that changes in nominal demand give rise to fluctuations in real variables. The key insight of New Keynesian economics is that *small* menu costs are sufficient to generate monetary non-neutrality while the resulting fluctuations involve *large* effects on welfare. In this section we show that taxation mitigates the minimum effective menu costs even further and, at the same time, magnifies the welfare consequences of macroeconomic fluctuations.

First, we derive the levels of menu costs of firms and workers that are sufficient to make price and wage rigidity a Nash equilibrium. For the firms to keep prices fixed, menu costs must be greater than or equal to the loss in profits resulting from non-adjustment of prices. Following the standard approach, we approximate the profit loss by making a second-order Taylor expansion on the profit function around the initial equilibrium. This gives (see Appendix B)

$$L_f = (1 - t_p)\frac{(1-\alpha)^2(1-\mu)}{2\alpha(1+\alpha\mu-\alpha)}\left(\frac{dm}{m}\right)^2, \tag{7}$$

where the loss is measured in proportion to firm revenue.

Analogously, workers choose to hold wages constant if menu costs are greater than or equal to the loss in utility resulting from non-adjustment. By making a second-order Taylor approximation on the indirect utility function around the initial equilibrium, it can be shown that the utility loss of non-adjustment in proportion to the total wage bill equals (see Appendix C)

$$L_{\mathrm{w}} = (1 - t_{\mathrm{w}})\frac{1-\rho}{2\gamma\alpha^{2}(1+\rho\gamma)}\left(\frac{dm}{m}\right)^{2}. \tag{8}$$

By simple inspection of Eqs. (7) and (8), we may state the following proposition.

Proposition 1. (i) *The menu costs required for price rigidity are decreasing in the profit tax*, t_p, *and independent of the wage tax*, t_w, *and the payroll tax*, t_{pr}. (ii) *The menu costs required for wage rigidity are decreasing in the wage income tax*, t_w, *and independent of the profit tax*, t_p, *and the payroll tax*, t_{pr}.

The implication of Proposition 1 is that the presence of taxation, for a given level of menu costs, increases the range of nominal demand shocks leading to fluctuations in real variables. In other words, wage taxation increases the degree of wage rigidity while taxation of profits increases the degree of price rigidity.[4]

Our formulation of the tax system allows for the study of other types of taxes such as a value-added tax, t_{v}, or a tax on firm revenues (sales tax), t_{s}. A value-added tax corresponds to a general income tax, i.e. $t_{\mathrm{w}} = t_{\mathrm{p}} = t_{v}$ and $t_{\mathrm{pr}} = 0$, which implies more rigidity in both prices and wages. A sales tax corresponds to a uniform rate on profits and payrolls, i.e. $t_{\mathrm{p}} = t_{\mathrm{pr}} = t_{\mathrm{s}}$, and, according to Proposition 1, such a tax system increases the degree of price rigidity while leaving wage rigidity unaffected.

Interestingly, some of the basic neutrality and equivalence results from the theory of taxation break down once we account for the presence of nominal rigidities. First, the result that a tax on pure profits is neutral for the resource allocation no longer holds. By increasing the degree of price rigidity, the imposition of profit taxes has real implications for the economy. Second, in a frictionless economy it is irrelevant if a tax is levied on the supply or the demand side of the market in terms of the effects on equilibrium resource allocation. For example, a wage tax paid by workers is equivalent to a payroll tax levied on firms and, likewise, there is no difference between a sales tax and a general income tax or a value-added tax. By contrast, in the presence of nominal imperfections it becomes important who pays the tax, firms or workers, as these taxes have different implications for the degree of nominal rigidity. The idea that it matters who pays the tax when prices are sticky was previously pointed out and tested by

[4] By focusing on the incentives for adjustment as a fraction of firm revenue and wage income, respectively, we neglect the impact of taxes on the levels of revenue and the wage bill. As distortionary taxation involves a reduction of these magnitudes, this effect reinforces the conclusion of Proposition 1.

Poterba et al. (1986). Looking at data for the UK and the US, they found strong empirical support for this Keynesian prediction.[5]

It should be noted that the above analysis implicitly rests on the assumption that the costs of price and wage changes are not affected by the introduction of taxes or, more precisely, that menu costs are not *fully* deductible in taxable income. The appropriateness of this assumption depends, of course, on the exact nature of menu costs. In a narrow literal interpretation, menu costs represent the physical costs of changing price tags, printing and distributing new catalogs to customers, etc., in which case they are likely to reduce taxable income. Taking a broader view of menu costs to include the costs of decision and elements of bounded rationality it seems natural to assume that they do not reduce taxable income, at least not to the full extent. Note, finally, that all the qualitative conclusions continue to hold even if menu costs are *partly* deductible in the tax bases.

If menu costs are sufficiently large, a change in nominal demand will affect production, employment, and welfare. The effect on welfare of a change in the money stock is derived by making a second-order Taylor approximation on (1) around the initial equilibrium. As shown in Appendix D, the welfare effect in proportion to aggregate income amounts to

$$W = \frac{dm}{m} - \frac{(1-t_{\mathrm{w}})(1-t_{\mathrm{p}})}{1-t_{\mathrm{p}}+t_{\mathrm{pr}}}(1-\mu)(1-\rho)\left[\frac{dm}{m} + \frac{\gamma+1-\alpha\gamma}{2\alpha\gamma}\left(\frac{dm}{m}\right)^2\right]. \tag{9}$$

Consider, for example, a positive demand shock. Then the first component on the right-hand side is the increase in welfare resulting from more consumption while the second component constitutes the loss in welfare due to an increase in the number of working hours. As production is below its first best level, a positive demand shock boosts total welfare, implying that the first component will always be numerically larger than the second component. Therefore, we can state the following proposition on the welfare consequences of nominal disturbances.

Proposition 2. *Fluctuations in welfare are increasing in the wage income tax, t_w, the payroll tax, t_{pr}, and the profit tax, t_p.*

The intuition behind Proposition 2 is easy to grasp. The presence of distortionary taxation moves the equilibrium level of activity further below its first best level. Because of the concavity of the utility function, a reduction in the

[5] There is a subtle difference between Poterba et al. (1986) and the present paper. The former contribution points out that a revenue-neutral shift between indirect and direct taxation will affect output *given that the nominal wage rate is exogenously fixed*. By contrast, we point out that a shift between indirect and direct taxation has real implications by affecting the degree of price and wage rigidity.

equilibrium level of activity increases the slope of utility. Accordingly, the introduction of a tax system implies that fluctuations in consumption and employment take place where the utility function is steeper than it would otherwise have been.

Note also that, in the absence of payroll taxes, the effect on welfare is independent of profit taxes. This is because taxes on pure profits, in this case, do not affect the equilibrium level of activity. Finally, a corollary on the above proposition is that value-added taxes (i.e. $t_w = t_p = t_v$ and $t_{pr} = 0$) and sales taxes (i.e. $t_p = t_{pr} = t_s$) also magnify the fluctuations in welfare, which is seen by inserting the respective definitions into Eq. (9).

4. Implications of a general non-linear tax system

The previous section assumed that the tax system is linear in the neighborhood of the initial equilibrium, so that marginal rates are unaffected by the presence of nominal disturbances. One may argue, however, that real world tax systems are piecewise linear, implying that some people do experience changes in marginal tax rates during economic fluctuations. Let us therefore turn to the case of a general non-linear tax system. Note first that this extension does not change the initial equilibrium, cf. Eq. (6), which depends only on the level of marginal tax rates. Indeed, in the derivation of the initial equilibrium we imposed no restrictions whatsoever on the properties of tax functions (besides that of differentiability). Given that the initial equilibrium is unaffected, as is the output response to a monetary shock under price rigidity, so is the proposition on the welfare effects of nominal disturbances.

Since non-linearities in profit and payroll taxes are of minor importance for realistic tax systems, we will concentrate on the effects of rising marginal wage income tax rates. This will only affect the wage setters' incentives for adjustment, which now become (see Appendix C)

$$\tilde{L}_w = L_w\left(1 + \frac{\gamma\tau t_w}{1-t_w}\right)^2 \Big/ \left(1 + \frac{1-\rho}{1+\gamma\rho}\frac{\gamma\tau t_w}{1-t_w}\right), \tag{10}$$

where L_w is the menu cost requirement under linearity, given in Eq. (8), and $\tau \equiv t_w'(\cdot)w_i l_i / t_w$ is the elasticity of the marginal tax rate with respect to before-tax wage income. By recalling that the Lerner index ρ lies between 0 and 1 and that the labor supply elasticity γ is positive, it becomes clear that the presence of increasing rates, i.e. $\tau > 0$, ceteris paribus increases the incentive for wage adjustment. The intuition for this result is as follows. Following a positive monetary disturbance, if workers respond by keeping wages constant and accommodating the higher labor demand, nominal income and thus the marginal tax rate go up. Alternatively, workers may choose to increase the wage rate, which, given that labor demand is elastic, implies a lower nominal income and a lower marginal tax rate compared to the non-adjustment strategy. Therefore, rising marginal tax rates favor adjustment.

Now we have two contrasting effects of taxation on the degree of nominal rigidity; the effect analyzed in Section 3 versus the effect of non-linearity mentioned above. It turns out though that, for any reasonable constellation of parameters, the former effect strongly dominates the latter one, implying that taxation is still unambiguously destabilizing. For example, a linear tax system with $t_w = 0.4$ reduces the incentive for adjustment by 40%. The effect of a non-linear tax system also depends on the marginal tax rate elasticity τ as well as on the parameters ρ and γ. According to Auerbach and Feenberg (2000), the marginal tax rate response of a 1% increase in income is 0.08 percentage points for the average US household, corresponding to a τ value of 0.2. Setting τ, and also ρ and γ, equal to 0.2, we find that the overall effect of taxation is to reduce the required menu costs by 38%, i.e. essentially the same order of magnitude as the linear case. With a τ value equal to 1, implying a marginal tax rate response which is five times higher than that of the current US income tax scheme, the incentive for adjustment is reduced by 30%, still clearly destabilizing.

5. Conclusion

The linkage between taxation and business cycles is more complex than previously thought. In a world of imperfect competition and nominal frictions, taxation will affect the price and wage setting decisions of firms and workers. In the widely used New Keynesian framework, we have shown that taxes act as automatic destabilizers. Firstly, taxes destabilize by increasing the degree of wage and price rigidity and, secondly, the presence of taxation magnifies the welfare consequences of nominal disturbances. These results are in sharp contrast to Agell and Dillén (1994), who claim that progressive taxes will make firms more prone to price adjustments, implying less volatility in output and welfare.

Our findings are also at odds with the old Keynesian idea that taxes serve as automatic stabilizers. Note, however, one important difference between our model and the traditional Keynesian fixed price models. We assume, like Agell and Dillén, that the government keeps a balanced budget, so that the traditional effect of taxes on effective demand is neutralized. Accordingly, our sole focus is on the supply side effect of taxation, whereas the traditional Keynesian approach concentrates entirely on the demand side effect. In reality, the effect of taxation on fluctuations will be a mixture of the supply side effects, stressed by the present paper, and the conventional demand side effect.

Acknowledgements

We wish to thank Peter Birch Sørensen, a referee, and Editor James Poterba for valuable comments and suggestions for improvements.

Appendix A. Derivation of Eq. (6)

We start by deriving the aggregate demand for good j. By maximizing (1) subject to (2) and aggregating over the households, we obtain

$$c_j = \left(\frac{p_j}{p}\right)^{-1/\mu} \frac{m}{p}, \text{ where } p \equiv \left(\int_{j=0}^{1} p_j^{(\mu-1)/\mu} \, \mathrm{d}j \right)^{\mu/(\mu-1)}. \tag{A.1}$$

Next, we find the demand for workers of type i by solving the cost minimization problem of firm j. This gives

$$l_{ij} = \left(\frac{w_i}{w}\right)^{-1/\rho} (\alpha y_j)^{1/\alpha}, \text{ where } w \equiv \left(\int_{i=0}^{1} w_i^{(\rho-1)/\rho} \, \mathrm{d}i \right)^{\rho/(\rho-1)}. \tag{A.2}$$

Then we insert Eqs. (4), (A.1), and (A.2) so as to obtain the indirect profit function of firm j:

$$\begin{aligned} \pi(p_j, m) = \; & p_j \left(\frac{p_j}{p}\right)^{-1/\mu} \frac{m}{p} - w \left(\frac{p_j}{p}\right)^{-1/(\alpha\mu)} \left(\alpha \frac{m}{p}\right)^{1/\alpha} \\ & - T_{\mathrm{p}} \left(p_j \left(\frac{p_j}{p}\right)^{-1/\mu} \frac{m}{p} - w \left(\frac{p_j}{p}\right)^{-1/(\alpha\mu)} \left(\alpha \frac{m}{p}\right)^{1/\alpha} \right) \\ & - T_{\mathrm{pr}} \left(w \left(\frac{p_j}{p}\right)^{-1/(\alpha\mu)} \left(\alpha \frac{m}{p}\right)^{1/\alpha} \right). \end{aligned} \tag{A.3}$$

Maximizing the above equation with respect to p_j gives

$$\frac{p_j}{p} = \left[\frac{1 - t_{\mathrm{p}} + t_{\mathrm{pr}}}{1 - t_{\mathrm{p}}} \frac{1}{1-\mu} \frac{w}{p} \left(\alpha \frac{m}{p}\right)^{(1/\alpha)-1} \right]^{\mu\alpha/(\mu\alpha+1-\alpha)}. \tag{A.4}$$

The utility of household i can be expressed in the following way:

$$u_i = \frac{w_i l_i}{p} - \frac{T_{\mathrm{w}}(w_i l_i)}{p} + \int_{j=0}^{1} \frac{\pi_{ij}}{p} \, \mathrm{d}j + \frac{S_i}{p} - \frac{\gamma}{\gamma+1} l_i^{(\gamma+1)/\gamma}. \tag{A.5}$$

The aggregate demand for the labor of worker i is derived from Eq. (A.2) and inserted into the above equation so as to obtain the indirect utility function:

$$v(w_i,m) = \frac{w_i}{p}\left(\frac{w_i}{w}\right)^{-1/\rho}\left(\alpha\frac{m}{p}\right)^{1/\alpha} - \frac{1}{p}T_{\mathrm{w}}\left(w_i\left(\frac{w_i}{w}\right)^{-1/\rho}\left(\alpha\frac{m}{p}\right)^{1/\alpha}\right)$$
$$+ \int_{j=0}^{1} \frac{\pi_{ij}}{p}\,\mathrm{d}j + \frac{S_i}{p} - \frac{\gamma}{\gamma+1}\left(\left(\frac{w_i}{w}\right)^{-1/\rho}\left(\alpha\frac{m}{p}\right)^{1/\alpha}\right)^{(\gamma+1)/\gamma}. \quad \text{(A.6)}$$

Taking the derivative with respect to w_i, we obtain

$$\frac{w_i}{w} = \left((1-t_{\mathrm{w}})(1-\rho)\frac{w}{p}\right)^{-\rho\gamma/(1+\rho\gamma)}\left(\alpha\frac{m}{p}\right)^{\rho/[\alpha(1+\rho\gamma)]}. \quad \text{(A.7)}$$

A symmetric equilibrium satisfies $w_i = w \ \forall i$ and $p_j = p \ \forall j$. Using this and Eqs. (A.4) and (A.7), we obtain

$$y = \frac{m}{p} = \frac{1}{\alpha}\left(\frac{(1-t_{\mathrm{p}})(1-t_{\mathrm{w}})}{1-t_{\mathrm{p}}+t_{\mathrm{pr}}}(1-\mu)(1-\rho)\right)^{\alpha\gamma/[1+\gamma(1-\alpha)]}.$$

Appendix B. Derivation of Eq. (7)

The profit loss of non-adjustment is derived by making a second-order Taylor expansion on (A.3) around the initial equilibrium, assuming that other firms do not change their prices and that workers keep wages fixed.

If firm j chooses not to adjust its price, profits equal

$$\pi^{\mathrm{N}} \simeq \pi^0 + \pi_2 dm + \tfrac{1}{2}\pi_{22}(dm)^2,$$

where π^0 is profits in the initial equilibrium and π_2 and π_{22} are derivatives of (A.3) evaluated in the initial equilibrium. If the firm instead chooses to adjust its price, profits equal

$$\pi^{\mathrm{A}} \simeq \pi^0 + \pi_1 dp_j + \pi_2 dm + \tfrac{1}{2}\pi_{11}(dp_j)^2 + \tfrac{1}{2}\pi_{22}(dm)^2 + \pi_{12}dp_j dm.$$

The loss of non-adjustment is found by subtracting π^{N} from π^{A} and using the envelope theorem, i.e. $\pi_1 = 0$:

$$d\pi = \pi^{\mathrm{A}} - \pi^{\mathrm{N}} \simeq \pi_{12}dm\,dp_j + \tfrac{1}{2}\pi_{11}(dp_j)^2. \quad \text{(B.1)}$$

Differentiating (A.3) and using the fact that $\pi_1 = 0$ and $p_j = p \ \forall j$ in the initial equilibrium, we obtain

$$\pi_{11} = (1-t_{\mathrm{p}})\frac{1+\alpha\mu-\alpha}{\alpha\mu}\left(1-\frac{1}{\mu}\right)\frac{m}{p^2},$$

$$\pi_{12} = (1-t_{\mathrm{p}})\left(1-\frac{1}{\alpha}\right)\left(1-\frac{1}{\mu}\right)\frac{1}{p}.$$

From Eq. (A.4), we obtain

$$\frac{dp_j}{p} = \frac{dp_j}{p_j} = \frac{\mu\alpha}{\mu\alpha + 1 - \alpha}\left(\frac{1}{\alpha} - 1\right)\frac{dm}{m} = \mu\frac{1-\alpha}{1+\alpha\mu-\alpha}\frac{dm}{m}.$$

By insertion of the three above equations into (B.1), we obtain

$$d\pi \simeq (1-t_{\mathrm{p}})\frac{(1-\alpha)^2(1-\mu)}{2\alpha(1+\alpha\mu-\alpha)}m\left(\frac{dm}{m}\right)^2.$$

Finally, by measuring the loss relative to firm revenue, $p_j y_j = m$, we obtain Eq. (7).

Appendix C. Derivation of Eqs. (8) and (10)

Reasoning analogous to the derivation of (B.1) implies that the utility loss from not adjusting the wage, w_i, may be approximated by

$$dv \simeq v_{12} dmdw_i + \tfrac{1}{2} v_{11}(dw_i)^2, \tag{C.1}$$

where v_{12} and v_{11} are derivatives of Eq. (A.6) evaluated in the initial equilibrium. Differentiating (A.6) and using the fact that $v_1 = 0$ and $w_i = w$ $\forall i$ in the initial equilibrium, we obtain

$$v_{11} = \left(1-\frac{1}{\rho}\right)\left[(1-t_{\mathrm{w}})\frac{1+\gamma\rho}{\gamma\rho} - \tau t_{\mathrm{w}}\left(1-\frac{1}{\rho}\right)\right]\frac{wl}{p}\frac{1}{w^2},$$

$$v_{12} = -\frac{1}{\alpha}\left(1-\frac{1}{\rho}\right)\left[(1-t_{\mathrm{w}})\frac{1}{\gamma} + \tau t_{\mathrm{w}}\right]\frac{wl}{p}\frac{1}{mw},$$

where $\tau \equiv t'_{\mathrm{w}}(\cdot)w_i l_i / t_{\mathrm{w}}$ is the elasticity of the marginal tax rate with respect to before-tax wage income. This is equal to zero in the derivation of Eq. (8) due to the assumption that the tax system is linear in the neighborhood of the initial equilibrium.

From Eq. (A.7), we have

$$\frac{dw_i}{w} = \frac{dw_i}{w_i} = \frac{1}{\alpha}\frac{\rho/(1+\rho\gamma) + pyrt_{\mathrm{w}}/(1+\rho\gamma)[(1-t_{\mathrm{w}})]}{1-(1-1/p)pyrt_{\mathrm{w}}/[(1+py)(1-t_{\mathrm{w}})]}\frac{dm}{m}.$$

By insertion of the three above equations into (C.1), we obtain

$$\begin{aligned} dv \simeq \quad & (1-t_{\mathrm{w}})\frac{1-\rho}{2\gamma\alpha^2(1+\rho\gamma)} \\ & \times \frac{[1+\gamma\tau t_{\mathrm{w}}/(1-t_{\mathrm{w}})]^2}{1+1-yrt_{\mathrm{w}}[(1+\gamma\rho)(1-t_{\mathrm{w}})]}\frac{wl}{p}\left(\frac{dm}{m}\right)^2. \end{aligned}$$

By measuring the loss in proportion to real wage income, wl/p, we obtain

$$\frac{dv}{wl/p} \simeq \quad \tilde{L}_{\mathrm{w}} \equiv (1-t_{\mathrm{w}})\frac{1-\rho}{2\gamma\alpha^2(1+\rho\gamma)} \times \frac{[1+\gamma\tau t_{\mathrm{w}}/(1-t_{\mathrm{w}})]^2}{1+(1-\rho)yrt_{\mathrm{w}}/[(1+\gamma\rho)(1-t_{\mathrm{w}})]}\left(\frac{dm}{m}\right)^2,$$

which is Eq. (10). By setting τ equal to zero, we obtain Eq. (8).

Appendix D. Derivation of Eq. (9)

In equilibrium, the aggregate utility of households may be written in the following manner:

$$u \equiv \int_{i=0}^{1} u_i \,\mathrm{d}i = \frac{m}{p} - \frac{\gamma}{\gamma+1} l^{(\gamma+1)/\gamma} = \frac{m}{p} - \frac{\gamma}{\gamma+1}\left(\alpha\frac{m}{p}\right)^{(\gamma+1)/(\alpha\gamma)},$$

where the last equality follows from the production function (4) and the fact that $l_{ij} = l\ \forall i,j$ and $y_j = y = m/p\ \forall j$ in equilibrium. A second-order Taylor expansion around the initial equilibrium yields

$$du \simeq \quad \frac{dm}{p} - \left(\alpha\frac{m}{p}\right)^{(\gamma+1)/(\alpha\gamma)-1}\frac{1}{p}dm - \frac{1}{2}\left(\frac{\gamma+1}{\alpha\gamma}-1\right)\alpha\left(\alpha\frac{m}{p}\right)^{(\gamma+1)/(\alpha\gamma)-2}\left(\frac{1}{p}\right)^2(dm)^2,$$

or, equivalently,

$$du \simeq \quad \frac{dm}{m}\frac{m}{p} - \frac{1}{\alpha}\left(\alpha\frac{m}{p}\right)^{(\gamma+1)/(\alpha\gamma)}\frac{dm}{m} - \frac{1}{2}\left(\frac{\gamma+1}{\alpha\gamma}-1\right)\frac{1}{\alpha}\left(\alpha\frac{m}{p}\right)^{(\gamma+1)/(\alpha\gamma)}\left(\frac{dm}{m}\right)^2.$$

By insertion of $m/p = y$ and (6) into the above equation and measuring the change in welfare in proportion to aggregate income, we obtain Eq. (9).

References

Agell, J., Dillén, M., 1994. Macroeconomic externalities. Are Pigouvian taxes the answer? Journal of Public Economics 53, 111–126.

Auerbach, A.J., Feenberg, D., 2000. The significance of federal taxes as automatic stabilizers. Journal of Economic Perspectives 14 (3), 37–56.

Ball, L., Romer, D., 1989. Are prices too sticky? Quarterly Journal of Economics 104, 507–524.

Ball, L., Romer, D., 1990. Real rigidities and the nonneutrality of money. Review of Economic Studies 57, 183–203.

Ball, L., Romer, D., 1991. Sticky prices as coordination failure. American Economic Review 81 (3), 539–552.

Blanchard, O.J., Kiyotaki, N., 1987. Monopolistic competition and the effects of aggregate demand. American Economic Review 77, 647–666.

Dutta, S., Bergen, M., Levy, D., Venable, R., 1999. Menu costs, posted prices, and multiproduct retailers. Journal of Money, Credit, and Banking 31 (4), 683–703.

Levy, D., Bergen, M., Dutta, S., Venable, R., 1997. On the magnitude of menu costs: direct evidence from large U.S. supermarket chains. Quarterly Journal of Economics 102 (3), 791–825.

Poterba, J.M., Rotemberg, J.J., Summers, L.H., 1986. A tax-based test for nominal rigidities. American Economic Review 76 (4), 659–675.

Romer, D., 1993. The New Keynesian synthesis. Journal of Economic Perspectives 7 (1), 5–22.