European Commission

ISSN 1725-3187

EUROPEAN ECONOMY

Economic Papers 503 | September 2013

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Economic and Financial Affairs

European Commission
Directorate-General for Economic and Financial Affairs
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KC-AI-13-503-EN-N
ISBN 978-92-79-32330-0
doi: 10.2765/54597

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Do corporate taxes distort capital allocation? Cross-country evidence from industry-level data

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Abstract

The paper analyses the effect of corporate taxes on new investment in different types of capital assets in the manufacturing industries of 11 advanced economies over the period 1991-2007. The magnitude of the asset substitution elasticities points to a significant inter-asset distortionary effect induced by differences in the tax-adjusted user cost of capital. Overall, differential taxation leads on average to under-investment in ICT capital and to over-investment in other machinery and equipment compared to a counterfactual benchmark where marginal tax rates are equalized across assets. Once cross-country heterogeneity in corporate taxation is accounted for, the results are more mixed, in terms of both the size and the direction of the distortions. On average, 4 percent of the aggregate capital stock appears misallocated.

Keywords: user cost of capital, investment, corporate taxation

JEL Classification: E22, H25, H32

This paper was started in the context of a joint project with Gaetan Nicodeme, whose help with the tax data is gratefully acknowledged. The views expressed are solely of the author and do not necessarily reflect those of the European Commission. E-mail: Serena.fatica@ec.europa.eu.

1. Introduction

Tax incentives to stimulate investment can distort the allocation of capital in multiple ways. While the corporate income tax rate applies uniformly to all investments, depreciation allowances generally vary across capital asset categories. Different types and durations for depreciation methods, which approximate economic depreciation patterns over time, generate a different effective tax burden for assets depending on their economic life. Likewise, different assets might bear specific taxes other than those falling on the corporate income they generate, e.g. property taxes applicable to commercial and industrial buildings. Substantial and long-lasting variability in the user cost of capital for different asset classes has been extensively documented for the US tax system as a consequence of differential tax rules applicable to specific asset categories (Auerbach, 1983, King and Fullerton, 1984; Gravelle, 1994; Auerbach and Hassett, 1991; Mackie, 2002).

Following the seminal work of Harberger (1966) about the losses caused by misallocation of investment due to non-uniform capital income taxes, the literature has focused on pinning down the macroeconomic effects of the observed user-cost differentials. Auerbach (1983) and Gravelle (1994) calculate welfare costs of differential capital taxes in the range of 0.10 to 0.15 percent of GNP assuming an aggregate Cobb-Douglas production technology. Other studies have quantified the welfare costs using general equilibrium models for the US economy (Fullerton and Henderson, 1989a, 1989b; Jorgenson, 1996; Auerbach, 1989). In particular, Fullerton and Henderson (1989a, 1989b) find that the inter-asset distortions are larger than the inter-sectoral and inter-industry distortions, although the relative size of the effects is shown to depend upon the value of the asset substitution elasticities. While their simulations rely on ad hoc assumptions for such elasticities, a sensitivity analysis indicates that if these are sufficiently large (above 0.4 percent) the welfare costs of inter-asset distortions are of the order of magnitude reported above. The Cobb-Douglas benchmark would yield instead somewhat larger welfare impacts (around 0.18 of GNI). From a methodological point of view, their results suggest that partial equilibrium analyses focusing on the corporate sector can provide insightful indications on the size of the distortions from differential capital taxation.

Notwithstanding the concern raised by these results, little empirical work has been carried out on the distortions due to differential taxation within the corporate sector. As pointed out by Auerbach (1983), the main challenge lies indeed in the quantification of elasticities of substitution among different types of capital (and labour) in production in each corporate industry. Although the cross-elasticities are crucial for evaluating the efficiency and distributional effects of alternative tax policies, the issue of capital asset heterogeneity has been largely ignored by the literature on taxation and investment. The studies looking at disaggregated series, such as, for instance, Schaller (2006) and Ramirez Verdugo (2005), usually consider only broad categories of assets, mostly structures and machinery, and limit the analysis to the direct incentive effect of corporate taxation, without investigating the substitution patterns among the different asset types. To our knowledge the only previous work directly estimating the effect of corporate taxes on the mix of investment across capital assets is Liu (2011). She provides evidence for US manufacturing industries using 7 waves of the Survey of Current Business over the period 1962-1997, and finds unusually large own demand elasticities for the different capital assets.

In this paper we investigate the effect of corporate taxes – summarized by the tax-adjusted user cost of capital – on the allocation of new capital investment using a unique dataset that combines two different data sources at the industry level for a panel of advanced economies over the period 1991-2007. The use of cross-country data facilitates identification by providing sufficient variation in the tax variables, which is not always achieved in studies covering only single countries for a limited time span. In this respect, our paper is related to Vartia (2008) and Bond and Xing (2012) who exploit cross-country variability to estimate the impacts of changes in the user cost on capital accumulation. However, since their focus is on the aggregate series for the capital stock as routinely done in the literature, they do not estimate elasticities of substitution among different asset types.

Our estimates of the asset substitution elasticities suggest a significant inter-asset distortion effect of corporate taxes. Overall, differential taxation has led to under-investment in ICT capital, and in transportation equipment, and over-investment in other machinery and equipment over the sample period. On average, the magnitude of the misallocated capital is in the range of 4 percent of the existing aggregate stock in our sample of countries, compared to a hypothetical benchmark where the marginal effective tax rates are uniform across assets (and set equal to the observed average). Given the well-documented differential contribution of the different capital assets to growth (Timmer et al. 2010), the results have non-trivial implications for policy makers in their use of corporate tax incentives to stimulate capital accumulation as an engine for growth.

The remainder of the paper is organized as follows. Section 2 briefly introduces the concept of the user cost of capital and section 3 describes the data. Section 4 illustrates the regression methodology. The results are discussed in Section 5 while section 6 provides robustness checks to the baseline econometric specification. Section 7 quantifies the distortions in the accumulation of capital assets through a counterfactual exercise where investment is assumed to adjust to an equalized marginal tax burden.

2. Taxes and investment: the cost of capital

In the traditional approach dating back to Jorgenson (1963) and Hall and Jorgenson (1967), the effects of tax policy on investment demand are captured by the tax-adjusted user cost of capital. Conceptually, the user cost of capital (COC) is the minimum pre-tax real rate of return a firm needs on the next unitary investment to cover depreciation, taxes, and the opportunity cost of investment. Formally, the cost of capital is obtained in the maximization process of the firm's net present value whereby the optimal level of investment is chosen, subject to a standard neoclassical production function and to the additional constraint that the rate of growth of the capital stock is given by new investment net of replacement[1]. Assuming that the firm holds static expectations on the price of capital assets, the resulting first order condition is:

$$(1-\tau)P_t^Y Q'(K_t, L_t) = P_t^K\ (1-\tau\Phi)(r+\delta)\,. \qquad (1)$$

which states that, at equilibrium, the after-tax marginal revenue (left-hand side of the equality) equals the cost of increasing the stock of capital K_t (right-hand side). In equation (1), *Q(.)* is the production function using labor (L) and capital (K) as inputs; P^k and P^Y are the prices for capital and output, respectively; Φ is the net present value of depreciation allowances for tax purposes, which can be offset against the statutory tax rate on corporate

[1] A formal derivation can be found for instance in Jorgenson and Yun (1996).

profits,τ; r is the real interest rate and δ is the rate of replacement of the capital stock. As the first order condition does not allow for changes in debt or new equity finance, equation (1) implicitly assumes that new investment is financed by a reduction in dividends, that is by retained earnings.

After normalizing both the prices of output and capital to 1, in what follows we refer to the tax-adjusted user cost of capital as simply:

$$COC^{RE} \equiv \frac{(1-\tau\Phi)(r+\delta)}{(1-\tau)}, \qquad (2)$$

which is easily obtained by rearranging (1). If it is assumed that marginal investment is fully financed by issuing one-period bonds, the derivation of the cost of capital proceeds as above, except that the variation in the stock of debt and the payment of interests need to be taken explicitly into account when defining the firm's net present value. Moreover, importantly, tax codes usually allow for deductibility of interest payments in the determination of corporate income. As a result, the cost of capital with debt financing can be conveniently expressed as the sum of the user cost with retained earnings and an additional term indicating the savings due to the favorable tax treatment of debt, that is:

$$COC^{D} \equiv COC^{RE} - \frac{(1-\tau\phi)(i-(1-\tau)i)}{(1-\tau)}. \qquad (3)$$

In equation (3) i indicates the (pre-tax) interest rate paid on the firm's outstanding debt, while ϕ is the value of the first year corporate tax allowance, which reduces correspondingly the amount that the firm must borrow to finance its unit investment at time t.

Starting from the expressions in (2) and (3), the real social rate of return is derived as the cost of capital net of economic depreciation:

$$\rho = COC - \delta \ . \qquad (4)$$

Efficiency in the allocation of capital requires that the additional wealth generated by acquiring a marginal unit of capital asset, net of depreciation, be the same for all assets (Jorgenson and Yun, 1996). From that, the effective marginal tax rate can be calculated as the difference between the gross-of-tax social return and the real rate of return in the absence of taxes (r), relative to the social return:

$$emtr = (\rho - r) / \rho. \quad (5)$$

Thus, the effective marginal tax rate measures to which extent corporate taxes increase the cost of capital above r. It can be thought of as a measure of the distortions impact of taxation on the scale of the investment. As a benchmark value, it suffices to consider that in a cash-flow type of corporate tax, when investment outlays are fully expensed for tax purposes when they are incurred, the marginal effective tax rate is zero.

3. The data

The paper uses two main data sources. The data on new investment is taken from the EU KLEMS database, constructed by a consortium of universities and research institutes and financed by the European Commission. EU KLEMS allows for comparable cross-country analyses of economic growth in European countries and a number of OECD economies (such as the US and Japan) from 1970 onwards (O'Mahony and Timmer, 2009). To this purpose, harmonized measures of employment, capital formation and technological change at the industry level are provided. Constrained by the availability of tax variables, our sample consists of 11 countries over the period 1991-2007. We include 11 manufacturing industries corresponding to the SIC 2-digit classification. The lists of countries and industries are reported in the Appendix.

EU KLEMS provides data on new investment, in real terms, for several types of capital assets. In our analysis we consider the following asset categories: information and communication technology (henceforth, ICT) capital; industrial structures; other machinery and equipment; and transportation equipment[2]. Asset-specific price indices for gross fixed capital formation are also available for each of the industry-country pairs in our sample. The base year for the price indices is 1995.

[2] We obtain the series on information and communication technology capital by aggregating the series on communication equipment, computing equipment and software. Residential structures are excluded from the analysis.

The tax data are taken from ZEW (2013). The cost of capital, and the associated effective marginal tax rates, under the assumption of retained earnings finance are calculated as in section 2. In particular, tax rules on depreciation allowances and other incentives, such as accelerated depreciation, are asset-specific. In calculating the net present value of depreciation allowances, in case multiple rules are allowed under national tax codes, the most efficient scheme is applied[3]. Profit taxes are summarized by the headline statutory tax rates on corporate income, augmented, whenever applicable, by surcharges and local taxes. In addition to taxes on profits, the cost of capital includes other taxes on assets in general (such as wealth taxes), and on specific types of assets, such as the real estate tax. When it comes to economic variables, inflation and the interest rate are set constant so as to isolate variation in the tax rules from fluctuations due to the general macroeconomic conditions. The economic depreciation rates are taken from EU KLEMS and are asset-specific, constant across time and countries, but varying across industries.

All in all, the cross-sectional variation of the cost of capital derives from the cross-country variation in the tax rules, notably the depreciation allowances and the corporate tax rates. Likewise, the time series variation relies on the changes to such tax rules within countries. This rich variation should therefore help identification of the effects of tax policy on capital accumulation. Table 1 reports summary statistics calculated for the sample used in the regression analysis, where the variables have been winsorized at the 1 percent and 99 percent of their empirical distributions. Overall, other machinery and equipment has the largest share of new investment, followed by ICT capital and by non-residential structures. The cost of capital shows sizable inter-asset variation, largely accounted for by the differences in the economic depreciation rates. Expectedly, the inter-asset variation is reduced when the marginal tax rates are considered.

[Table 1]

4. Regression methodology: the translog function

The traditional production function relying on homogenous inputs (labor and capital) is not well suited for analyzing multiple capital assets. For instance, the single-level CES

[3] In our sample, the straight line method and the declining balance method are the most commonly applied depreciation schemes. Under the straight-line method the historic cost of the asset is written down in equal amounts over the asset's estimated economic life, while under the declining-balance method depreciation allowances decrease over the asset's life.

imposes the unappealing restrictions that the elasticities of substitution between all pairs of inputs are the same. Moreover, the Cobb-Douglas workhorse constrains such elasticities to assume unit value. Properly accounting for heterogeneous factors of production requires adopting a flexible functional form which should allow for distinct patterns of substitution between different pairs of inputs.

To this purpose, it is convenient to consider the dual of the profit maximization problem, where the firm is assumed to minimize its costs taking the level of output as given (Bond and van Reenen, 2007). A function commonly used in the empirical literature is the translog, developed by Christensen, Jorgenson, and Lau (1973), and described in detail in Berndt and Christensen (1973), Berndt and Wood (1975), and Berndt (1991). The translog function allows for a rich pattern of substitution between input pairs, while being relatively parsimonious and easy to implement with data. It is also theoretically appealing because it can be obtained as a second-order approximation to an arbitrary twice differentiable cost function. In its general long-run formulation, given N_k variable inputs and the associated vector of factor prices (W), the translog function for total cost takes the form:

$$\begin{aligned}\ln C &= \alpha_0 + \alpha_Y \ln Y + \sum_{k=1}^{N_k} \alpha_k \ln W_k + \frac{1}{2}\beta_{YY}(\ln Y)^2 + \sum_{k=1}^{N_k} \beta_{Yk} \ln Y \ln W_k + \\ &\frac{1}{2}\sum_{k=1}^{N_k}\sum_{j=1}^{N_k} \beta_{kj} \ln W_k \ln W_j + \gamma_T t + \frac{1}{2}\gamma_T t^2 + \gamma_{TY} t \ln Y + \sum_{=1}^{N_k} \gamma_{Tk} t \ln W_k\end{aligned} \qquad (6)$$

where Y is the level of output, and the coefficients on the time variable, t, and its interactions capture the effects of technical change. In particular, γ_T and γ_{TT} represent factor-neutral technical change, while the coefficients γ_{Tk} reflect technical change biased towards factor k. The cost-minimizing choices of inputs demands (X_k) can then be expressed as log-linear cost share equations.

Applying Shephard's lemma, the conditional factor demand for each input factor k (k=1,.., N_k) is derived by differentiating the total cost function with respect to the (log of the) factor price:

$$S_k = \frac{\partial \ln C}{\partial \ln W_k} = \frac{W_k}{C}\frac{\partial C}{\partial W_k} = \frac{X_k W_k}{C} = \alpha_k + \beta_{Yk} \ln Y + \sum_j \beta_{kj} \ln W_j + \gamma_{Tk} t \qquad (7)$$

where S_k is the share of cost for capital asset k in total capital expenditure, or $(X_k W_k)/C$, with X_k the cost-minimizing inputs demands. The estimated parameters must obey certain conditions for the translog approximation to be well-behaved. First of all, by construction, the cost shares must sum to one. Furthermore, the cost function must be linear homogeneous in the vector of factor prices, given the level of output Y. That is, when all the factor prices increase proportionally, total cost must increase proportionally as well, for a given level of output. Combined, these conditions imply that the following restrictions should hold:

$$\sum_k \alpha_k = 1,$$
$$\sum_k \beta_{Yk} = 0, \text{ and}$$
$$\sum_j \beta_{kj} = \sum_k \beta_{kj} = 0.$$

Further, the symmetry restriction $\beta_{kj} = \beta_{jk}$ for all inputs k and j can be derived from the twice differentiability of the production function. Finally, it is possible to test a number of additional restrictions on the set of equations in (7), corresponding to different characteristics of the underlying production technology, which can be derived from economic theory. In particular, a necessary and sufficient condition for homotheticity is that $\beta_{Yk} = 0$ for all k, whereas homogeneity in output requires also that $\beta_{YY} = 0$, such that the output term drops out of the share equations[4]. In this case the degree of homogeneity equals $1/\alpha_Y$ [5]. There are constant returns to scale of the dual production function when, in addition to the conditions above, $\alpha_Y=1$ [6] .

Taking the full model to the data requires specifying the error terms in the cost and the share equations. While the assumption of independence across observations is maintained, it is likely that the disturbances in the different equations are correlated. Thus, joint

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[4] Homotheticity means that the cost function can be written as a separable function in output and factor prices. With non-homothetic cost functions their ratios of cost-minimizing inputs demands are allowed to depend on the level of output, by contrast, with homothetic functions relative input demands are independent of the level of output. The cost function is homogeneous in output if the elasticity of cost with respect to output is constant.

[5] The returns to scale term is computed as the inverse of the elasticity of costs with respect to output, $RS=(\partial \ln C_t/\partial \ln Y_t)^{-1}$.

[6] Testing for the returns to scale requires estimating the total cost function together with the share equations, as in Christensen and Greene (1976).

estimation of the system of equations gives more efficient estimates than estimating each equation separately (Greene, 2005). Moreover, fitting the equations jointly allows one to impose the cross-equation restrictions. Then, consistent parameter estimates can be obtained weighing the observations with a consistent estimate of the error covariance matrix. This can be achieved using the method of seemingly unrelated regression (Zellner, 1962) which uses single equation estimates of the parameters to obtain the estimated covariance matrix and then minimizes a generalized least squares objective function. If the covariance matrix is recomputed at each iteration, and the disturbances are multivariate normal, the estimator converges to the maximum likelihood estimator. The adding up property of the share equations implies that, out of the N_k factor share equations, only N_k - *1* are linearly independent. In turn, this means that for each observation the sum of the disturbances across equations must equal zero. That is to say, the covariance matrix of the errors is singular and non-diagonal. To solve the singularity problem, it is sufficient to delete any one of the share equations. Barten (1969) has shown that the maximum likelihood estimates of the parameters are invariant with respect to the equation deleted.

5. Empirical implementation and results

We obtain our system of estimating equations by adapting the general model in (7). In particular, we include the pre-tax price of the capital assets and the tax-adjusted cost of capital in separate logarithms. This allows us to separate the effects of variation in prices from those brought about by variation in tax rules. Hence, the investment shares take the form: of each asset *k* in industry *i* at time *t* in country *c* is:

$$S_{k,i,c,t} = \alpha_k + \sum_j \beta_{kj} \ln\left(\frac{COC_j}{COC_{traeq}}\right)_{i,c,t} + \sum_j \lambda_{kj} \ln\left(\frac{P_j}{P_{traeq}}\right)_{i,c,t} + \gamma_{Tk} t + \varepsilon_{k,i,c,t} \qquad (8)$$

Where the subscripts *k, j* index the asset types (*k, j* = other machinery, ICT and structures), and *i, t* and *c* indicate the industry, year and country, respectively. To avoid singularity of the covariance matrix, we have dropped the share equation for that of transportation equipment, and divided the relevant controls – prices (*P*) and cost of capital (*COC*) – for all of the remaining assets by those for transportation equipment. In the system of equations in (8), *t* is an asset-specific time trend controlling for time series variation in the form of technical change biased towards the corresponding asset, and ε is the disturbance term. Following Baltagi (1995), we assume a one-way error component, that is $\varepsilon_{k,i,c,t} = \mu_{k,i,c} + \nu_{k,i,c,t}$, where μ are time-invariant fixed effects for each country-industry pair, and ν is the residual component of the disturbance term. The symmetry restrictions are:

$$\beta_{kj} = \beta_{jk} \text{ and } \lambda_{kj} = \lambda_{jk}, \text{for all } k, j = \text{other machinery, ICT, structures.}$$

[Table 2]

Column 1 in Table 2 reports the coefficient estimates and the standard errors for the user cost of capital from the system of equations (8). The estimates have little economic meaning *per se*. In particular, taken alone, they are not informative on the size of the impacts of changes in the cost of capital. However, one conclusion that can be drawn concerns the degree of precision of the estimates, which is in general very high with the exception of ICT assets. Bootstrap standard errors also clearly indicate that in general heteroskedasticity is not a particularly relevant issue, perhaps not surprisingly, given that the estimating equations are in log-differences.

To verify the adequacy of the joint estimation , we perform the Breusch-Pagan Lagrange multiplier test for the independence of the disturbances across the equations. The value of the test, computed using a $\chi^2(3)$ distribution, is very high (it equals 1040.76), with an associated p-value of 0.00. Therefore, the test strongly rejects the null hypothesis of no contemporaneous correlation among the residuals in the different equations. Thus, expectedly, investment in the different types of capital assets is likely driven by the same underlying determinants.

5.1 Instrumental variables estimation

The estimates in column 1 of table 2 may be inconsistent if an unobserved factor in the error term is correlated with the dependent variable and the explanatory variables at the same time. For instance, country-specific business cycle conditions may affect both investment in different industries and the cost of capital. The argument has been considered compelling for the real interest rate, since positive investment shocks can directly translate into positive output shocks. In turn, the subsequent increase in the demand for credit would drive required returns upwards. Thus, simultaneity between interest rates and investment will likely bias the estimates for the user cost towards zero (Chirinko et al. 1999). While this channel is less of a concern in our case, given the assumption of exogenous financial structure in the construction of the cost of capital variables, arguably, an endogenous response of tax policy to economic fluctuations cannot be ruled out either. Indeed, investment incentives can be used as a supply-side measure to stimulate subdued economic activity, and more and more so in a context of increasingly integrated international capital markets.

We address potential endogeneity issues using instrumental variables. A common approach in the literature is to use lagged values of the user cost of capital as instruments. Specifically, we instrument the user cost values for the different capital assets with their first lag. Hence, provided the error term in the equation is not serially correlated, there will be no simultaneity given the absence of contemporaneous explanatory variables at time *t* as controls. Column 2 in table 2 reports the regression results from the system of equations in (8) estimated with 3SLS. The IV point estimates are highly significant and have the same sign as the estimates in the baseline specification. When it comes to the magnitude of the coefficients, it is apparent that the simultaneity bias affects primarily investment in ICT assets. Conversely, this alternative regression strategy does not impact significantly the estimates for structures and other machinery and equipment.

Inference on the IV coefficients rests on the validity of asymptotic theory to characterize their finite-sample distribution. To test formally whether our instruments are relevant we calculate the partial R-squared proposed by Shea (1997). The statistics corrects the usual goodness-of-fit measure for the first stage regressions by partially out the effects of the other covariates, including the non-interesting excluded instruments[7]. The value of Shea's partial R-squared from the first stage regressions is 0.73 for ICT assets, 0.91 for structures, and 0.92 for the equation of other machinery and equipment. Not surprisingly, they are in all cases reasonably high to exclude a problem of weak instruments in our IV regressions. Therefore, we take the results in column 2 as our preferred estimate. Table 3 shows the estimated coefficients on the cost of capital variables - the β_{kj} in the system of equations (8) -, the standard errors, and the associated 95% confidence intervals. The coefficients

[7] Unlike the R-squared (and adjusted R-squared), Shea's statistics therefore reveals whether the fit from the first stage regression is due only to a subset of instruments. This is particularly relevant in cases like ours. Indeed, in a just-identified model with multiple endogenous regressors, weakness of some instruments implies that the model is basically unidentified.

and the standard errors for transportation equipment are obtained as linear combinations of the directly estimated coefficients and of the relevant elements in the estimated variance-covariance matrix, respectively.

[Table 3]

5.2 Elasticities

In this section we use the parameter estimates reported in table 3 to derive investment elasticities with respect to the user cost of capital. By quantifying the responsiveness of investment to changes in the user cost, we gauge the effects of tax policy on the accumulation of capital, and thus the associated inter-asset distortions. As shown by Uzawa (1962), the Allen elasticities of substitution between two inputs can be computed as:

$$\sigma_{kj} = \frac{C(\partial^2 C / \partial W_k \partial W_j)}{(\partial C / \partial W_k)(\partial C / \partial W_j)},$$

and, by construction, $\sigma_{kj} = \sigma_{jk}$. For the translog cost function, the Allen partial elasticities are:

$$\sigma_{kj} = \frac{\beta_{kj} + S_k S_j}{S_k S_j}, \quad \text{for } k \neq j,$$

and

$$\sigma_{kk} = \frac{\beta_{kk} + S_k^2 - S_k}{S_k^2}.$$

The Allen elasticities measure the responsiveness of the relative shares of inputs with respect to changes in the relative prices, keeping output and the cost of capital of other inputs constant. Thus, they are a measure of the local convexity of the isoquants. A more intuitive measure, demand elasticities, can be expressed as follows:

$$\eta_{kj} = \sigma_{kj} S_j = \frac{\beta_{kj} + S_k S_j}{S_k}, \quad \text{for all } k \neq j, \text{ and}$$

$$\eta_{kk} = \sigma_{kk} S_k = \frac{\beta_{kj} + S_k^2 - S_k}{S_k}, \text{ otherwise.}$$

The demand elasticities are inversely related to the investment shares. This implies that assets with smaller shares are relatively more sensitive to increases in the user cost of other capital inputs. Thus, changes in the user cost have a heterogeneous impact across asset pairs. Since the elasticities vary at each data point, as common in the literature we calculate them at the mean (fitted) cost shares. Following Pindyck (1979), we obtain the associated standard errors using the delta method[8]. The results are reported in table 4.

[Table 4]

Before analyzing the inter-asset substitution patterns, we first look at the responsiveness of the investment shares with respect to their own user cost. In doing so, we put our results into perspective by directly comparing them with the findings of the broad literature on tax incentives and capital accumulation. The own-COC elasticities of demand are negative and highly statistically significant, except for transportation equipment. In this case, the effect of the user cost, while still negative, is not estimated with precision. The estimated elasticities are around 1.2 for ICT assets and non-residential structures, and around 1.3 for other machinery and equipment. The coefficient for transportation equipment is half that order of magnitude. The elasticities are larger than those found in the literature on aggregate investment, including the more recent cross-country evidence reported by Bond and Xing (2012). The upward deviation from the unit benchmark is likely to reflect precisely the asset substitution effects, which would be partly compensated by the direct incentive effects when aggregate capital is considered. Still, our estimated elasticities are in the lower range of the (limited) available evidence on disaggregated capital assets. In particular, Schaller (2006) finds that the responsiveness of investment in equipment to its user is around 1.6 percent in Canada. Liu (2011) reports elasticities that are 50 percent larger (in absolute value) for both machinery and electronic equipment for the US. Of roughly the same order of magnitude are those found by Ramirez Verdugo (2005) in his analysis of firm-level investment in machinery and equipment in Mexico. These discrepancies suggest that the effectiveness of tax incentives might depend crucially on

[8] Thus the variance of the Allen partial elasticities of substitution is $V(\sigma_{kj}) = V(\beta_{kj})(S_k S_j)^{-2}$ for all k and j. Likewise, the variance of the demand elasticities is $V(\eta_{kj}) = V(\beta_{kj})(S_j)^{-2}$ for all k and j.

the presence of outside options for investment, for which the degree of openness of the economy has non trivial implications. Indeed, the opportunities to substitute away from assets with large user costs are clearly stronger when a single economy is considered than in our multi-country framework.

Turning our attention to the inter-asset effects, we find evidence of distortions in the allocation of investment across asset types induced by the differences in the user cost. The Allen partial elasticities indicate a relatively strong degree of substitutability between transportation equipment and other machinery and equipment. The same pattern emerges between structures, ICT assets, and other machinery and equipment, although the effect is proportionally smaller in magnitude. Transportation equipment and structures show instead Allen complementarity. Overall, these findings are consistent with the substitution patterns found by Liu (2011) for the US. They are also in line with the results obtained in the productivity literature by Morrison (2000), although the focus there is on the price effects and not specifically on taxes.

Of the 12 implied cross-elasticities of demand, 10 significantly different from zero. The size of the cross-elasticities for substitute capital assets range from 3.3 percent to slightly less than half a percentage point. In particular, a 1 percent increase in the user cost of other machinery and equipment leads to a 3 percent increase in investment in transportation equipment. Conversely, a 1 percent increase in the user cost of transportation equipment is associated with an increase in investment in other machinery by roughly half a percentage point. The asymmetry in the magnitude of the impacts is due to the fact that the cross-elasticities are inversely related to the investment shares. Hence, for a given degree of substitutability measured by the Allen elasticity, there is a tendency to substitute away less strongly towards assets with a large investment share, ceteris paribus. A 1 percent increase in the user cost for other machinery and equipment raises investment in structures and in ICT capital by roughly 1 percent. Conversely, an increase of the same relative size in the user cost for structures or for ICT capital is associated with larger investment in other machinery and equipment of slightly more than 0.4 percent. Finally, substitution between structures and ICT capital is such that a percent increase in the user cost of either asset translates into higher investment for the other in the range of 0.5 – 0.7 percent.

Transportation equipment and non-residential structures are complementary inputs in the production process. A 1 percent increase in the user cost of structures decreases investment in transportation equipment by 1.7 percent. In the opposite case, when the user cost of transportation equipment were to increase by 1 percent, the decrease in investment in structures would be roughly 0.7 percent. For each of the asset types excluding transportation equipment, the estimated cross-elasticities are smaller than the own-COC elasticities, implying that the first order effect of the direct tax incentive outweighs the corresponding inter-asset distortion effect.

6. Robustness checks

6.1 Debt as a source of finance

Our baseline estimates use the cost of capital derived under the assumption of equity finance in the form of retained earnings, in line with the corporate finance literature positing a hierarchy of finance (Myers, 1984). As shown in section 2, the tax-adjusted user cost depends crucially on the source of finance for the investment because corporate tax systems in general allow for deductibility of interest payments without offering a similar relief for the cost of equity.

One possible way to take the different sources of finance into account would be to implicitly assume than the marginal financing structure equals the average one, and thus consider a weighted average cost of capital, with the weights given by the proportion of the two financing sources. Unfortunately, we do not observe the shares of investment financed by equity and by debt for each country-industry pair. Nonetheless, testing the responsiveness of investment to the cost of capital under debt financing is of particular interest in our disaggregated approach, since the different asset types might offer different incentives to resort to external finance. For instance, structures might be more easily pledged as collateral than tangible ICT assets, which are relatively short-lived and more specialized, and, therefore, less redeployable. However, augmenting the baseline estimating equations with the additional cost of capital term raises concerns for collinearity, particularly because the controls are in log-difference. Therefore, we take an alternative route and re-run the estimations including only the user cost calculated under the assumptions of debt finance, and then compare the estimates with our baseline ones.

Table 5 reports the estimated coefficients and their standard errors, alongside the associated 95% confidence interval. The results show that only investment in structures and in other machinery and equipment is significantly affected by their user cost under debt finance, both directly, in terms of the own-COC impact, and indirectly, when it comes to their substitution pattern. In contrast, the user cost under external finance turns out uninformative in explaining investment in ICT assets and in transportation equipment. The associated own and cross-asset coefficients are indeed not significantly different from zero. These findings corroborate the view that less specialized assets might offer better opportunities for debt financing when used as collateral. More in general, they hint at a non-trivial interaction between financial structure and the composition of real investment, which is worth exploring in future research.

[Table 5]

6.2 Testing the effects of the pre-tax asset prices

In the system of equations (8) the coefficients on the pre-tax price of the capital assets and those on the tax-adjusted user cost have been allowed to differ in the estimation. In this section, we test formally whether the impacts of the two variables on the investment shares are of the same magnitude, as suggested by the neoclassical investment theory. This is relevant also in the light of Goolsbee’s (1998) findings that tax incentives might be partly passed through into higher capital prices, at least in the short run, in the presence of an upward sloping supply curve for capital. The fact that tax subsidies could partially translate into a higher remuneration for the producers of capital goods would explain why investment is often found to be only modestly responsive to the user cost of capital in the literature (see e.g. Hassett and Hubbard, 2002). Alternatively, the set of coefficients on the user cost and on the pre-tax price might differ due to error in the measurement of either variable (Goolsbee, 2000).

We restrict the coefficients on relative prices and those on the relative tax-adjusted user cost to be the same in the model in (8). Thus, we estimate the following system of equations:

$$S_{k,i,c,t} = \alpha_k + \sum_j \beta_{kj} \ln\left(\frac{COC_j}{COC_{traeq}} \frac{P_j}{P_{traeq}}\right)_{i,c,t} + \gamma_{Tk} t + \varepsilon_{k,i,c,t} \qquad (9)$$

with the usual symmetry restrictions imposed on the βs.

Since, under the null hypothesis of equal coefficients, the restricted model (9) is nested into the unrestricted model (8), we use a likelihood ratio test using on the instrumented estimates. The test is distributed as a $\chi^2(6)$. The value of the test statistics is 10.46, with an associated p-value of 0.106. Thus, the null hypothesis cannot be rejected, suggesting that the responsiveness of investment to its pre-tax price and to the cost of capital is the same across all asset categories.

7. Quantifying the inter-asset distortions

The estimated elasticities lend support to the view that the distortions in corporate investment decisions brought about by changes in the user cost of different capital assets are potentially non-negligible. Following Fullerton and Henderson (1989a), we measure them using a counterfactual experiment where we compare the investment shares predicted by the estimated model with the hypothetical investment outcomes which would be in place under neutral taxation at the margin. By construction, this allows us to quantify the effects that differential taxation has on the *composition* of investment, and thus of the capital stock, while the aggregate volume of gross investment is held constant. We stress that this is not a normative exercise, and that our theoretical scenario with equalized taxation should not be considered a policy proposal. Clearly, asset substitution possibilities in response to changes to relative prices find a limit in firms' production technologies. Therefore, the point of the exercise is to measure the extent to which deviations from a first best with equalized after tax returns affect the allocation of capital, not to suggest that the composition of the capital stock could be easily adjusted should marginal tax rates be equalized.

The cross-COC elasticities in table 4 are the key parameters for this exercise. To build the counterfactual investment shares, we move from the cost of capital to the related concept of effective marginal tax rates introduced in section 2, which allows us to properly capture the excess burden of taxation at the margin. Operationally, we set the marginal tax rates on the different assets equal to the overall average marginal tax rate across assets and countries. Then, applying the estimated demand elasticities, for each asset we back out the investment shares under neutral taxation, that is the investment shares corresponding to the equalized user cost, in each year. By construction, in this way we are able to capture the aggregate average distortion in our sample of countries.

The hypothetical investment shares are plotted against the fitted shares in figure 1. Compared to the benchmark with uniform taxation, we observe significant over-investment in other machinery and equipment. Conversely, investment shares for transportation equipment and for ICT capital are lower than their counterfactual under neutral taxation. For the latter asset type, the recorded actual under-investment is particularly pronounced at the beginning of the sample period, while the gap between observed and hypothetical investment shares narrows in the latest years after 2000. Finally, on average, investment in non-residential structures does not seem to bear substantial distortions stemming from discrepancies in marginal tax rates across asset categories.

[Figure 1]

How severe are the distortions induced by the gap between observed investment in the different assets and the investment patterns under neutral taxation? One possible way to answer this question is to measure the deadweight loss from differential taxation in terms of misallocated capital stock, like in Auerbach (1983). Using a Cobb-Douglas technology, he quantifies the welfare loss induced by the discrepancies in the marginal tax burden on the different asset types in the US as the difference between actual aggregate capital and the minimum capital stock required to produce the same level of output, given the quantity of labor employed in the economy and the level of inputs remuneration. Likewise, we do not attempt any quantification of the output effects induced by changes in the relative marginal tax burden on capital assets[9]. Abstracting from general equilibrium effects, with the substitution elasticities at hand, we can adopt a simple accounting approach that does not rely on any functional form assumption for the production technology but maintains the flexibility of the translog. Specifically, we employ only the capital accumulation constraint to construct a counterfactual capital stock (K^C), for each of the capital asset types (indexed with *k*) as follows:

$$K^C{}_{k,t} = K_{k,t-1}(1-\delta_k) + I^C{}_{k,t}$$

[9] Auerbach's (1983) analysis does not account for general equilibrium effects. Increased demand for some types of assets would translate into changes in the supply of the capital factors and in the composition of output, as firms would adjust their mix of capital inputs accordingly. Moreover, shifts in the intertemporal pattern of consumption and labor supply in response to the change in relative prices for assets would also affect output.

where I^C is the counterfactual real gross investment level obtained applying the estimated elasticities and the equalized effective marginal tax rates, and K is the observed stock of capital asset k in year t, which is taken from EU KLEMS[10]. Then, for each capital asset, we define the distortion in year t as the difference between the observed and the counterfactual stock of capital, divided through by the observed aggregate capital stock:

$$D_{k,t} = \frac{\left(K_{k,t} - K_{k,t}^C\right)}{\sum_k K_{k,t}}.$$

Finally, we obtain an aggregate measure of the 'misallocated' capital by adding up the asset-specific distortions (in absolute value):

$$D_t = \sum_k \left|D_{k,t}\right|.$$

We perform this exercise at the country level to properly account for heterogeneity in capital taxation in our sample. Thus, we equalize the marginal effective tax rates across assets and industries within each country. The resulting counterfactual capital stock series, compared with the observed ones, are intended to measure the extent of the *within-countries distortions*. For the given inter-asset elasticities and economic parameters, these will be driven by the combined effect of the differences in the depreciation methods and in the level of the tax rates on corporate income. Table 6 shows the calculated distortions averaged over the sample period.

[Table 6]

Overall, the aggregate pattern of increased investment in ICT capital under neutral taxation is replicated in almost all the countries. The observed under-investment ranges from 0.3 to 1.6 percent of the national aggregate capital stocks. On average, if marginal tax rates on the different assets were equalized and investment fully adjusted accordingly, the stock of ICT assets over the total capital stock in the manufacturing industries in our sample of countries would be higher by 0.7 percent. By contrast, the corresponding hypothetical reduction in the stock of other machinery and equipment would be twice as large on average. The variability across countries is substantial, with the amount of

[10] The stock of capital for the different assets is obtained using the perpetual inventory method and the asset-specific depreciation rates δ_k.

misallocated investment in this asset type reaching almost 3 percent of the capital stock in Spain. Under-investment in transportation equipment in general does not amount to more than 1 percent of the aggregated capital stock, reflecting the low share of this asset type over total capital. More mixed is the picture for non-residential structures. Against the background of no substantial average distortion, the country-specific results show very different patterns. Both under-investment and over-investment are apparent, depending on the country considered, amounting in some cases to more than 1 percentage point of the total capital stock. In aggregate, slightly less than 4 percent of the total capital stock in our sample appears misallocated compared to our hypothetical scenario with uniform taxation. This upshot is of the same order of magnitude of that found by Auerbach (1983) for the US in the latest years of the sample period covered in his analysis. The results at the country level show again considerable variability, ranging from 2 percent in Ireland to almost 6 percent in Spain.

8. Conclusion

This paper provides additional evidence on the responsiveness of capital accumulation to changes in the user cost of capital. It shows that when heterogeneity in the composition of aggregate capital is explicitly accounted for, the effects of the tax-adjusted user cost on investment are significant and quantitatively sizable. Given the estimated substitution patterns and the fact that the tax burden is not equally distributed among assets categories, corporate taxation potentially leads to important distortionary effects on the allocation of business investment across asset types at the margin. A counterfactual experiment where marginal effective tax rates are set equal to their mean value in manufacturing industries shows that, on average, under-investment occurs in less tax-favored assets (particularly ICT capital) whereas the opposite holds for other machinery and equipment. Overall, misallocated capital would amount to slightly less than 4 percent of the aggregate capital stock. Although in practice many other factors, primarily technology constraints, prevent the capital input mix to be freely readjusted in response to changes in relative prices, nonetheless the results have important implications for policy-makers, as they suggest that tax incentives to stimulate business investment might have significant efficiency and welfare consequences due to change in the composition of aggregate variables.

Appendix

Table A. 1 Industry coverage

Description: Manufacture of	SIC code
Food, beverages and tobacco	15, 16
Textiles, leather and footwear	17, 18, 19
Wood and of products of wood and cork	20
Pulp, paper, printing and publishing	21, 22
Chemical, rubber, plastics and fuel	23, 24, 25
Other non-metallic minerals	26
Basic metals and fabricated metal	27, 28
Machinery, nec	29
Electrical and optical equipment	30, 31, 32, 33
Transport equipment	34, 35
Manufacturing nec; recycling	36, 37

Table A. 2 Country coverage

	Country	coverage	obs
AUT	Austria	1991-2007	187
DNK	Denmark	1991-2007	187
FIN	Finland	1991-2007	187
FRA	France	1991-2007	187
GER	Germany	1991-2007	187
IRL	Ireland	1991-2007	187
ITA	Italy	1991-2007	187
NLD	Netherlands	1991-2007	187
ESP	Spain	1991-2007	187
GBR	United Kingdom	1991-2007	187
USA	United States	1991-2007	187

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Table 1. Summary statistics

	Mean	Std. Dev	1st quartile	2nd quartile	3rd quartile
ICT assets					
Investment share	0.23	0.16	0.12	0.19	0.30
Cost of capital (in %)	37.42	4.27	34.74	38.53	40.20
Real price index	74.75	29.48	49.68	72.45	100
Effective marginal tax rate (in %)	43.30	13.14	37.29	43.93	49.78
Structures					
Investment share	0.19	0.10	0.12	0.17	0.24
Cost of capital (in %)	11.89	1.50	10.86	12.05	13.00
Real price index	109	17.72	100	105	117
Effective marginal tax rate (in %)	39.70	12.09	33.85	42.83	48.42
Other machinery and equipment					
Investment share	0.51	0.14	0.43	0.53	0.61
Cost of capital (in %)	18.28	1.64	17.33	17.81	19.04
Real price index	106.28	14.61	100	104	113
Effective marginal tax rate (in %)	29.23	14.33	22.72	27.54	39.50
Transportation equipment					
Investment share	0.07	0.09	0.03	0.03	0.07
Cost of capital (in %)	25.76	2.09	24.16	25.51	27.01
Real price index	101.82	10.83	97	100	106
Effective marginal tax rate (in %)	35.13	13.62	27.94	34.77	45.37
Number of observations: 2057					

Table 2. Parameter estimates for the cost of capital

	(1)	(2)
Equation for ICT assets		
ICT assets	-0.033 (0.035) [0.034]	-0.113*** (0.047) [0.044]
Structures	0.042* (0.022) [0.024]	0.088*** (0.029) [0.032]
Other machinery and equipment	0.015 (0.037) [0.044]	0.114** (0.049) [0.056]
Equation for Structures		
Structures	-0.061** (0.029) [0.022]	-0.071*** (0.036) [0.027]
Other machinery and equipment	0.105*** (0.038) [0.035]	0.116*** (0.047) [0.040]
Equation for Other machinery and equipment		
Other machinery and equipment	-0.269*** (0.081) [0.078]	-0.429*** (0.096) [0.098]
Observations	2057	1936
R-sqr of equation for:		
ICT assets	0.774	0.774
Structures	0.695	0.694
Other machinery and equipment	0.651	0.649

Notes: Column (1) reports the results from the system of three cost share equations estimated with iterative SUR. Column (2) reports results from the IV specification (3SLS) where the cost of capital variables are instrumented with their first lag. Standard errors are in parentheses. Heteroskedasticity-robust standard errors using bootstrap method with 200 repetitions are in square brackets. * denotes $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. The estimating equations include pre-tax prices for capital assets (in log-difference), as well as asset-specific time trends and country-industry pair fixed effects.

Table 3. Parameter estimates – IV specification

	Coefficients	Standard errors	95% confidence interval	
$\beta_{ICT, ICT}$	-0.113	0.047	-0.206	-0.020
$\beta_{structures, structures}$	-0.071	0.036	-0.143	0.000
$\beta_{machinery, machinery}$	-0.429	0.096	-0.617	-0.241
$\beta_{transport\ eq., transport\ eq.}$	0.021	0.118	-0.211	0.253
$\beta_{ICT, structures}$	0.088	0.029	0.031	0.145
$\beta_{ICT, machinery}$	0.114	0.049	0.017	0.211
$\beta_{ICT, transport\ eq.}$	-0.088	0.058	-0.202	0.026
$\beta_{structures, machinery}$	0.116	0.047	0.025	0.207
$\beta_{structures, transport\ eq.}$	-0.132	0.052	-0.235	-0.029
$\beta_{machinery, transport\ eq.}$	0.200	0.094	0.014	0.385

Notes: estimates from the IV specification in table 2, column (2).

Table 4. Allen partial elasticities of substitution and demand elasticities

	Equation for			
	ICT assets	**Structures**	**Other machinery and equipment**	**Transportation equipment**
Average cost shares (fitted)	0.230	0.186	0.514	0.071
Asset type:	**Allen Elasticities of Substitution**			
ICT assets	-5.206***			
	(0.772)			
Structures	3.029***	-6.635***		
	(0.733)	(0.819)		
Other machinery and equipment	1.939***	2.247***	-2.618***	
	(0.460)	(0.436)	(0.377)	
Transportation equipment	-4.272	-9.307***	6.565***	-8.956
	(3.713)	(3.504)	(2.579)	(24.093)
	Demand Elasticities			
ICT assets	-1.239***	0.721***	0.461***	-1.017
	(0.199)	(0.159)	(0.097)	(0825)
Structures	0.552***	-1.209***	0.409***	-1.696***
	(0.121)	(0.200)	(0.091)	(0.745)
Other machinery and equipment	0.988***	1.144***	-1.333***	3.344***
	(0.207)	(0.255)	(0.188)	(1.341)
Transportation equipment	-0.301	-0.656***	0.463***	-0.631
	(0.244)	(0.228)	(0.186)	(1.680)

Notes: implied AES and demand elasticities based on the parameter estimates in table 3, and evaluated at the mean cost shares.

Table 5. Parameter estimates with debt-financed investment – IV specification

	Coefficients	Standard errors	95% confidence interval	
$\beta_{ICT, ICT}$	0.011	0.043	-0.073	0.095
$\beta_{structures, structures}$	-0.091	0.016	-0.123	-0.060
$\beta_{machinery, machinery}$	-0.212	0.089	-0.387	-0.037
$\beta_{transport\ eq., transport\ eq.}$	-0.010	0.100	-0.206	0.185
$\beta_{ICT, structures}$	0.014	0.018	-0.022	0.050
$\beta_{ICT, machinery}$	0.035	0.047	-0.057	0.128
$\beta_{ICT, transport\ eq.}$	-0.060	0.052	-0.162	0.042
$\beta_{structures, machinery}$	0.092	0.024	0.045	0.138
$\beta_{structures, transport\ eq.}$	-0.014	0.027	-0.067	0.038
$\beta_{machinery, transport\ eq.}$	0.085	0.086	-0.084	0.253

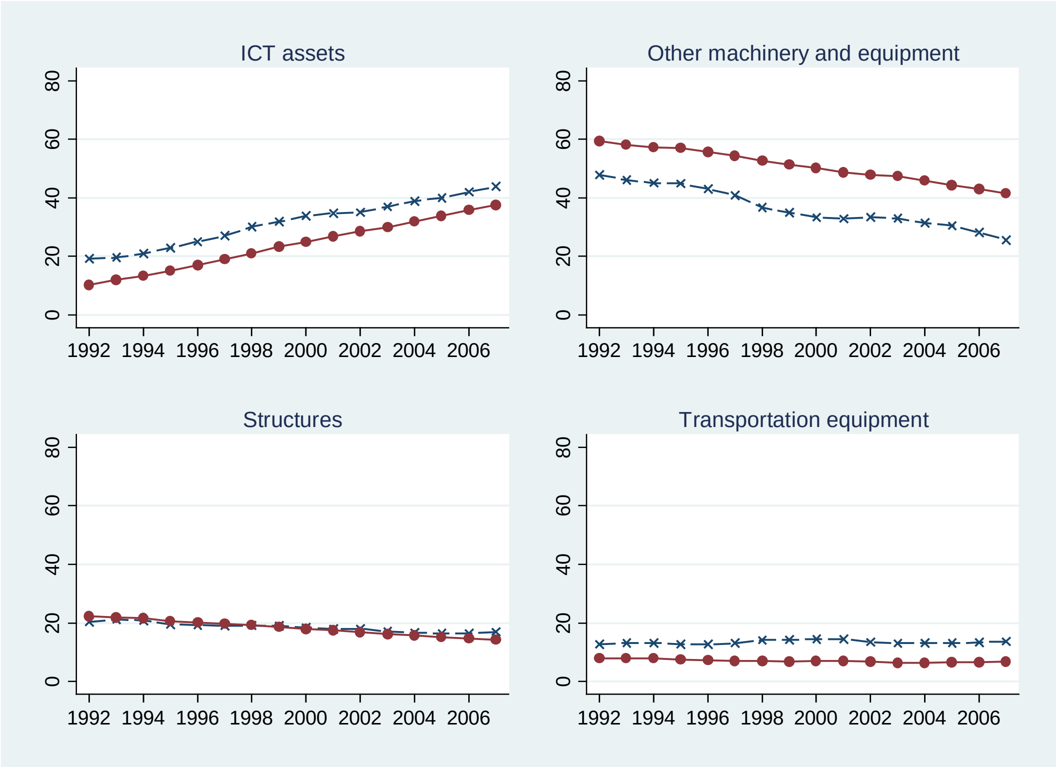
Note: estimates from the IV specification (3SLS) where the cost of capital variables are instrumented with their first lag.

Table 6. Misallocated capital under differential taxation (as a percentage of total capital stock)

	Asset type:				
	ICT	**Structures**	**Other machinery and equipment**	**Transportation equipment**	***Aggregate capital***
Austria	-1.630	0.350	1.842	-0.562	4.384
Denmark	-0.300	-0.685	1.852	-0.867	3.705
Finland	-1.296	-0.161	2.191	-0.733	4.381
France	0.565	-0.954	0.528	-0.138	2.184
Germany	-1.039	0.270	1.188	-0.419	2.915
Ireland	-0.421	-0.052	1.003	-0.530	2.006
Italy	-1.437	-0.210	2.508	-0.861	5.016
Netherlands	-0.399	1.600	-0.860	-0.340	3.200
Spain	-0.751	-1.239	2.997	-1.006	5.993
United Kingdom	-0.119	-0.584	1.895	-1.191	3.790
United States	-1.208	1.307	0.380	-0.479	3.375
average	*-0.731*	*-0.033*	*1.411*	*-0.648*	*3.723*
standard deviation	*0.632*	*0.841*	*1.051*	*0.299*	*1.131*

Note: misallocated capital is obtained as the difference between the actual stock and the counterfactual stock of capital simulated under neutral taxation.

Figure 1. Investment shares under different tax regimes – All manufacturing industries



Notes: fitted investment shares (in percent) under differential taxation in solid line. Counterfactual investment shares (in percent) under equalized marginal taxation in dash line.

KC-AI-13-503-EN-N

Publications Office