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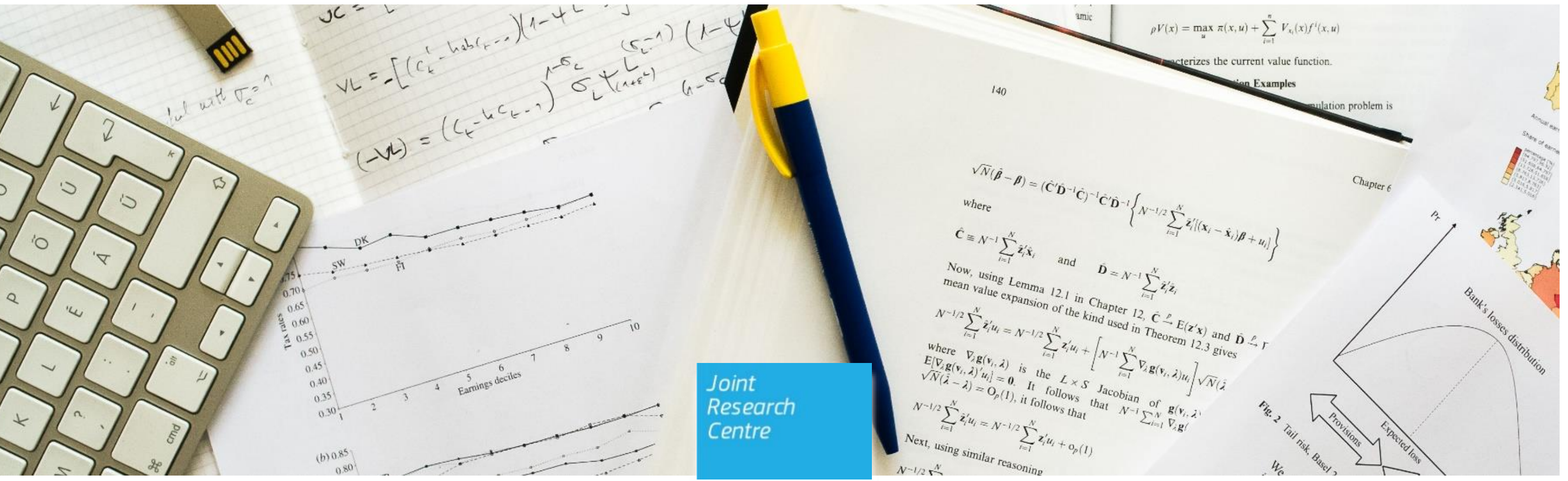

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Contact information
Name: Serena Fatica
Address: Via E. Fermi 2749, I-21027 Ispra (VA)
Email: serena.fatica@ec.europa.eu
Tel.: +39 0332 78 3620

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Business capital accumulation and the user cost: is there a heterogeneity bias?

Serena Fatica*

Abstract

Empirical models of capital accumulation estimated on aggregate data series are based on the assumption that capital asset types respond in the same way to cost variables. Likewise, aggregate models do not consider potential heterogeneity in investment behavior originating on the demand side for capital, e.g. at the sector level. We show that the underlying assumption of homogeneity may indeed lead to misspecification of standard aggregate investment models. Using data from 23 sectors in 10 OECD countries over the period 1984-2007, we adopt a fully disaggregated approach – by asset types and sectors – to estimate the responsiveness of investment to the tax-adjusted user cost of capital. While accounting for the different sources of heterogeneity, we find that fixed capital accumulation is significantly affected by changes in the user cost. However, the estimated substitution elasticities are smaller than one - the benchmark value under a Cobb-Douglas production function. We do not find robust evidence that the long run substitution elasticities are statistically different across asset types.

JEL classification: E22, H25, C33

Keywords: Capital accumulation; User cost of capital; Corporate taxation; Panel data

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1. Introduction

Capital accumulation is crucial for business cycles and economic growth. Understanding its drivers is therefore essential. Among the potential determinants, the literature has extensively investigated the role of the user cost (see Chirinko (1993a, 2008) for comprehensive surveys). Most studies treat capital mostly as a homogeneous good. However, there is motivated concern that the single capital good model inadequately describes the effects of changes in the user cost on capital accumulation, primarily because it neglects compositional shifts in investment.

In fact, different capital goods command different prices, display different depreciation patterns, and receive a specific tax treatment. First, market prices vary widely across assets and over time. In some cases, price changes might reflect long-term trends, such as technological progress. For instance, quality improvements in high-tech components have led to a dramatic decline of market prices for computers and similar goods (Greenwood *et al.*, 1997). By contrast, price developments for other capital goods closely reflect demand shocks, particularly in the presence of supply constraints. Real estate assets are a typical example. Secondly, technological features directly affect adjustment costs, which presumably increase with the useful life of the assets. Likewise, the durability of capital goods determines the amount of replacement investment needed to sustain a given level of production, under unchanged technological constraints. Thirdly, the impact of tax policy differs across capital asset types. Tax allowances for depreciation of capital expenditure are typically asset–specific, or defined for relatively narrow asset categories (Clark, 1993). Likewise, temporary policy measures, such as accelerated or bonus depreciation, may selectively apply to specific capital goods (House and Shapiro, 2008). Moreover, even non-targeted tax policy measures, e.g. changes to the headline statutory corporate tax rate, translate into different relative changes of the user cost of different assets, depending on its initial level (Cummins *et al.*, 1996).

Importantly, both asset and sector specificities matter for the trajectories of capital accumulation. In so far as different sectors are technologically constrained to rely on specific capital assets, investment evolves unevenly across industries. The responsiveness to cost variables changes further if supply is rigid and if the capital assets are not easily redeployable, even within sectors (Goolsbee, 1998). Moreover, increased specialization of physical capital, possibly combined with intangible and organizational capital that creates expertise in holding certain asset classes, may contribute to market segmentation, not only across sectors but also within sectors. Such asset specificities, by impairing the functioning of the secondary markets for capital, might reduce the incentives for disinvestment, thus ultimately altering the responsiveness of investment to cost variables. As Desai and Goolsbee (2004) point out, these types of irreversibilities are likely to manifest at the microeconomic level – i.e. at the level of the individual asset and sector – "rather than apply to all assets in all sectors homogeneously".

Abandoning the assumption of homogeneous capital creates challenges for investment modelling. In the context of structural models, the combination of different types of capital goods into a single aggregate imposes unappealing restrictions, either on the level and the shape of adjustment costs (Wildasin, 1984; Chirinko, 1993b) or on the degree of substitutability among assets (Hayashi and Inoue, 1991). On the empirical side, aggregation creates issues in the first place for the construction and measurement of variables. Then, naturally, econometric models with aggregate variables force homogeneity on the estimated parameters. Likewise, the standard pooled estimators for panel data constrain the slopes in the estimating equation to be the same across cross-section units. This might have severe consequences in reduced-form models of capital accumulation resting on the long run cointegrating relationship between the actual and the frictionless level of capital implied by economic theory (Caballero *et al.*, 1995). As Pesaran and Smith (1995) have shown, this kind of heterogeneity mis-specification might invalidate the long run equilibrium relationship that holds at the microeconomic level, increasing the risk of spurious regression.

In this paper, we investigate the consequences of imposing homogeneity when estimating the sensitivity of investment to the tax-adjusted user cost of capital. We use data – including detailed information on business tax incentives – for 23 sectors comprising the market economy in 10 OECD countries over the period 1984-2007. Our setup accommodates heterogeneity across capital asset types and economic sectors. As such, it departs from the bulk of the literature on the substitution elasticity, based on aggregate data (Schaller, 2006; Caballero, 1997; Bond and Xing, 2015). In focusing on asset heterogeneity we take inspiration from Tevlin and Whelan (2003), who reveal the shortcomings of aggregate models due to the rising importance of computers as of the 1990s in the US. Smith (2008) and Bakhshi *et al.* (2003) provide similar analyses for the UK. We extend their contributions not only by considering a broader set of assets, countries and sectors, but also by systematically investigating the effects of neglected heterogeneity along these dimensions. Our paper also relates to the recent article by Bond and Xing (2015). They use the same investment data (although a slightly different sample definition) as we do, but still work with aggregate measures of capital. We show that their conclusions do not necessarily survive a finer definition of capital goods. Moreover, we formally examine how heterogeneity affects econometric estimates of the substitution elasticity, something that is inherently different from the focus of their analysis.

The remainder of the paper proceeds as follows. Section 2 discusses a way to deal with multiple capital assets in a standard empirical investment model. Section 3 introduces the data, and some stylized facts. Section 4 describes our empirical strategy. The results are in section 5. Finally, section 6 offers some concluding remarks.

2. Investment model: theoretical background and empirical specification

The traditional setup with aggregate capital series implicitly assumes a constant elasticity of substitution across assets. We stick to this assumption to derive the estimating equations, and then verify whether it holds in the data given the estimated elasticities[1]. The simplest way to accommodate different types of capital goods is a single-level constant elasticity of substitution (CES) production function. Under constant returns to scale, output in sector *i* is:

(1) $$Y_{i,t} = \left[\sum_{j=1}^{J} A_{ijt}\, K_{ij,t}^{\frac{\sigma_i - 1}{\sigma_i}} + \left(1 - \sum_{j=1}^{J} A_{j,t}\right) L_t^{\frac{\sigma_i - 1}{\sigma_i}}\right]^{\frac{\sigma_i}{\sigma_i - 1}},$$

where K_j denotes the *j*-th type of capital, L is labor, and the A_j's are distribution parameters capturing capital-biased technological progress. The parameter of interest is σ_i, the elasticity of substitution. While in equation (1) we allow for different sector-specific production functions, the CES implies that the elasticity of substitution is constant across asset types within each sector. As a special case, $\sigma_i = 1$ holds for the Cobb-Douglas production function.

In competitive markets without adjustment costs, the optimal level of capital type *j* is a log-linear combination of output and the user cost of capital:

(2) $$k_{ij}^{*} = \widetilde{a_{ij}} + y_i - \sigma_i c_{ij}\,,$$

where small caps indicate the natural logarithm of variables, and also $\widetilde{a_{ij}} = \sigma_i \ln(A_{ij})$. If the marginal investment is financed by retained earnings, the tax-adjusted user cost derived by Hall and Jorgenson (1967) is:

(3) $$C_{ij} = P_{ij}(r + \delta_j)\frac{(1-\tau\Psi_{ij})}{1-\tau}\,,$$

where P_{ij} is the price of the capital asset relative to the price of output, Ψ_{ij} is the net present value of depreciation allowances, r the real discount rate, and τ is the marginal corporate income tax rate. If instead the marginal source of finance is debt, one needs to account for the

[1] A more flexible functional form allowing for different substitution elasticities, such as a translog function leading to interrelated factor demand equations, could be envisaged. We have estimated a static translog treating all capital assets as quasi-fixed. In such context, however, the cross-equation restrictions imposed by the translog setup were rejected by the data, leading us to prefer the approach in this paper. Given the limited time dimension of our sample, the CES framework, avoiding parameter proliferation, allows for a better modelling of the dynamics of capital accumulation.

fact that in standard corporate income tax systems interest payments are deductible for tax purposes. The user cost of capital for a debt-financed investment is:

$$C_{ij}^{debt} = C_{ij}H_{ij}, \tag{4}$$

where the second term in squared brackets, $H_{ij} = 1 - [\rho - i(1-\tau)](1 - \tau\psi_{ij})/[(1 - \tau\Psi_{ij})(r + \delta_j)]$, represents the tax advantage of debt over equity finance. Here, ρ is the nominal discount rate, i is the nominal interest rate on the loan, and ψ is the fraction of a unit investment that can be deducted from corporate income in the year the investment is made.

Without adjustment costs, the capital stock, $k,$ would be set in each period equal to the frictionless level pinned down by the equilibrium condition in (2). To factor in sluggishness in the capital stock, we specify a dynamic demand for capital in error correction form as in Bond *et al.* (2003). Such reduced-form approach assumes that desired capital deviates from the frictionless level, but is adjusted in order to keep pace with it, and that short run dynamics in the convergence process are stable enough to be adequately approximated by distributed lags (Bond and Van Reenen, 2007). Following Caballero *et al.* (1995), the equilibrium condition can be expressed as:

$$k_{ij,t} = k_{ij,t}^{*} + e_{ij,t}\ . \tag{5}$$

The two capital series need not be equal on average, as they can differ up to a stationary error term, $e,$ which captures transitory deviations. In our framework, for a single cointegrating relationship to exist, the capital output ratio and the user cost must be cointegrated. In turn, this imposes constant returns to scale on the production technology, which we assume throughout as in Caballero (1997). Precisely relying on the cointegration between the two capital series, the full specification with short run dynamics can be reparametrized into an error correction model (ECM), as in Bloom *et al.* (2007). We discuss the empirical implementation of the ECM in section 4, and now turn to the issue of heterogeneity and aggregation.

2.1. Heterogeneity and aggregation

Imposing homogeneity through aggregation forces heterogeneity in the regression residual, thus resulting in biased and inconsistent estimates if the error term systematically correlates with the controls. Two closely related but separate issues are at play here: aggregation of microeconomic data and constrained estimates. Let us consider what happens in general when one neglects heterogeneity. To fix ideas, we focus on the aggregation over sectors, i.e. on the demand side for capital. In this context, let us consider the long run relationship in (5), rather than the nesting dynamic specification. Substitution of (3) into the cointegrating relationship in equation (5) gives (ignoring the constant):

(6) $$k_i - y_i = -\sigma_i c_i + e_i \,,$$

where $i = 1, \ldots, \ M$ denotes the cross-section units and we drop the other subscripts. Assume that the elasticities are the sum of a component (σ) that is common across groups and a group-specific (randomly) varying amount s_i that averages to zero, so that:

(7) $$\sigma_i = \sigma + s_i.$$

Thus, we can express the aggregate version of equation (6), which identifies the common component of the coefficient, as:

(8) $$\bar{k} - \bar{y} = -\sigma\bar{c} + e + \textstyle\sum_i^I \omega_i s_i c_i \,,$$

where $\bar{k} = \sum_i^I k_i$, $\bar{y} = \sum_i^I y_i$, $\bar{c} = \sum_i^I \omega_i c_i$, and $e = \sum_i^I \omega_i e_i$, with ω_i being the weights defined in terms of sectoral capital over total capital across sectors. Neglected heterogeneity ends up in the residual of the aggregate equation via the term $\sum_i^I \omega_i s_i c_i$. This also implies that the long run relationship between actual and desired level of capital that exists at the microeconomic level breaks down when aggregate variables are considered, increasing the risk for spurious regressions (Pesaran and Smith, 1995). Note that a similar issue arises when the microeconomic estimates are constrained to homogeneity, like pooled estimators for panel data do.

Aggregation over heterogeneous capital goods creates analogous econometric issues. In the first place, one should ensure consistency between the aggregate measures of quantities and cost variables (Bakhshi *et al.*, 2003). In practice, capital stock series available from the national accounts are obtained additively from the individual series. The corresponding tax-adjusted user cost is built as an aggregate quantity-weighted index of the asset-specific user costs. Fitting an equation for investment implies that, for consistency, the aggregate user cost should be built as a price index for investment, though. Thus, the sets of weights will differ unless all capital assets accumulate in proportion to their stock value[2]. Even with appropriately defined asset weights, aggregation of the non-price component of the user cost may still be problematic, as it would propagate any measurement errors affecting the tax terms of the single capital assets (Goolsbee, 2000).

[2] The problems of consistency between aggregate capital and the user cost carry over to the case when a service concept of capital, instead of a wealth stock concept, is used (Oulton et al., 2003). In this instance, the quantity variable is an index of aggregate capital services growth. The weights in the user cost should then reflect the share of the asset in total capital services, whereas in an aggregate index for investment the corresponding shares are defined in terms of investment. Again, the pattern of weights will be the same only if assets prices are changing at the same rate relative to the price of output, i.e. asset prices are constant in relative terms (Bakhshi et al., 2003).

Overall, the discussion above casts doubt on the fact that ignoring heterogeneity would lead to correctly specified empirical models of capital accumulation. To deal with cross-sectional heterogeneity, we analyze the dynamics of the different capital goods separately and use estimators that allow for heterogeneous parameters. With our data, we can factor in heterogeneity down to the country-sector level[3].

3. Data

3.1. Variables and main sources

Our dataset includes 23 sectors (SIC 2-digit classification) adding up to the market economy of 10 OECD economies over the period 1984-2007. Overall, this gives a panel of up to 5,060 observations, for 230 country-sector pairs. Details on the sample coverage are reported in Appendix A. Data on production are taken from the EU KLEMS database, which provides harmonized series for capital stock and output at the sector level for European and other advanced economies (O'Mahony and Timmer, 2009)[4]. The stock of fixed capital in the KLEMS data breaks down into several asset types. We focus on the following: computers, communication equipment, transportation equipment, and other machinery and equipment. These assets make up aggregate equipment capital. Adding up structures gives the overall stock of productive physical capital used in the market economy sectors[5]. The capital stock series (with 1995 as the base year) are obtained using the Perpetual Inventory method by summing up past real investments, weighted by the relative efficiencies of capital goods at different vintages. Asset-specific depreciation rates are equal across countries and time, but can vary across sectors. They are lowest for structures (the minimum rate is around 2%). When it comes to equipment capital, depreciation rates range from 9% for transportation equipment, to 31.5% for computers. Wear and tear for the different capital aggregates is determined endogenously by the relative importance of the different assets. Average depreciation rates are 8% for total capital and 14% for equipment over the sample period. Thus, average values hide significant cross-sectional differences across different asset types. Variation along the time-series dimension is equally important. The average economic depreciation rate for total capital

[3] Ideally, one would go to the finest level of breakdown and analyze capital accumulation at the level of the firm or individual establishment. However, these types of micro-data normally do not cover broad sets of capital assets. By using sector-level data we rely on the presumption that this this type of aggregation would not produce a severe bias, and would not hide heterogeneity in the dynamics and adjustment of capital due to different production technologies compared to more aggregate data. Our approach is consistent with the traditional productivity literature and the growth accounting framework based on sector-specific production technologies.

[4] The choice of countries in our sample has been driven by the availability of detailed tax data (see below).

[5] Residential structures are excluded from the analysis.

increases from 7% to almost 10% over the sample period, and the rate for equipment capital rises from 13% to 16%. As discussed in the next section, this is a result of the dramatic increase in the use of rapidly depreciating equipment capital. Asset-specific price indices for gross fixed capital formation are also available at the sector-country pair level. The base year for the price indices is 1995. We use value added as a measure of sector output. The corresponding deflator is also taken from the KLEMS database.

When it comes to the non-price component of the user cost of capital, the main source for the tax rules is ZEW (2013), which provides disaggregated data by asset and sector according to the KLEMS classification. To fill the gap of missing information in the earlier years of our sample, we have used the International Bureau of Fiscal Documentation and the International Tax Summaries by Coopers & Lybrand. Profit taxes are summarized by the headline statutory tax rates on corporate income, augmented by local taxes and surcharges, potentially sector-specific sectors, whenever applicable. Importantly, provisions on tax depreciation allowances and other incentives, such as accelerated depreciation, are also asset-specific. When there are multiple rules under national tax codes, the most efficient scheme is applied. The real discount rate is calculated as the opportunity cost of finance, namely as a weighted average of the cost of equity and the cost of debt, net of CPI inflation. Details on the calculations of the user cost are in Appendix B.

3.2. Stylized facts

Here we illustrate some key features of the data, which further motivate our preference for a disaggregated approach in modelling investment demand. Figure 1 plots the capital-output ratio and the user cost of capital for both the aggregate capital stock and equipment capital. The overall capital-output ratio decreases slightly over the sample period. At the same time, the series for equipment capital appears clearly rising as of the mid-1990s, while being relatively flat previously. Taken together, this evidence points to a compositional shift within physical capital. In particular, the increased use of aggregate equipment is accompanied by a decreased importance of structures, which ultimately drives down the aggregate capital-output ratio. The user cost of capital shows a clear downward trend, with the reduction especially marked in the case of aggregate equipment.

Figure 2 depicts the evolution of quantities and prices for disaggregated capital series. There is a clear declining trend in the use of structures (Panel A, left hand side). Likewise, aggregation hides diverging dynamics also within aggregate equipment capital, where a compositional shift towards short-lived high-tech capital assets is apparent. At the same time, other machinery and equipment shows a strong downward trend over the sample period (Panel B, left hand side). Figure 2 (right hand side column) plots the calculated tax-adjusted user cost of capital for the disaggregated asset series. Again, IT capital assets display similar patterns, with a downward trending user cost, particularly for computers. On the contrary, the user cost of transportation equipment and other machinery and equipment do not show overall clear trends, but rather upward and downward dynamics over shorter sub-periods. The same holds for the user cost of structures (panel A).

In logs, the user cost can be expressed as the sum of two components: the relative price of capital and the non-price component, which comprises the cost of finance and the tax term, in addition to economic depreciation. Figure 3 depicts the evolution of the relative market price and of the tax-term for each of the five assets. As a mirror image of the large rise in volumes, relative prices of both computers and communication equipment (averaged across country-sector pairs) display pronounced negative trends. This is a well-known fact, often taken as evidence of quality improvements stemming from investment-specific technological change (Greenwood *et al.*, 1997). By contrast, the market price for structures is trending upwards, while the relative prices of transportation equipment and other machinery are relatively flat. The tax term of the user cost displays far less heterogeneity across capital assets than the price component (right hand side of figure 3). The significant reduction in statutory tax rates on corporate income across OECD countries seemingly lies behind the generalized downward trend observed for the tax term. Short run dynamics are somewhat more volatile, as they are most likely driven by changes to the asset-specific depreciation allowances.

So far we have focused on the dynamic properties of quantities and prices. Taking a look at the cross-sectional variation in the allocation of the capital assets is also useful, as this would give an indication on the degree of heterogeneity in the underlying production technologies across sectors and countries. In Figure 4 we present box plots for the shares of each capital type into the stock of total capital across sector-country pairs in 2007. Expectedly, structures and other machinery and equipment show the largest median shares. In general, the interquartile range of shares is relatively narrow with respect to the tails of the respective distributions. Moreover, there are quite a few outliers for all assets the short-lived assets.

4. Econometric modelling

The error correction model nests the long run equilibrium demand for capital into a general dynamic regression framework that embeds both the accelerator and the partial adjustment models of capital accumulation. This allows for a flexible representation of the short run investment dynamics. As discussed in section 2, we model the evolution of capital towards its long run equilibrium level as an autoregressive distributed lag (ADL). After experimenting with different lag lengths, we opt for a parsimonious ADL(2,2) specification, written in error correction form as:

$$\Delta k_{i,t} = \alpha_{0i}\Delta y_{i,t} + \alpha_{1i}\Delta y_{i,t-1} - \beta_{0i}\Delta c_{i,t} - \beta_{1i}\Delta c_{i,t-1} + \gamma_{1i}\Delta k_{i,t-1} + \varphi_i\left[(k-y)_{i,t-2} - \beta_{2i}c_{it-2}\right] + u_{it}\ , \tag{9}$$

where small caps indicate natural logarithms of variables, *i* indexes the country-sector pairs, while the subscripts for the capital assets are omitted for simplicity, and the estimating coefficients are combinations of the corresponding coefficients in the model in levels. In equation (9) the growth rate of capital is a function of its own lagged growth rate, current and lagged growth rates of output and of the user cost variable, and an error correction term comprising the capital output ratio and the user cost in levels. This specification allows us to disentangle the short run dynamics and the long run equilibrium relationship between the capital output ratio and the user cost. In particular, error correcting behavior requires that the coefficient on the error correction term in squared brackets, φ_i, be negative, so that if the actual level of the capital stock is above its desired level low future investment rates are expected, and vice versa.

Taking equation (9) to the data in a standard panel approach restricts all the slopes to be the same for each cross-section unit, while only intercepts, modelled as fixed or random, are allowed to vary. In other words, imposing homogeneity constrains all the coefficients indexed with *i* to assume a single value across the cross-section units[6]. In turn, the error term is:

$$u_{it} = d_t + f_i + \varepsilon_{it}, \tag{10}$$

where *f* are fixed effects controlling for time-invariant shocks to investment and *d* are time dummies. The heterogeneous intercepts *f* allow for variation across country-sector pairs of initial conditions, or unobserved factors that affect capital accumulation. The time dummies capture the evolution of these factors. The time effects are constrained to be common across country-sectors and independent of other factors affecting investment. Finally, ε_{it} captures idiosyncratic transitory shocks.

Heterogeneity stemming from different sources, if not adequately accounted for, invalidates the slope homogeneity restriction imposed in the traditional panel approach, with a systematic component being subsumed in the error term[7]. Pesaran and Smith (1995) show that aggregate

[6] Formally, $\alpha_{si} = \alpha_s$ and $\beta_{si} = \beta_s$, for *s=0,1*; $\beta_{2i} = \beta_2$, $\gamma_{1i} = \gamma_1$, and $\varphi_i = \varphi$.

[7] An important issue arises when fitting an equation for gross investment. In that case, conventionally the approximation $\Delta k_{ij,t} \approx I_{ij,t}/K_{ij,t-1} - \delta_j$ is used, where *I* denotes gross investment and *K* the capital stock, both

estimation with non-stationary variables can lead the cointegrating relationship existing at the micro level to break down in a pooled setting, raising the potential for spurious regressions, as discussed in section 2.1. In this case, the error term incorporates a non-stationary component. As a solution, one can estimate individual equations separately, and then average the individual estimates across the cross-section units to obtain the aggregate effects. We implement this approach – the 'Mean Group' (MG) type estimators – by running separate time series regressions for each country-sector pair. Given the underlying theoretical model, this means that each country-sector pair is allowed to use their own (constant-elasticity-of-substitution) production function. Since we are interested mainly in the long run substitution elasticity, we let both long and short run parameters to be heterogeneous[8]. Then, we obtain outlier-robust estimates of the macro impacts as a weighted average of the coefficients. In practice, this entails leaving φ_i and all of the short-term coefficients as group-specific in equation (9).

In addition to coefficient heterogeneity, another important source of concern in estimation is the presence of cross-sectional dependence in the error term due to omitted common factors. Common correlations can arise from macroeconomic shocks affecting all the sectors. Moreover, in our setup, sectoral linkages imply that shocks that are specific to capital-producing sectors propagate throughout the rest of the economy (Foerster *et al.*, 2011). Such interlinkages in the use of capital inputs may effectively transform idiosyncratic shocks into common shocks. While the strength of the amplification mechanism depends on the structure of production linkages between sectors (Horvath, 1998), the scope for transmission clearly increases when an aggregate measure of capital is considered. Common shocks can induce cross-sectional dependence in the residual, and, if correlated with the regressors, result into inconsistent estimates. Likewise, correlation across cross-section units may also lead to significant size distortions in panel unit root tests that assume independence. However, if the extent of cross-sectional dependence of errors is sufficiently weak, or limited to a small number

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in levels. Substituting for net investment into equation (6) to obtain a specification for the gross investment rate shows that the variation in the rate of economic depreciation, δ_j, enters directly the disturbance term (Mairesse et al., 1999). In a pooled model, fixed effects and time dummies can be used to control for such variation. The adequacy of this approach rests on the dynamic characteristics of δ_j, however. As highlighted in section 3.1, the aggregate depreciation rates depend on the composition of aggregate capital, which has changed over time and across sector-country pairs. In this case, part of the variation in the depreciation rate would be subsumed by the idiosyncratic component of the error term, which would then comprise a non-random element. This is likely to induce correlation between the error term and the aggregate user cost, and increase the scope for biased estimates due to cross-section dependence. Thus, the case against aggregation is reinforced when interest lies in the behaviour of gross investment.

[8] An alternative formulation, the Pooled Mean Group proposed by Pesaran and Smith (1997) would only allow the short-term coefficients to be potentially heterogeneous, while imposing homogeneity on the long run coefficients.

of units, then its consequences in a standard setup are negligible (Chudik and Pesaran, 2014). While the conventional pooled estimators control for the presence of unobserved common factors with the time fixed effects, relaxing the slope homogeneity restriction calls for alternative strategies to deal with such unobservables[9]. Specifically, we first implement the Mean Group estimator on cross-sectionally demeaned variables (CDMG), viz., variables measured as deviation from their year-specific average over the whole sample. This procedure eliminates trending components that are common to all sector-country pairs, and thus allows one to deal with common factors affecting capital accumulation, although only imperfectly when slopes are heterogeneous. In addition, by augmenting the estimating equations with country-sector specific linear trends we control for group-specific shocks that evolve linearly over time.

A more general way to model the impact of time-varying unobservables would be to allow for a multiplicative factor structure whereby one lets the common shocks affect freely each cross-section unit. The error term in the estimating equation (9) becomes then:

$$u_{it} = \gamma_i' \boldsymbol{d}_t + \varepsilon_{it} \,, \tag{11}$$

where $\boldsymbol{d}_t$ is a vector of unobserved common factors, and γ_i is the associated vector of factor loadings. The common factors $\boldsymbol{d}_t$, possibly serially correlated, simultaneously affect all cross section units, albeit with different degrees as measured by the loading coefficients. The idiosyncratic error term ε_{it} is still assumed serially uncorrelated. Pesaran (2006) proposes the Common Correlated Effects (CCE) estimators to account for unobserved common factors with heterogeneous factor loadings that can be distinguished from the idiosyncratic errors. The idea is that the linear combinations of the unobserved factors can be approximated by cross-sectional averages of the dependent and of the explanatory variables. Consequently, these terms are used to augment the baseline regression equation. The CCE approach has been shown to be robust with respect to an unknown number of unobserved common factors – as long as their number is relatively fixed compared to the number of cross-section units – of both weak and strong type, which may arise in the presence of global common shocks or local effects, respectively (Pesaran, 2006; Chudik *et al.*, 2011). With heterogeneous coefficients, the CCE correction applies to the MG estimator (CCEMG estimator).

[9] Cross-sectional correlation in macro panels has been addressed using a seemingly unrelated regressions (SURE) framework and estimating the corresponding system of equations by generalized least squares. This approach is not applicable in our context given that the cross-sectional dimension is much larger than the time dimension. Moreover, the SURE approach assumes that the errors are uncorrelated with the regressors.

5. Empirical results

5.1. Time series properties

Since the error correction specification rests on the cointegration between the frictionless capital and the actual level of capital, it is important to investigate the time series properties of the variables. To this end, we employ the panel unit root test proposed by Pesaran (2007), which allows for heterogeneity and cross-sectional correlation[10]. We run the test for up to 3 lags, and found that in general the quantity and price variables are non- stationary in levels, both for the raw and the demeaned series. The detailed results are in Appendix C.

5.2. Investment equations

We estimate equation (9) on both aggregate measures of capital and disaggregated asset types. Our composite variables are total capital and aggregate equipment, which differ only because of the inclusion of structures into the former aggregate[11]. Subsequently, we split aggregate equipment into its components – computers, communication equipment, transportation equipment and other machinery and equipment. In all cases, we apply the different panel techniques discussed in section 4. As an extension, we then allow the price and the non-price components of the user cost to have different impacts on capital accumulation in the long run. Further, we estimate the model for a debt-financed investment. In discussing the estimated coefficients, we focus on the adjustment coefficients and the implied long run substitution elasticity. To put our results in perspective and facilitate comparison with the literature, we test if the substitution elasticity is statistically different from one, the value of the Cobb-Douglas production function. More importantly for our purposes, we also test if the elasticities are equal across asset categories[12]. In this way, we can get an indication of the extent of heterogeneity of the responsiveness of the different types of capital to the price variable. We also perform diagnostic tests for residual stationarity, using again the test proposed by Pesaran

[10] The Pesaran (2007) test allows for heterogeneity in the autoregressive coefficient of the Dickey-Fuller regression and for the presence of a single unobserved common factor with heterogeneous factor loadings. The statistic is based on averaging individual Dickey-Fuller regressions where cross-section averages of the dependent and independent variables (including the lagged differences to account for serial correlation) are included in the model. Under the null hypothesis that each series in the panel has a unit root, the test statistic has a non-standard distribution.

[11] In line with the conventional literature, we use the stock value of these aggregates. The series are already available in EU KLEMS. As an alternative, we also estimated the model using a Tornqvist index for the growth of capital services. These results are available upon request.

[12] Specifically, for each model, we perform pairwise Wald tests for the equality of the long run elasticities. The tests statistics are distributed as chi-squared with degrees of freedom equal to the number of restrictions. Consistency is required to represent the non-linear function of parameters as a linear Taylor series approximation (Greene, 2000, p.298). We obtain the Wald tests under the assumption of independent samples.

(2007), and for the presence of cross-sectional correlation (Pesaran, 2004)[13]. The root mean squared error (RMSE) statistic is reported as a measure of goodness of fit.

5.2.1. Aggregate capital

We first estimate the error correction model for total capital and aggregate equipment using the standard two-way fixed effects (2FE) estimator and the MG estimators. The regression results are in Table 1. First, let us look at the models with homogeneous parameters (first and fourth column, respectively). The short run coefficients are all consistent with the underlying theory and significantly different from zero. The point estimates of φ suggest that the speed of adjustment towards the long-run target level is somewhat slower for total capital than for aggregate equipment. This is consistent with previous evidence pointing to a significantly sluggish adjustment of structures (Desai and Goolsbee, 2004; Schaller, 2006). The implied long run substitution elasticity for total capital is statistically different from one at conventional significance levels, whereas the case for rejecting the Cobb-Douglas benchmark is not equally compelling for equipment capital alone. The estimated elasticities are in the upper range of the literature results, in line with studies using firm-level data, such as Cummins et al. (1996), Schaller (2006), and Caballero et al. (1995). The Wald test rejects the hypothesis of equal long run elasticities at 5% level (p-value of 0.012). Residual diagnostics reveal the presence of strong cross-sectional dependence. Moreover, the residuals in the equation for aggregate equipment appear non-stationary, which casts doubt on the validity of the inference drawn for that specification.

Allowing for heterogeneous parameters with demeaned variables (second and fifth column in Table 1) results into a faster speed of adjustment and decreased long-run elasticities (in absolute value). In particular, the coefficients are half in size compared to the 2FE estimates. The test for a unit long-run elasticity is rejected for both capital aggregates. Moreover, the Wald test does not reject the hypothesis that the long-run elasticities for the two capital series are equal. While the residuals in both equations appear stationary, demeaning does not alleviate the problem of strong cross-sectional dependence. The estimates from the CCE version of the Mean Group model (third and sixth column) point to long-run elasticities centered on 0.4 rather than one. These results broadly corroborate the findings in Bond and Xing (2015), who estimate

[13] The test for cross-section dependence (CD) is based on estimates of pairwise error correlations. The null is that the average pairwise correlations are equal to zero, thus errors are not correlated. Pesaran (2015) has shown that the distribution of the test depends on the relative order of convergence of N and T (the cross-section and time series dimensions, respectively), and thus redefined the implicit null in terms of weak cross-sectional correlation. Chudik and Pesaran (2014) prove validity of the test in the presence of weakly exogenous regressors.

elasticities for total capital between -0.5 and -0.3, values within the range of previous findings (Smith, 2008). Again, we cannot reject the hypothesis that the elasticities are statistically equal at conventional significance levels. Importantly, the residuals from the model are well behaved, as they are stationary and reveal only weak cross-sectional dependence.

5.2.2. Disaggregated capital

We estimate the error correction model in equation (9) separately for structures and for the different equipment types – computers, communication equipment, transportation equipment, and other machinery and equipment. We start from the standard 2FE pooled model, and then implement the Mean Group approach. The results are reported in Table 2 and 3, respectively. The speed of adjustment of the capital series to their long-run targets is faster for computers than for other types of equipment, while structures exhibit, expectedly, a sluggish behavior. The long-run substitution elasticity is not statistically different from one in the case of IT capital (computers and communication equipment) and, marginally, transportation equipment. Structures and other machinery and equipment display much lower elasticities (in absolute value), but still statistically significant (see Table 2). The findings are consistent with previous evidence pointing to a relatively high responsiveness of short-lived capital, particularly computers (Tevlin and Whelan, 2003) compared to slow depreciating assets (Bakhshi et al. 2003). Residual inspection for the different types of equipment does not give fully reassuring results when it comes to stationarity, however. Strong cross-sectional dependence is also an issue for all asset types, except computers. We interpret this result as evidence of the different nature of the unobservable common shocks hitting the different capital goods. Specifically, in the case of computing equipment the shocks seem common to sectors and countries. This is fully consistent with supply side shocks, stemming precisely from the technological improvements reflected in steadfastly declining market prices. As such, these unobservable factors can be adequately controlled for by the time fixed effects in the model with homogeneous parameters. By contrast, unobservable shocks to the other types of capital seemingly have a different nature. Hence, in this case, we expect neglected heterogeneity across countries and sectors to play an important role in contributing to overall cross-sectional dependence.

Next, we relax the assumption of homogeneous parameters across country-sector pairs by implementing the Mean Group approach. The results are in Table 3. We first consider variables in deviations from their sample mean in the different years, which allows us to control for unobservables under the maintained assumption that they have common impact on the cross-section units (the corresponding estimates are in the columns with CDMG headings). The estimated parameters of interest are highly significant throughout. The long run elasticities (in absolute value) are half in size compared to the regression with homogeneous parameters. By contrast, the estimates of the error correction term point to a much faster speed of adjustment for all the assets. The residuals are in general stationary. However, in general, the ability to control for strong cross-sectional dependence is not particularly satisfactory. Results from the CCE version of the MG estimator are reported in the CCEMG columns. Strikingly, the speed of adjustment for computers is much faster than the previous estimates would suggest. Looking at the diagnostics shows that the residuals from all the equations are stationary, while cross-sectional dependence also appears significantly reduced for all asset types, except for computers. The combined reading of these regression diagnostics leads us to prefer the CCEMG estimates. The estimated long run substitution elasticities, of the same order of magnitude as the CDMG estimates but with a lower dispersion, are centered on 0.5, a value that does not deviate substantially from the bulk of the results in the literature obtained with different techniques and data samples (Chirinko, 2008).

Table 4 reports the p-values of the pairwise Wald statistics testing the equality of the long run elasticities in Tables 2 and 3. The test results for the homogeneous parameter models suggest the clustering of capital assets into two classes. The long run elasticities of the fast depreciating assets are not statistically different from one another, although at varying significance levels. Likewise, structures and other machinery and equipment display statistically similar elasticities. These results are broadly confirmed when the Mean Group estimator with demeaned variables is used. However, our preferred MG estimator with common correlated effects points to a much lower degree of differentiation of the long run elasticities. In particular, the p-values confirm that the hypothesis of equality in general cannot be rejected, although only marginally in the comparison between computers and the long-lived assets, i.e. structures and other machinery and equipment.

5.2.3. Extensions

Disentangling the effects of the price and the non-price components of the user cost. – The stylized facts presented in section 3.2 corroborate our claim that both components of the user cost, namely the relative price and the non-price term, are potential sources of heterogeneity. Thus, we look at them separately in the regressions. Splitting the user cost into its two components increases the number of estimated parameters, making the implementation of the

MG estimators quite problematic given the moderate time series dimension of our sample. Therefore, we opt for a more parsimonious specification where we let the two terms affect investment differently only in the long run, while the short-term dynamics are left unchanged compared to the baseline regressions. The estimating equation is:

$$\Delta k_{i,t} = \alpha_{0i}\Delta y_{i,t} + \alpha_{1i}\Delta y_{i,t-1} - \beta_{0i}\Delta c_{i,t} - \beta_{1i}\Delta c_{i,t-1} + \gamma_{1i}\Delta k_{i,t-1} + \varphi_i\big[(k-y)_{i,t-2} - \beta_{2i}p_{it-2} - \beta_{3i}g_{it-2}\big] + u_{it} \, , \tag{12}$$

where all of the variables are as before, except that the variable for the user cost of capital is now replaced by two terms, i.e. the relative price of capital (p) and the non-price term (g), both in logs. We report only the results for the error correction term and the long run elasticities in Table 5[14]. Since the CCEMG estimator again shows the most satisfactory performance in addressing cross-section dependence, we focus on the results from that model. The long run elasticities for both the relative price and the non-price components of the user cost have the expected sign and are mostly estimated with precision. The coefficients of the price term show a larger dispersion than those of the non-price term. In general, the pairwise Wald tests cannot reject the null hypothesis of equal coefficients, although only marginally for communication equipment, whose long run elasticity is not statistically different from zero, however (see table D-1 in Appendix D).

Debt-financed investment. – In standard corporate income tax systems, debt enjoys a favorable treatment relative to equity financing because interest is deductible. As shown in section 2, the tax advantage of debt reduces the tax-adjusted user cost with respect to the equivalent under equity finance. Testing the responsiveness of investment to the user cost under debt financing is of particular interest in our setup because, presumably, incentives to resort to external finance differ across asset types and sectors. For instance, long-lived and relatively non-specialized capital goods might be more easily pledged as collateral, and thus offer better opportunities for debt finance than short-lived and specialized assets, ceteris paribus. Again, to avoid a significant challenge to our data in terms of the number of parameters to be estimated the MG approach, we restrict the short run dynamics and allow for separate identification of the debt term as in equation (4) only in the long run equilibrium condition. The estimating equation is therefore:

[14] Full results are available upon request.

$$\Delta k_{i,t} = \alpha_{0i}\Delta y_{i,t} + \alpha_{1i}\Delta y_{i,t-1} - \beta_{0i}\Delta c_{i,t}^{debt} - \beta_{1i}\Delta c_{i,t-1}^{debt} + \gamma_{1i}\Delta k_{i,t-1} + \varphi_i\left[(k-y)_{i,t-2} - \beta_{2i}c_{it-2} - \beta_{4i}h_{it-2}\right] + u_{it}\ , \tag{13}$$

where $c_i^{debt}$is the tax-adjusted user cost calculated under debt finance, with h being the debt term that reduces the user cost with retained earnings finance, still indicated by c (see equation (4) in section 2). The results are in Table 6. The long-run substitution elasticities obtained from the MG models are broadly in line with those estimated under retained earnings finance (see Table 3), particularly for transportation equipment and other machinery and equipment. However, as before, the CCEMG model performs better in terms of correction for cross-sectional dependence in the residuals. In both cases, the pairwise Wald tests reported in Appendix D again seem to point to the elasticities being not significantly different. The term capturing the tax advantage of debt is not estimated with precision, except in the case of transportation equipment, where it is negative and relatively large in magnitude. Overall, the results do not indicate a strong additional effect of tax savings from debt finance on capital accumulation, except for the case of transportation equipment.

6. Conclusions

Empirical models of investment for aggregate capital may be plagued by inherent biases because of neglected heterogeneity originating from asset and sector specificities. In this paper, we investigate the effects of imposing homogeneity on the long run substitution elasticity using a panel of 23 sectors in 10 OECD countries over the period 1984-2007. We perform the analysis for capital stock aggregates as well as for individual asset types – namely computers, communication equipment, transportation equipment, other machinery and equipment, and structures. We further relax homogeneity by using panel techniques with heterogeneous parameters next to the standard pooled models.

We find that the tax-adjusted user cost significantly influences capital accumulation, both for aggregate and disaggregated series. Results from the standard two-way fixed effects model suggest that long-lived assets displays statistically similar long run elasticities, consistent in size with the unit benchmark. We do not find significant differences also among the elasticities short-lived assets, which are, expectedly, also smaller in magnitude. However, conventional panel data models, by imposing parameter homogeneity across countries and sectors, increase the risk of spurious regression and do not correct for cross-sectional correlation in the residuals. In this respect, the homogeneity assumption proves critical for virtually all assets, except computers, for which we can pin down the common supply side nature of technological shocks.

Allowing for heterogeneous parameters reduces both the magnitude and the dispersion of the estimated long run elasticities for the different assets types. Once we account for unobserved common factors affecting investment using cross-section averages in the country-industry regressions, we cannot reject the hypothesis that the long run substitution elasticities are statistically similar across asset types. Moreover, we concur with evidence of a more muted impact than the neoclassical unit benchmark.

References

Bakhshi, Hasan, Nicholas Oulton and Jamie Thompson. 2003. "Modelling investment when relative prices are trending: theory and evidence for the United Kingdom." Bank of England Working Papers, 189.

Bloom, Nick, Steve Bond, and John Van Reenen. 2007. "Uncertainty and investment dynamics." *Review of Economic Studies*, 74: 391-415.

Bond, Steve, and Jing Xing. 2015. "Corporate Taxation and Capital Accumulation: Evidence from Sectoral Panel Data for 14 OECD Countries." *Journal of Public Economics*, 130: 15-31.

Bond, Steve, and John Van Reenen. 2007. *Microeconometric models of investment and employment*, Chapter 65, Handbook of Econometrics, vol. 6A.

Bond, Steve, Julie Elston, Jacques Mairesse, and Benoit Mulkay. 2003. "Financial Factors and Investment in Belgium, France, Germany, and the United Kingdom: A Comparison Using Company Panel Data." *The Review of Economics and Statistics*, 85(1): 153-165.

Caballero, Ricardo J. 1997. "Aggregate Investment." NBER Working Paper 6264.

Caballero, Ricardo J., Eduardo M.R.A. Engel, and John C. Haltiwanger. 1995. "Plant-level Adjustment and Aggregate Investment Dynamics." *Brookings Papers on Economic Activity*, 2: 1-39.

Chirinko, Robert S. 2008. "σ – The Long and Short of it." *Journal of Macroeconomics*, 30(2): 671-86.

Chirinko, Robert S. 1993a. "Business Fixed Investment Spending: Modeling Strategies, Empirical Results, and Policy Implications." *Journal of Economic Literature*, 31(4): 1875-1911.

Chirinko, Robert S. 1993b. "Multiple Capital Inputs, Q, and Investment Spending." *Journal of Economic Dynamics and Control*, 17 (5–6): 907-28.

Chudik, Alexander, and M. Hashem Pesaran. 2014. "Large Panel Data Models with Cross-Sectional Dependence: A Survey" In *The Oxford Handbook of Panel Data*, ed. Badi H. Baltagi. 3–45. Oxford University Press.

Chudik, Alexander, M. Hashem Pesaran and Elisa Tosetti. 2011. "Weak and Strong Cross Section Dependence and Estimation of Large Panels." *Econometrics Journal*, 14(1):C45–C90.

Clark, Peter K. 1993. "Tax Incentives and Equipment Investment." *Brookings Papers on Economic Activity*, 1: 317-39.

Coopers & Lybrand, various years. International Tax Summaries.

Cummins, Jason G., Kevin A. Hassett, and R. Glenn Hubbard. 1996. "Tax Reforms and Investment: a Cross-Country Comparison." *Journal of Public Economics*, 62(1-2): 237-73.

Desai, Mihir, and Austan Goolsbee. 2004. "Investment, Overhang, and Tax Policy." *Brookings Papers on Economic Activity*, 2:285-338.

Foerster, Andrew T., Pierre-Daniel Sarte, and Mark W. Watson. 2011. "Sectoral versus Aggregate Shocks: A Structural Factor Analysis of Industrial Porduction." *Journal of Political Economy*, 119(1): 1-38.

Goolsbee, Austan. 1998. "Investment Tax Incentives, Prices, and the Supply of Capital Goods." *Quarterly Journal of Economics*, 113(1):121-48.

Goolsbee, Austan. 2000. "The Importance of Measurement Error in the Cost of Capital." *National Tax Journal*, 53(2):215-28.

Greene, William H. (2000). *Econometric Analysis*, Prentice Hall International.

Greenwood, Jeremy, Zvi Hercowitz, and Per Krusell. 1997. "Long-run implications of investment-specific technological change." *American Economic Review*, 87(3): 342-362.

Hall, Robert E., and Dale W. Jorgenson. 1967. "Tax Policy and Investment Behavior." *American Economic Review*, 57 (3): 391-414.

Hayashi, Fumio, and Tohru Inoue. 1991. "The Relation between Firm Growth and Q with Multiple Capital Goods: Theory and Evidence from Panel Data on Japanese Firms." *Econometrica*, 59(3): 731-53.

Horvath, Michael. 1998. "Cyclicality and Sectoral Linkages: Aggregate Fluctuations from Independent Sectoral Shocks." *Review of Economic Dynamics*, 1:781–808.

House, Christopher L., and Matthew D. Shapiro. 2008. "Temporary Investment Tax Incentives: Theory with Evidence from Bonus Depreciation." *American Economic Review*, 98(3): 737-68.

International Bureau of Fiscal Documentation (IBFD), various years. European Tax Handbook.

Mairesse, Jacques, Bronwyn H. Hall, and Benoit Mulkay. 1999. "Firm-level Investment in France and the United States: an Exploration of What We Have Learned in Twenty Years." *Annales d'Economie et Statistique*, 55-56: 27-67.

O'Mahony, Mary, and Marcel P. Timmer. 2009. "Output, Input and Productivity Measures at the Sector Level: the EU KLEMS Database." *Economic Journal*, 119(538): F374-F403.

Pesaran M. Hashem, and Ronald P. Smith. 1995. "Estimating Long-Run Relationships from Dynamic Heterogeneous Panels." *Journal of Econometrics* 68(1):79–113.

Pesaran, M. Hashem. 2015. “Testing Weak Cross-Sectional Dependence in Large Panels.” *Econometric Reviews*, 34(6-10), 1089-1117.

Pesaran, M. Hashem. 2007. “A simple panel unit root test in the presence of cross-section dependence.” *Journal of Applied Econometrics*, 22(2): 265–312.

Pesaran, M. Hashem. 2004. “General Diagnostic Tests for Cross Section Dependence in Panels.” Cambridge Working Papers in Economics 0435.

Pesaran, M. Hashem. 2006. “Estimation and Inference in Large Heterogeneous Panels with a Multifactor Error Structure.” *Econometrica*, 74(4): 967–1012.

Schaller, Huntley. 2006. “Estimating the Long-Run User Cost Elasticity.” *Journal of Monetary Economics*, 53: 725-36.

Smith, Jamie. 2008. “That Elusive Elasticity and the Ubiquitous Bias: is Panel Data a Panacea?” *Journal of Macroeconomics*, 30(2): 760–779.

Tevlin, Stacey, and Karl Whelan. 2003. “Explaining the Investment Boom of the 1990s.” *Journal of Money, Credit and Banking* 35(1): 1-22.

Wildasin, David E. 1984. “The Q Theory of Investment with Many Capital Goods.” *American Economic Review*, 74(1): 203-10.

ZEW, 2013. *Effective Tax Rates at the Sector Level using the Devereux-Griffith methodology*. Report for the European Commission, DG Taxation and Customs Union.

Figures and tables

Figure 1 Capital-output ratios and user cost of capital – aggregate capital series

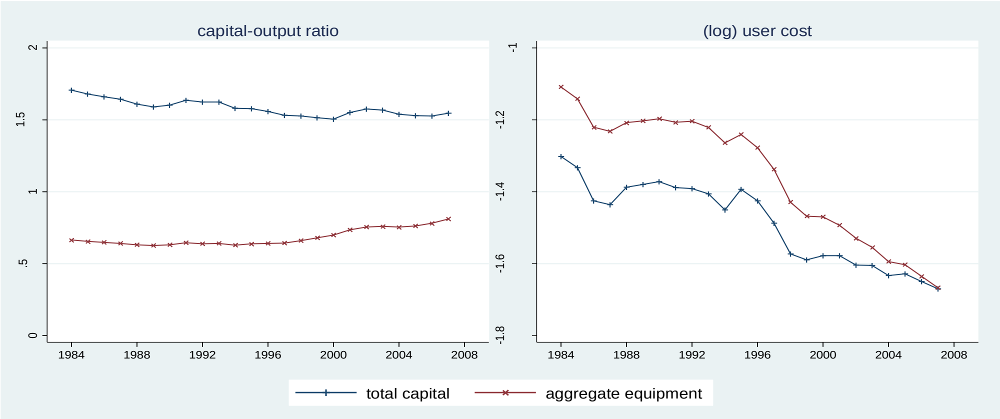


Figure 2 Capital-output ratios and user cost of capital – disaggregated capital series

Panel A: Structures

Panel B: Equipment

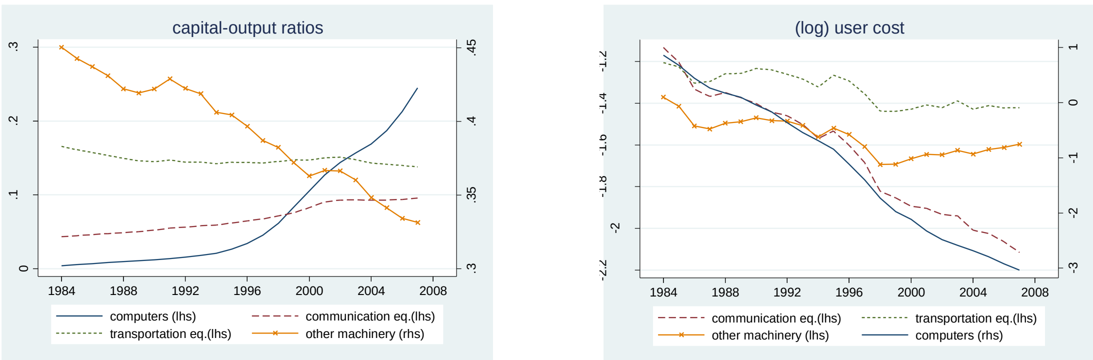


FIGURE 3 USER COST OF CAPITAL: RELATIVE PRICE AND TAX TERM (IN LOGS) – DISAGGREGATED CAPITAL SERIES

PANEL A: STRUCTURES

PANEL B: EQUIPMENT

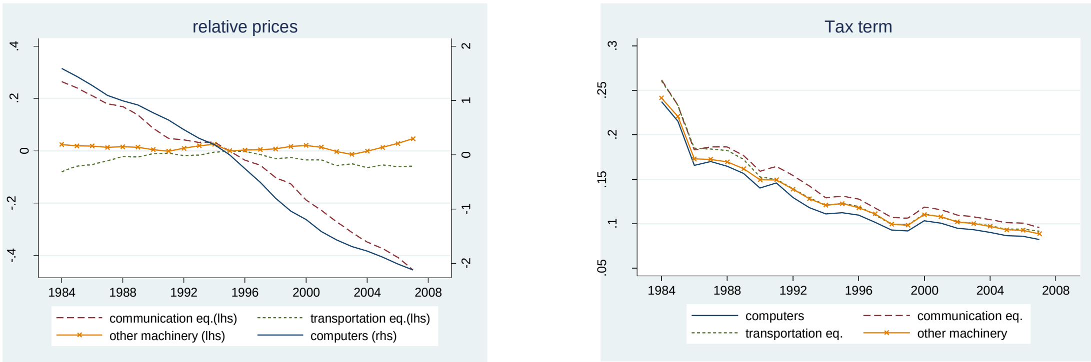
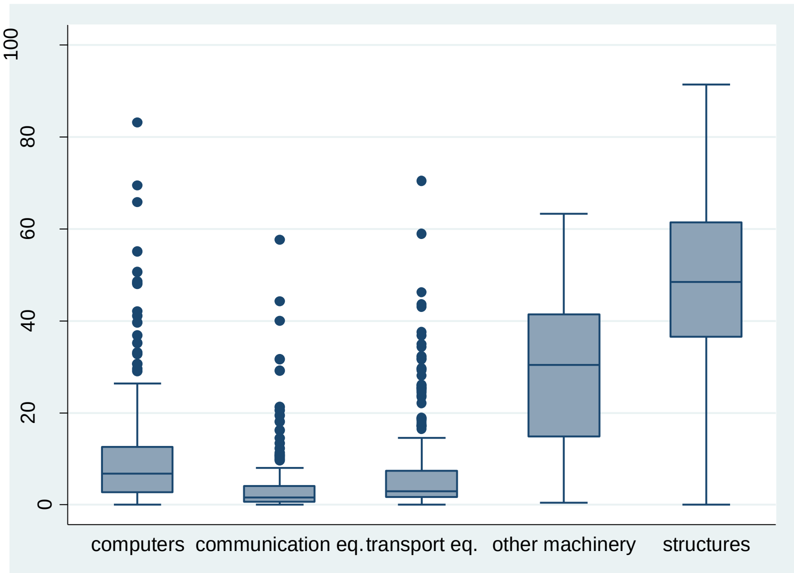


FIGURE **4** **ASSET SHARES ACROSS COUNTRIES AND SECTORS**



Notes: Box plots for the median and the interquartile ranges (shaded) of the shares of asset types into aggregate capital stock at the level of country-sector pairs. Shares are for 2007. Dots indicate outliers.

TABLE 1. ERROR CORRECTION MODEL FOR AGGREGATE CAPITAL

	Total capital			*Aggregate equipment*		
Coefficient of:	*2FE*	*CDMG*	*CCEMG*	*2FE*	*CDMG*	*CCEMG*
Δy	0.045***	0.082***	0.102***	0.070***	0.151***	0.159***
	[0.008]	[0.007]	[0.011]	[0.013]	[0.009]	[0.019]
Δy_{t-1}	0.043***	0.093***	0.128***	0.057***	0.141***	0.230***
	[0.009]	[0.007]	[0.015]	[0.018]	[0.011]	[0.024]
Δuc	-0.036***	-0.027***	-0.027***	-0.050***	-0.056***	-0.056***
	[0.006]	[0.005]	[0.009]	[0.009]	[0.009]	[0.014]
Δuc_{t-1}	-0.027***	-0.031***	-0.055***	-0.052***	-0.055***	-0.113***
	[0.007]	[0.006]	[0.012]	[0.009]	[0.011]	[0.022]
Δk _{t-1}	0.501***	0.181***	-0.242***	0.438***	0.113***	-0.419***
	[0.035]	[0.023]	[0.031]	[0.035]	[0.022]	[0.032]
Speed of adjustment (φ)	-0.029***	-0.115***	-0.156***	-0.042***	-0.172***	-0.317***
	[0.005]	[0.008]	[0.015]	[0.006]	[0.011]	[0.023]
Long-run elasticity (β_2)	-0.729***	-0.308***	-0.409***	-0.863***	-0.321***	-0.422***
	[0.101]	[0.067]	[0.096]	[0.083]	[0.078]	[0.090]
Unit long run elasticity (p-value)	0.007	0.000	0.000	0.097	0.000	0.000
Order of integration	I(0)	I(0)	I(0)	I(1)	I(0)	I(0)
CD test (p-value)	0.000	0.000	0.074	0.001	0.000	0.859
RMSE	0.0253	0.0156	0.0083	0.0396	0.0251	0.0131
Observations	5060	5060	5060	5060	5060	5060
Country-sector pairs	230	230	230	230	230	230

Notes: we estimate the error correction model: $\Delta k_{I,t} = \alpha_{0i}\Delta y_{I,t} + \alpha_{1i}\Delta y_{I,t-1} - \beta_{0i}\Delta c_{I,t} - \beta_{1i}\Delta c_{I,t-1} + \gamma_{1i}\Delta k_{I,t-1} + \varphi_i\left[(k - y)_{I,t-2} - \beta_{2i}c_{it-2}\right] + u_{it}$. Estimation methods: 2FE – Two-way Fixed Effects, CDMG – Mean Group (MG) estimator with cross-sectionally demeaned variables, CCEMG – Pesaran (2006) Common Correlated Effects (CCE) version of the MG estimator. MG estimates also include linear trends (specific to the country-sector pairs). For the MG estimates, outlier-robust estimates of the mean for each parameter across country-sector pairs are reported. White heteroskedasticity-robust standard errors in brackets. *** p<0.01, ** p<0.05, * p<0.1. Diagnostics: The CD test (p-value) is the p-value of the Pesaran (2015) test for cross section dependence in the residuals, which is distributed as a standard normal under the null hypothesis of weak cross section dependence. The order of integration of the residuals is determined using the Pesaran (2007) test: I(0) – stationary, I(1) – non-stationary, I(1)/I(0) – ambiguous result. RMSE: Root Mean Squared Error. Results of the Wald tests for equal long-run elasticities (p-value): 2FE: 0.012; CDMG: 0.924; CCEMG: 0.754.

TABLE 2. ERROR CORRECTION MODELS FOR DISAGGREGATED CAPITAL: HOMOGENEOUS PARAMETERS

	Computers	*Transportation equipment*	*Other machinery and equipment*	*Communication equipment*	*Structures*
Δy	0.248***	0.110***	0.089***	0.111***	0.248***
	[0.065]	[0.029]	[0.014]	[0.030]	[0.065]
Δy_{t-1}	0.145***	0.057**	0.071***	0.056***	0.145***
	[0.039]	[0.035]	[0.014]	[0.017]	[0.039]
Δuc	-0.182***	-0.068***	-0.042***	-0.098***	-0.182***
	[0.031]	[0.015]	[0.009]	[0.013]	[0.031]
Δuc_{t-1}	-0.179***	-0.048***	-0.036***	-0.065***	-0.179***
	[0.032]	[0.016]	[0.008]	[0.013]	[0.032]
Δk_{t-1}	0.168***	0.235***	0.391***	0.485***	0.168***
	[0.029]	[0.081]	[0.067]	[0.035]	[0.029]
Speed of adjustment (φ)	-0.102***	-0.044***	-0.035***	-0.039***	-0.014***
	[0.013]	[0.017]	[0.010]	[0.005]	[0.005]
Long-run elasticity (β_2)	-1.018***	-1.475***	-0.562***	-1.047**	-0.434**
	[0.068]	[0.284]	[0.102]	[0.129]	[0.129]
Unit long run elasticity (p-value)	0.794	0.095	0.000	0.716	0.000
Order of integration	I(0)/ I(1)	I(1)	I(1)/I(0)	I(1)/I(0)	I(0)
CD test (p-value)	0.983	0.000	0.000	0.002	0.000
RMSE	0.1374	0.0854	0.0483	0.0611	0.0223
Observations	5060	5038	5060	5038	5038
Country-sector pairs	230	229	230	229	229

Notes: we estimate the error correction model: $\Delta k_{I,t} = \alpha_{0i}\Delta y_{I,t} + \alpha_{1i}\Delta y_{I,t-1} - \beta_{0i}\Delta c_{I,t} - \beta_{1i}\Delta c_{I,t-1} + \gamma_{1i}\Delta k_{I,t-1} + \varphi_i\left[(k - y)_{I,t-2} - \beta_{2i}c_{it-2}\right] + u_{it}$. Estimation method: 2FE – Two-way Fixed Effects. White heteroskedasticity-robust standard errors in brackets. *** p<0.01, ** p<0.05, * p<0.1. Diagnostics: the CD test (p-value) is the p-value of the Pesaran (2015) test for cross section dependence in the residuals, which is distributed as a standard normal under the null hypothesis of weak cross section dependence. The order of integration of the residuals is determined using the Pesaran (2007) test: I(0) – stationary, I(1) – non-stationary, I(1)/I(0) – ambiguous result. RMSE: Root Mean Squared Error. Results of the pairwise Wald tests for equal long run elasticities are in Table 4.

TABLE 3. ERROR CORRECTION MODELS FOR DISAGGREGATED CAPITAL: HETEROGENEOUS PARAMETERS

	Computers		*Transportation equipment*		*Other machinery and equipment*		*Communication equipment*		*Structures*	
	CDMG	*CCEMG*	*CDMG*	*CCEMG*	*CDMG*	*CCEMG*	*CDMG*	*CCEMG*	*CDMG*	*CCEMG*
Δy	0.326***	0.399***	0.159***	0.121***	0.117***	0.146***	0.145***	0.153***	0.033***	0.034***
	[0.045]	[0.068]	[0.018]	[0.031]	[0.011]	[0.018]	[0.017]	[0.025]	[0.006]	[0.008]
Δy_{t-1}	0.341***	0.565***	0.079***	0.220***	0.138***	0.195***	0.107***	0.162***	0.044***	0.050***
	[0.040]	[0.063]	[0.017]	[0.035]	[0.011]	[0.019]	[0.017]	[0.034]	[0.006]	[0.011]
Δuc	-0.134***	-0.189***	-0.060***	-0.018	-0.037***	-0.045***	-0.070***	-0.085***	-0.008***	-0.008
	[0.037]	[0.055]	[0.015]	[0.027]	[0.009]	[0.013]	[0.013]	[0.022]	[0.003]	[0.005]
Δuc_{t-1}	-0.275***	-0.457***	-0.078***	-0.088**	-0.049***	-0.075***	-0.065***	-0.083***	-0.013***	-0.023***
	[0.043]	[0.077]	[0.018]	[0.037]	[0.010]	[0.017]	[0.015]	[0.031]	[0.003]	[0.006]
Δk_{t-1}	-0.101***	-0.693***	0.027	-0.293***	-0.081***	-0.225***	0.174***	-0.243***	0.218***	-0.190***
	[0.025]	[0.034]	[0.025]	[0.033]	[0.023]	[0.033]	[0.023]	[0.034]	[0.022]	[0.031]
Speed of adjustment (φ)	-0.328***	-0.782***	0.245***	-0.254***	-0.164***	-0.217***	-0.158***	-0.294***	-0.064***	-0.084***
	[0.018]	[0.047]	[0.015]	[0.024]	[0.011]	[0.020]	[0.010]	[0.026]	[0.006]	[0.013]
Long-run elasticity (β_2)	-0.558***	-0.733***	-0.737***	-0.604***	-0.281***	-0.318***	-0.508***	-0.479***	-0.254***	-0.372***
	[0.138]	[0.128]	[0.107]	[0.196]	[0.071]	[0.104]	[0.112]	[0.141]	[0.061]	[0.120]
Unit long run elasticity (p value)	0.001	0.037	0.014	0.043	0.000	0.000	0.000	0.000	0.000	0.000
Order of integration	I(0)	I(0)	I(0) / I(1)	I(0)	I(0)	I(0)	I(0)	I(0)	I(0)	I(0)
CD test (p-value)	0.059	0.000	0.000	0.249	0.000	0.027	0.000	0.251	0.000	0.707
RMSE	0.0903	0.0445	0.0497	0.0238	0.0301	0.0167	0.0414	0.0215	0.0147	0.0084
Observations	5060	5060	5038	5038	5060	5060	5060	5060	5038	5038
Country-sector pairs	230	230	229	229	230	230	230	230	229	229

Notes: we estimate the error correction model: $\Delta k_{I,t} = \alpha_{0i}\Delta y_{I,t} + \alpha_{1i}\Delta y_{I,t-1} - \beta_{0i}\Delta c_{I,t} - \beta_{1i}\Delta c_{I,t-1} + \gamma_{1i}\Delta k_{I,t-1} + \varphi_i\left[(k-y)_{I,t-2} - \beta_{2i}c_{it-2}\right] + u_{it}$. Estimation methods: CDMG – Mean Group (MG) estimator with cross-sectionally demeaned variables, CCEMG – Pesaran (2006) Common Correlated Effects (CCE) version of the MG estimator. Estimates also include linear trends (specific to the country-sector pairs). Outlier-robust estimates of the mean for each parameter across country-sector pairs are reported. White heteroskedasticity-robust standard errors in brackets. *** p<0.01, ** p<0.05, * p<0.1. Diagnostics: the CD test (p-value) is the p-value of the Pesaran (2015) test for cross section dependence in the residuals, which is distributed as a standard normal under the null hypothesis of weak cross section dependence. The order of integration of the residuals is determined using the Pesaran (2007) test: I(0) – stationary, I(1) – non-stationary, I(1)/I(0) – ambiguous result. RMSE: Root Mean Squared Error. Results of the pairwise Wald tests for equal long run elasticities are in Table 4.

TABLE 4. PAIRWISE TESTS (P-VALUES) FOR EQUALITY OF LONG RUN ELASTICITIES – BASELINE MODEL

	Computers	*Transportation equipment*	*Other machinery and equipment*	*Communication equipment*
		2FE		
Transportation equipment	0.108			
Other machinery and equipment	0.000	0.002		
Communication equipment	0.828	0.151	0.001	
Structures	0.000	0.000	0.373	0.000
		CDMG		
Transportation equipment	0.306			
Other machinery and equipment	0.073	0.000		
Communication equipment	0.777	0.140	0.088	
Structures	0.044	0.000	0.780	0.047
		CCEMG		
Transportation equipment	0.581			
Other machinery and equipment	0.012	0.198		
Communication equipment	0.182	0.606	0.357	
Structures	0.039	0.312	0.738	0.560

Notes: the table reports the p-values for the tests of equal long run elasticities for the error correction models with homogeneous parameters (regression results in Table 2) and with heterogeneous parameters (regression results in Table 3). The Wald statistics is distributed as a $\chi^2(1)$.

TABLE 5. ERROR CORRECTION MODELS FOR DISAGGREGATED CAPITAL: HETEROGENEOUS PARAMETERS – DECOMPOSED USER COST

	Computers		*Transportation equipment*		*Other machinery and equipment*		*Communication equipment*		*Structures*	
	CDMG	CCEMG	CDMG	CCEMG	CDMG	CCEMG	CDMG	CCEMG	CDMG	CCEMG
Speed of adjustment $(\varphi\quad)$	-0.352***	-0.827***	-0.272***	-0.309***	-0.183***	-0.251***	-0.171***	-0.246***	-0.074***	-0.094***
	[0.019]	[0.056]	[0.016]	[0.035]	[0.013]	[0.026]	[0.011]	[0.026]	[0.006]	[0.018]
Long-run elasticity:										
Relative price component (β_2)	-0.683***	-0.745***	-0.634***	-0.689***	-0.323***	-0.412***	-0.644***	-0.251	-0.334***	-0.554***
	[0.160]	[0.155]	[0.132]	[0.215]	[0.091]	[0.139]	[0.150]	[0.163]	[0.090]	[0.178]
Non-price component (β_3)	-0.326	-0.452**	-0.741***	-0.418	-0.332***	-0.478***	-0.445**	-0.385**	-0.202***	-0.300**
	[0.295]	[0.222]	[0.143]	[0.272]	[0.105]	[0.154]	[0.178]	[0.165]	[0.072]	[0.141]
Unit long run elasticity - price component (p-value)	0.047	0.100	0.005	0.147	0.000	0.000	0.018	0.000	0.000	0.012
Order of integration	I(0)	I(0)	I(0)	I(0)	I(0) /I(1)	I(0)	I(0)	I(0)	I(0)	I(0)
CD test (p-value)	0.029	0.377	0.000	0.096	0.000	0.112	0.000	0.018	0.000	0.293
RMSE	0.0851	0.0333	0.0468	0.0176	0.0286	0.0112	0.0389	0.0148	0.0138	0.0067
Observations	5060	5060	5038	5038	5060	5060	5060	5060	5038	5038
Country-sector pairs	230	230	229	229	230	230	230	230	229	229

Notes: we estimate the error correction model: $\Delta k_{i,t} = \alpha_{0i}\Delta y_{i,t} + \alpha_{1i}\Delta y_{i,t-1} - \beta_{0i}\Delta c_{i,t} - \beta_{1i}\Delta c_{i,t-1} + \gamma_{1i}\Delta k_{i,t-1} + \varphi_i\left[(k-y)_{i,t-2} - \beta_{2i}p_{it-2} - \beta_{3i}g_{it-2}\right] + u_{it}$. Estimation methods: CDMG – Mean Group (MG) estimator with cross-sectionally demeaned variables, CCEMG – Pesaran (2006) Common Correlated Effects (CCE) version of the MG estimator. Estimates also include linear trends (specific to the country-sector pairs). Outlier-robust estimates of the mean for each parameter across country-sector pairs are reported. White heteroskedasticity-robust standard errors in brackets. *** p<0.01, ** p<0.05, * p<0.1. Diagnostics: the CD test (p-value) is the p-value of the Pesaran (2015) test for cross section dependence in the residuals, which is distributed as a standard normal under the null hypothesis of weak cross section dependence. The order of integration of the residuals is determined using the Pesaran (2007) test: I(0) – stationary, I(1) – non-stationary, I(1)/I(0) – ambiguous result. RMSE: Root Mean Squared Error. Results of the pairwise Wald tests for equal long run elasticities are in Table D-1 in Appendix D.

TABLE 6. ERROR CORRECTION MODELS FOR DISAGGREGATED CAPITAL: HETEROGENEOUS PARAMETERS – DEBT FINANCE

	Computers		*Transportation equipment*		*Other machinery and equipment*		*Communication equipment*		*Structures*	
	CDMG	CCEMG	CDMG	CCEMG	CDMG	CCEMG	CDMG	CCEMG	CDMG	CCEMG
Speed of adjustment	-0.350***	-0.849***	-0.278***	-0.377***	-0.179***	-0.327**	-0.196***	-0.381***	-0.068***	-0.093***
	[0.019]	[0.065]	[0.015]	[0.034]	[0.012]	[0.032]	[0.010]	[0.038]	[0.007]	[0.017]
Long-run elasticity:										
User cost (β_2)	-0.424***	-0.467***	-0.655***	-0.559***	-0.362***	-0.301**	-0.373***	-0.269**	-0.206***	-0.034
	[0.131]	[0.148]	[0.120]	[0.173]	[0.079]	[0.122]	[0.114]	[0.131]	[0.064]	[0.132]
Debt tax advantage (β_4)	-0.010	-0.393	-0.846***	-1.365***	-0.146	-0.268	-0.206	0.232	-0.040	0.419
	[0.612]	[0.397]	[0. 243]	[0.378]	[0.150]	[0.179]	[0.272]	[0.234]	[0.148]	[0.268]
Unit long run elasticity (p-value)	0.000	0.000	0.004	0.011	0.000	0.000	0.000	0.000	0.000	0.000
Order of integration	I(0)	I(0)	I(0)	I(0)	I(0)	I(0)	I(0)	I(0)	I(0)	I(0)
CD test	0.024	0.000	0.000	0.214	0.000	0.019	0.000	0.528	0.000	0.996
RMSE	0.0843	0.0299	0.0473	0.0176	0.0287	0.0138	0.0370	0.0172	0.0137	0.0061
Observations	5060	5060	5038	5038	5060	5060	5060	5060	5038	5038
Country-sector pairs	230	230	229	229	230	230	230	230	229	229

Notes: we estimate the error correction model: $\Delta k_{i,t} = \alpha_{0i}\Delta y_{i,t} + \alpha_{1i}\Delta y_{i,t-1} - \beta_{0i}\Delta c_{i,t}^{debt} - \beta_{1i}\Delta c_{i,t-1}^{debt} + \gamma_{1i}\Delta k_{i,t-1} + \varphi_i[(k-y)_{i,t-2} - \beta_{2i}c_{it-2} - \beta_{4i}h_{it-2}] + u_{it}$. Estimation methods: CDMG – Mean Group (MG) estimator with cross-sectionally demeaned variables, CCEMG – Pesaran (2006) Common Correlated Effects (CCE) version of the MG estimator. Estimates also include linear trends (specific to the country-sector pairs). Outlier-robust estimates of the mean for each parameter across country-sector pairs are reported. White heteroskedasticity-robust standard errors in brackets. *** p<0.01, ** p<0.05, * p<0.1. Diagnostics: the CD test (p-value) is the p-value of the Pesaran (2015) test for cross section dependence in the residuals, which is distributed as a standard normal under the null hypothesis of weak cross section dependence. The order of integration of the residuals is determined using the Pesaran (2007) test: I(0) – stationary, I(1) – non-stationary, I(1)/I(0) – ambiguous result. RMSE: Root Mean Squared Error. Results of the pairwise Wald tests for equal long run elasticities are in Table D-2 in Appendix D.

APPENDIX A – COVERAGE

TABLE A - 1 SECTOR COVERAGE

Sector	***ISIC code***
Agriculture, forestry and fishing	1-5
Mining and quarrying	10-14
Food, beverages and tobacco products	15-16
Textiles, clothing and leather	17-19
Wood products	20
Paper, printing and publishing	21-22
Chemical, rubber, plastics and fuel	23- 25
Non-metallic mineral products	26
Metal products	27-28
Machinery	29
Electrical and electronic equipment and instruments	30-33
Transport equipment	34-35
Furniture and miscellaneous manufacturing	36-37
Electricity, gas and water	40-41
Construction	45
Sale, maintenance and repair of motorcycles	50
Wholesale trade	51
Retail trade	52
Hotels and restaurants	55
Transport and storage	60-63
Postal and telecommunication services	64
Financial intermediation	65-67
Business services	71-74

TABLE A - 2 COUNTRY COVERAGE

Code	Country	Code	Country
AUT	Austria	ITA	Italy
DNK	Denmark	NLD	Netherlands
FIN	Finland	ESP	Spain
FRA	France	GBR	United Kingdom
IRL	Ireland	USA	United States

APPENDIX B – CALCULATING THE TAX-ADJUSTED USER COST OF CAPITAL

The tax-adjusted user cost of capital (see equation (3) in the text) at time *t* is:

$$C_{jt} = P_{jt}(r_t + \delta_{jt})\frac{(1-\tau_t \Psi_{jt})}{1-\tau_t}.$$

where P_j is the price of the capital asset relative to the price of output, Ψ_j is the net present of depreciation allowances, r the real discount rate, and τ is the marginal corporate income tax rate.

The data to calculate the real user cost are taken from a number of sources. Capital asset prices and value added prices at the sector level are taken from the EU KLEMS database. Asset-specific economic depreciation rates are also derived from the KLEMS dataset, where they vary across country-sector pairs. This ensures full consistency between the quantity and the cost variables used in the empirical exercise.

The real discount rate is obtained as the difference between the nominal rate of return and CPI inflation, or $r_t = \rho_t - \pi_t$. The nominal rate ρ is assumed to reflect the cost of finance for the corporate investor. In line with the corporate finance literature, both equity and debt are considered to build a weighted average of the respective after-tax rates of return:

$$\rho_t = \theta_t i_t^e + (1-\theta_t) i_t^d (1-\tau_t).$$

Thus, i_t^e is the annual return to equity and i_t^d is the annual return to debt, while θ_t denotes the share of equity in total funding. The deductibility of interest payments from the corporate income tax base is accounted for by introducing the marginal corporate income tax rate. All the variables entering the calculation for the external rate vary across years and countries.

The cost of equity is constructed as the earnings plus the dividend yield taken from Datastream. Building a measure for the cost of debt is more challenging given the limited information available on corporate bond yields and bank loan rates in some European countries for the early sample years. Therefore, the cost of debt in each country is calculated by applying a risk premium to the national government bond yield. The premium is set at 202 bps, equal to the average spread of BAA-rated US corporate bonds on the 10-year Treasury Constant Maturity over the sample period[15]. As conventionally done in the literature, the shares of debt

[15] We use the BAA rather than a higher rated bond as more representative of the average credit risk conditions in the market. The spread between Moody's Seasoned BAA and the 10-Year Treasury Constant Maturity is taken from the FRED database of the Federal Reserve Bank of St. Louis. The choice of setting a constant risk premium is corroborated by two important observations. First, the series of the actual US spreads shows a relatively low volatility over the period considered. Second, notwithstanding differences in corporate financial structure, there seem to be a remarkable similarity between the risk spread over the corresponding risk-free rate faced by corporations in the US and in the Euro area. This has been recently documented, for instance, by De Fiore, F. and H. Uhlig, "Bank Finance versus Bond Finance", Journal of Money, Credit and Banking, 43 (7), 1399–1421, 2011.

and equity in total funding are calculated using the aggregate balance sheet of non-financial corporations, obtained from a number of different sources [16, 17].

Finally, tax rules data are taken from ZEW (2013), and, for the early sample years, from the International Bureau of Fiscal Documentation (IBFD) and the International Tax Summaries (Coopers & Lybrand). The information collected include headline statutory tax rates on corporate income – augmented, whenever relevant, by local taxes and surcharges, potentially applicable to specific sectors –, and asset-specific fiscal depreciation rules (including temporary bonus depreciation schemes). The sector and asset classifications employed are the same as in EU KLEMS. In calculating the net present value of the tax allowances, in case multiple rules are allowed under national tax codes, the most efficient scheme is applied.

[16] Debt comprises credit market instruments (sum of commercial paper, municipal securities, corporate bonds, bank loans, other loans and advances, mortgages), while equity is given by the market value of equities outstanding (excluding corporate farm equities).

[17] The data for the European countries is taken from the AMECO dataset. For the US the source is the Flow of Funds Accounts of the Federal Reserve Board.

APPENDIX C – TIME SERIES PROPERTIES

TABLE B - 1 PANEL STATIONARITY TEST – AGGREGATE CAPITAL

Lags	*Capital*		*Capital-output ratio*		*User cost*		*Relative asset price*		*Non-price component*	
					Constant					
					Total capital					
0	9.216	*1.000*	11.635	*1.000*	-3.438	*0.000*	-4.016	*0.000*	1.464	*0.928*
1	1.944	*0.974*	11.334	*1.000*	-2.277	*0.011*	-6.707	*0.000*	6.500	*1.000*
2	5.022	*1.000*	14.098	*1.000*	-0.409	*0.341*	-3.062	*0.001*	11.337	*1.000*
3	5.844	*1.000*	15.276	*1.000*	-2.607	*0.005*	-2.162	*0.015*	10.424	*1.000*
					Aggregate equipment					
0	7.049	*1.000*	5.336	*1.000*	-3.646	*0.000*	-4.755	*0.000*	2.544	*0.995*
1	0.883	*0.811*	3.955	*1.000*	-4.458	*0.000*	-8.397	*0.000*	5.950	*1.000*
2	3.791	*1.000*	8.019	*1.000*	-4.402	*0.000*	-3.413	*0.000*	10.664	*1.000*
3	4.428	*1.000*	11.560	*1.000*	-4.976	*0.000*	-1.733	*0.042*	7.983	*1.000*
					Constant and trend					
					Total capital					
0	19.905	*1.000*	5.616	*1.000*	0.405	*0.657*	-1.283	*0.100*	-5.476	*0.000*
1	10.401	*1.000*	4.707	*1.000*	1.643	*0.950*	-3.905	*0.000*	-2.620	*0.004*
2	13.710	*1.000*	9.861	*1.000*	4.780	*1.000*	-2.366	*0.009*	6.343	*1.000*
3	15.923	*1.000*	12.587	*1.000*	1.781	*0.963*	-2.353	*0.009*	7.817	*1.000*
					Aggregate equipment					
0	14.596	*1.000*	5.256	*1.000*	2.078	*0.981*	-1.529	*0.063*	-2.315	*0.010*
1	4.252	*1.000*	2.482	*1.000*	0.862	*0.806*	-5.763	*0.000*	-0.502	*0.308*
2	7.820	*1.000*	8.271	*1.000*	2.901	*0.998*	-1.575	*0.058*	8.327	*1.000*
3	9.343	*1.000*	14.587	*1.000*	0.937	*0.826*	-1.713	*0.043*	5.857	*1.000*

Notes: all variables are in logs. The standardized Z-tbar statistic and the associated p-values (in italics) from the Pesaran (2007) panel unit root test are reported. The null hypothesis of the test is that all series are nonstationary. The first column indicates the lags augmentation in the Dickey Fuller regression. For all variables, both specifications – including only a constant, and including a constant and a trend, as indicated – are employed.

TABLE B - 2 PANEL STATIONARITY TEST – AGGREGATE CAPITAL (DEMEANED VARIABLES)

Lags	*Capital*		*Capital-output ratio*		*User cost*		*Relative asset price*		*Non-price component*	
Constant										
Total capital										
0	26.777	*1.000*	10.843	*1.000*	3.921	*1.000*	17.701	*1.000*	2.200	*1.000*
1	15.965	*1.000*	9.747	*1.000*	4.197	*1.000*	13.228	*1.000*	5.881	*1.000*
2	18.745	*1.000*	11.059	*1.000*	7.416	*1.000*	19.216	*1.000*	11.714	*1.000*
3	19.489	*1.000*	11.228	*1.000*	5.630	*1.000*	18.292	*1.000*	11.282	*1.000*
Aggregate equipment										
0	21.263	*1.000*	13.588	*1.000*	9.265	*1.000*	15.524	*1.000*	2.383	*0.991*
1	10.264	*1.000*	10.940	*1.000*	9.227	*1.000*	8.468	*1.000*	5.766	*1.000*
2	12.535	*1.000*	12.511	*1.000*	11.565	*1.000*	9.436	*1.000*	11.281	*1.000*
3	16.153	*1.000*	12.770	*1.000*	11.990	*1.000*	8.876	*1.000*	9.324	*1.000*
Constant and trend										
Total capital										
0	20.951	*1.000*	7.882	*1.000*	3.380	*1.000*	10.761	*1.000*	-2.129	*0.017*
1	5.369	*1.000*	6.125	*1.000*	6.146	*1.000*	4.976	*1.000*	-0.402	*0.344*
2	6.947	*1.000*	8.617	*1.000*	12.047	*1.000*	13.318	*1.000*	9.733	*1.000*
3	8.001	*1.000*	10.737	*1.000*	7.661	*1.000*	13.112	*1.000*	5.274	*1.000*
Aggregate equipment										
0	19.421	*1.000*	9.653	*1.000*	5.223	*1.000*	9.971	*1.000*	1.338	*0.991*
1	5.838	*1.000*	7.658	*1.000*	4.774	*1.000*	7.173	*1.000*	4.479	*1.000*
2	9.823	*1.000*	9.987	*1.000*	9.890	*1.000*	11.110	*1.000*	12.357	*1.000*
3	11.763	*1.000*	10.174	*1.000*	9.378	*1.000*	15.008	*1.000*	10.653	*1.000*

Notes: all variables are in logs. The standardized Z-tbar statistic and the associated p-values (in italics) from the Pesaran (2007) panel unit root test are reported. The null hypothesis of the test is that all series are nonstationary. The first column indicates the lags augmentation in the Dickey Fuller regression. For all variables, both specifications – including only a constant, and including a constant and a trend, as indicated – are employed.

TABLE B - 3 PANEL STATIONARITY TEST – DISAGGREGATED CAPITAL

Lags	*Capital*		*Capital-output*		*User cost*		*Relative asset*		*Non-price*	
					Constant					
					Computers					
0	3.637	*1.000*	-0.327	*0.372*	-2.619	*0.004*	-2.623	*0.004*	-10.423	*0.000*
1	-4.071	*0.000*	-5.799	*0.000*	-8.672	*0.000*	-8.611	*0.000*	-6.335	*0.000*
2	-0.695	*0.243*	-3.781	*0.000*	-5.536	*0.000*	-4.939	*0.000*	-3.151	*0.001*
3	0.851	*0.803*	-1.515	*0.065*	-1.434	*0.076*	-2.039	*0.021*	-5.376	*0.000*
					Communication equipment					
0	3.156	*0.999*	2.293	*0.989*	-6.519	*0.000*	-3.462	*0.000*	-13.100	*0.000*
1	2.143	*0.984*	-0.195	*0.423*	-9.959	*0.000*	-5.232	*0.000*	-15.039	*0.000*
2	5.685	*1.000*	2.584	*0.995*	-7.391	*0.000*	1.190	*0.883*	-8.431	*0.000*
3	5.846	*1.000*	4.071	*1.000*	-4.386	*0.000*	4.424	*1.000*	-7.723	*0.000*
					Transportation equipment					
0	10.273	*1.000*	10.941	*1.000*	-1.760	*0.039*	3.925	*1.000*	-11.274	*0.000*
1	6.004	*1.000*	8.663	*1.000*	-2.716	*0.003*	0.254	*0.600*	-13.680	*0.000*
2	7.734	*1.000*	9.863	*1.000*	-2.750	*0.003*	5.087	*1.000*	-4.273	*0.000*
3	6.716	*1.000*	10.841	*1.000*	0.463	*0.678*	4.638	*1.000*	-6.255	*0.000*
					Other machinery and equipment					
0	9.434	*1.000*	9.640	*1.000*	-1.865	*0.031*	7.412	*1.000*	-11.679	*0.000*
1	1.459	*0.928*	8.129	*1.000*	-3.113	*0.001*	5.512	*1.000*	-9.303	*0.000*
2	5.791	*1.000*	10.419	*1.000*	-3.181	*0.001*	8.976	*1.000*	-1.410	*0.079*
3	6.670	*1.000*	12.656	*1.000*	-7.556	*0.000*	7.293	*1.000*	-2.116	*0.017*
					Structures					
0	12.084	*1.000*	4.076	*1.000*	-1.869	*0.031*	2.806	*0.997*	-19.272	*0.000*
1	3.367	*1.000*	3.703	*1.000*	0.076	*0.530*	-2.001	*0.023*	-17.615	*0.000*
2	4.875	*1.000*	6.288	*1.000*	3.296	*1.000*	2.901	*0.998*	-7.175	*0.000*
3	4.127	*1.000*	8.506	*1.000*	3.333	*1.000*	1.932	*0.973*	-6.810	*0.000*
					Constant and trend					
					Computers					
0	10.900	1.000	6.233	*1.000*	5.950	*1.000*	6.443	*1.000*	-3.617	*0.000*
1	2.626	0.996	2.845	*0.998*	1.809	*0.965*	1.863	*0.969*	0.463	*0.678*
2	7.638	1.000	5.4421	*1.000*	4.760	*1.000*	4.918	*1.000*	6.710	*1.000*
3	8.682	1.000	9.278	*1.000*	8.409	*1.000*	8.482	*1.000*	5.601	*1.000*
					Communication equipment					
0	7.582	*1.000*	6.230	*1.000*	-0.078	*0.469*	1.976	*0.976*	-7.920	*0.000*
1	6.189	*1.000*	4.008	*1.000*	-2.012	*0.022*	-1.359	*0.087*	-9.331	*0.000*
2	9.310	*1.000*	5.637	*1.000*	0.026	*0.511*	5.382	*1.000*	-1.553	*0.060*
3	13.870	*1.000*	8.958	*1.000*	4.903	*1.000*	7.785	*1.000*	-0.920	*0.179*
					Transportation equipment					
0	18.065	*1.000*	10.621	*1.000*	0.032	*0.513*	-0.360	*0.359*	-5.526	*0.000*
1	12.993	*1.000*	9.302	*1.000*	0.476	*0.683*	0.245	*0.597*	-7.679	*0.000*
2	14.320	*1.000*	12.459	*1.000*	0.674	*0.750*	5.406	*1.000*	4.064	*1.000*
3	13.237	*1.000*	15.034	*1.000*	1.987	*0.977*	2.659	*0.996*	2.361	*1.000*

TABLE A – 5 CONT'D

Lags	*Capital*		*Capital-output*		*User cost*		*Relative asset*		*Non-price*	
					Other machinery and equipment					
0	15.236	*1.000*	5.874	*1.000*	1.741	*0.959*	6.954	*1.000*	-9.626	*0.000*
1	9.457	*1.000*	5.128	*1.000*	0.093	*0.537*	3.182	*0.999*	-8.432	*0.000*
2	13.872	*1.000*	7.258	*1.000*	1.304	*0.904*	7.953	*1.000*	3.845	*1.000*
3	14.275	*1.000*	9.971	*1.000*	-2.365	*0.009*	6.349	*1.000*	6.628	*1.000*
					Structures					
0	17.160	*1.000*	4.011	*1.000*	-1.405	*0.080*	5.793	*1.000*	-13.603	*0.000*
1	8.436	*1.000*	4.186	*1.000*	-0.457	*0.324*	1.338	*0.909*	-14.835	*0.000*
2	11.238	*1.000*	8.169	*1.000*	6.147	*1.000*	9.685	*1.000*	0.911	*0.819*
3	10.385	*1.000*	9.850	*1.000*	5.891	*1.000*	6.737	*1.000*	1.125	*0.870*

Notes: all variables are in logs. The standardized Z-tbar statistic and the associated p-values (in italics) from the Pesaran (2007) panel unit root test are reported. The null hypothesis of the test is that all series are nonstationary. The first column indicates the lags augmentation in the Dickey Fuller regression. For all variables, both specifications – including only a constant, and including a constant and a trend, as indicated – are employed.

TABLE B - 4 PANEL STATIONARITY TEST – DISAGGREGATED CAPITAL (DEMEANED VARIABLES)

Lags	*Capital*		*Capital-output*		*User cost*		*Relative asset*		*Non-price component*	
					Constant					
					Computers					
0	17.462	*1.000*	13.420	*1.000*	11.732	*1.000*	14.166	*1.000*	-7.017	*0.000*
1	10.020	*1.000*	9.859	*1.000*	1.784	*0.963*	15.280	*1.000*	-2.797	*0.003*
2	13.291	*1.000*	11.643	*1.000*	0.980	*0.836*	17.550	*1.000*	-5.545	*0.000*
3	12.433	*1.000*	12.389	*1.000*	5.041	*1.000*	19.016	*1.000*	-4.057	*0.000*
					Communication equipment					
0	13.989	*1.000*	8.057	*1.000*	3.910	*1.000*	7.375	*1.000*	-0.195	*0.423*
1	6.646	*1.000*	7.757	*1.000*	3.838	*1.000*	2.186	*0.986*	-0.524	*0.300*
2	8.549	*1.000*	8.261	*1.000*	4.320	*1.000*	5.401	*1.000*	3.499	*1.000*
3	10.276	*1.000*	8.388	*1.000*	7.407	*1.000*	9.431	*1.000*	-0.948	*0.171*
					Transportation equipment					
0	20.731	*1.000*	18.033	*1.000*	4.369	*1.000*	6.902	*1.000*	-6.717	*0.000*
1	9.977	*1.000*	14.483	*1.000*	2.941	*0.998*	6.064	*1.000*	-11.349	*0.000*
2	11.905	*1.000*	15.913	*1.000*	6.765	*1.000*	7.241	*1.000*	-4.179	*0.000*
3	13.856	*1.000*	14.177	*1.000*	8.304	*1.000*	8.210	*1.000*	-2.836	*0.002*
					Other machinery and equipment					
0	20.879	*1.000*	13.793	*1.000*	6.530	*1.000*	6.900	*1.000*	-3.453	*0.000*
1	10.899	*1.000*	12.229	*1.000*	5.348	*1.000*	2.967	*0.998*	-4.217	*0.000*
2	13.050	*1.000*	14.141	*1.000*	6.547	*1.000*	8.970	*1.000*	0.338	*0.632*
3	11.645	*1.000*	15.267	*1.000*	9.636	*1.000*	9.961	*1.000*	2.446	*0.993*
					Structures					
0	19.326	*1.000*	10.081	*1.000*	5.111	*1.000*	8.886	*1.000*	-7.132	*0.000*
1	13.499	*1.000*	9.428	*1.000*	6.970	*1.000*	6.129	*1.000*	-3.770	*0.000*
2	14.696	*1.000*	10.873	*1.000*	11.757	*1.000*	10.870	*1.000*	0.795	*0.787*
3	15.252	*1.000*	13.123	*1.000*	14.827	*1.000*	10.515	*1.000*	0.502	*0.692*
					Constant and trend					
					Computers					
0	15.809	*1.000*	12.057	*1.000*	10.534	*1.000*	12.614	*1.000*	-0.783	*0.217*
1	3.907	*1.000*	5.881	*1.000*	4.027	*1.000*	5.220	*1.000*	2.077	*0.981*
2	8.135	*1.000*	8.548	*1.000*	5.372	*1.000*	8.371	*1.000*	4.632	*1.000*
3	7.584	*1.000*	11.345	*1.000*	8.829	*1.000*	8.855	*1.000*	2.211	*0.986*
					Communication equipment					
0	15.447	*1.000*	8.066	*1.000*	0.531	*0.702*	5.056	*1.000*	1.040	*0.851*
1	5.054	*1.000*	7.938	*1.000*	-3.144	*0.001*	1.657	*0.951*	2.024	*0.979*
2	8.462	*1.000*	11.835	*1.000*	0.697	*0.757*	5.257	*1.000*	10.915	*1.000*
3	11.626	*1.000*	10.466	*1.000*	9.267	*1.000*	9.305	*1.000*	6.016	*1.000*
					Transportation equipment					
0	18.005	*1.000*	11.753	*1.000*	3.728	*1.000*	5.567	*1.000*	-1.776	*0.038*
1	3.598	*1.000*	7.806	*1.000*	1.172	*0.879*	0.126	*0.550*	-8.492	*0.000*
2	3.176	*0.999*	11.068	*1.000*	4.489	*1.000*	4.060	*1.000*	0.810	*0.791*
3	6.019	*1.000*	7.959	*1.000*	6.130	*1.000*	5.688	*1.000*	-0.959	*0.169*

TABLE A – 6 CONT'D

Lags	*Capital*		*Capital-output*		*User cost*		*Relative asset*		*Non-price component*	
					Other machinery and equipment					
0	15.851	*1.000*	9.493	*1.000*	7.344	*1.000*	7.273	*1.000*	-2.457	*0.007*
1	4.439	*1.000*	7.489	*1.000*	5.017	*1.000*	1.685	*0.954*	-7.702	*0.000*
2	9.689	*1.000*	9.169	*1.000*	6.256	*1.000*	8.055	*1.000*	3.662	*1.000*
3	9.454	*1.000*	8.884	*1.000*	7.712	*1.000*	8.818	*1.000*	3.221	*0.999*
					Structures					
0	19.389	*1.000*	8.056	*1.000*	4.000	*1.000*	9.407	*1.000*	-3.812	*0.000*
1	7.195	*1.000*	5.748	*1.000*	3.996	*1.000*	4.050	*1.000*	-3.696	*0.000*
2	9.854	*1.000*	7.658	*1.000*	*12.607*	*1.000*	12.628	*1.000*	7.686	*1.000*
3	10.728	*1.000*	8.527	*1.000*	11.021	*1.000*	8.556	*1.000*	11.123	*1.000*

Notes: all variables are in logs. The standardized Z-tbar statistic and the associated p-values (in italics) from the Pesaran (2007) panel unit root test are reported. The null hypothesis of the test is that all series are nonstationary. The first column indicates the lags augmentation in the Dickey Fuller regression. For all variables, both specifications – including only a constant, and including a constant and a trend, as indicated – are employed.

Appendix D – Further results of the pairwise tests for equal elasticities

Table D - 1 Pairwise tests (p-values) for equality of long run elasticities – model with decomposed user cost

	Computers	*Transportation equipment*	*Other machinery and equipment*	*Communication equipment*
CDMG				
Relative price component				
Transportation equipment	0.810			
Other machinery and equipment	0.050	0.052		
Communication equipment	0.860	0.956	0.067	
Structures	0.058	0.060	0.927	0.077
Non-price component				
Transportation equipment	0.205			
Other machinery and equipment	0.985	0.021		
Communication equipment	0.730	0.193	0.584	
Structures	0.683	0.001	0.308	0.204
CCEMG				
Relative price component				
Transportation equipment	0.704			
Other machinery and equipment	0.110	0.103		
Communication equipment	0.028	0.033	0.451	
Structures	0.392	0.291	0.523	0.197
Non-price component				
Transportation equipment	0.982			
Other machinery and equipment	0.924	0.946		
Communication equipment	0.806	0.793	0.678	
Structures	0.687	0.678	0.526	0.861

Notes: the table reports the p-values for the tests of equal long run elasticities for the error correction model with heterogeneous parameters, decomposing the user cost in its price and non-price components (regression results in Table 5). The Wald statistics is distributed as a $\chi^2(1)$.

TABLE D - 2 PAIRWISE TESTS (P-VALUES) FOR EQUALITY OF LONG RUN ELASTICITIES – MODEL FOR DEBT-FINANCED INVESTMENT

CDMG				
	Computers	*Transportation equipment*	*Other machinery and equipment*	*Communication equipment*
Relative price component				
Transportation equipment	0.193			
Other machinery and equipment	0.686	0.041		
Communication equipment	0.770	0.088	0.936	
Structures	0.135	0.001	0.124	0.201
CCEMG				
	Computers	*Transportation equipment*	*Other machinery and equipment*	*Communication equipment*
Relative price component				
Transportation equipment	0.688			
Other machinery and equipment	0.388	0.223		
Communication equipment	0.317	0.181	0.857	
Structures	0.067	0.037	0.238	0.317

Notes: the table reports the p-values for the tests of equal long run elasticities for the error correction model with heterogeneous parameters, using the user cost for a debt-financed investment (results in Table 6). The Wald statistics is distributed as a $\chi^2(1)$.

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