Three Essays on Capital Taxation

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We see the world in terms of our theories. – Thomas S. Kuhn

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Declaration

All chapters of this thesis are independent research articles. The first chapter is written under the supervision of Professor Jean-François Tremblay. Chapters two and three are written under the supervision of Professor Kathleen Day.

Abstract

The main idea of this thesis is to deepen our understanding of the relationship between tax policy and heterogeneous capital. The first chapter revisits the question of whether preferential tax regimes are desirable in a context where some jurisdictions have leadership advantages in their choice of tax policy. It is argued that if regions or countries involved in tax competition act sequentially as Stackelberg competitors, they will prefer to limit the use of preferential tax policy. If firms located in small regions face higher mobility costs on average than those located in large regions, small regions want to ban preferential tax regimes while large regions will tend to support them. If jurisdictions are populated mainly by firms with low mobility costs, they will prefer preferential tax treatments. On the other hand, if they are populated mostly by firms with high mobility costs, small regions want to restrict preferential tax policies while large regions will favour them.

The second chapter embraces the neoclassical theory of investment to model the rate of investment in physical and intangible capital. It uses data from the EU KLEMS database, the Oxford University Centre for Business Taxation and the Tax Foundation. It concludes that the equations for the rate of investment in physical and intangible capital are distinct. Corporate tax incentives affect the rates of investment in physical and intangible capital, but differently. The higher rate of depreciation of intangible capital relative to physical capital seems to explain the increasing ratio of investment in intangible to physical capital.

The third chapter examines heterogeneity by type of capital within the relationship between capital and its user cost, for five types of physical capital asset and two types of intangible capital asset. The dataset is almost similar to that of chapter two. The results show that, in the short-run dynamics, both the dynamic fixed-effects and GMM results seem to agree on the role of changes in the user cost of capital on the accumulation of the stock of capital. Overall, dynamic fixed-effects estimation seems to yield results that are more consistent with the theoretical conclusions on investment behaviour and empirical results for physical capital already established in the literature.

General introduction

Changes in taxation may have different effects on different components of capital. Heterogeneity of capital may arise from being located in a domestic or foreign jurisdiction, or from belonging to different types of assets. There are discriminatory tax practices that treat distinct tax bases differently, in other words, preferential tax regimes. Moreover, changes in tax policy can alter the relative prices of different types of capital assets differently, thereby altering differently their user cost of capital. The central idea of this thesis is to deepen our understanding of the relationship between tax policy and heterogeneous capital.

In the first chapter I assume an economy composed of two asymmetric regions (domestic and foreign) and a fixed number of heterogeneous firms distributed between the two regions. Firms can operate in their domestic location, or shift to the foreign region while incurring a mobility cost. Local governments in each region can apply preferential or non-preferential tax policies. This model suggests a sequential tax setting where one region has leadership advantages in selecting tax policy. The results show that if the regions involved in tax competition interact sequentially as Stackelberg competitors where the large region is a leader while the small a follower, they will prefer non-preferential tax policy.

Furthermore, if firms located in the large region are not very productive compared to domestic firms in the small region, the large region prefers preferential tax regimes while the small region prefers non-preferential tax regimes. If domestic firms in the smaller region face higher mobility costs on average compared to domestic firms in the larger region, when the regions choose their tax rates simultaneously à la Nash-Cournot, the larger region prefers a preferential tax policy while the smaller one prefers a non-preferential tax regime. In addition, when mobility costs are distributed non-uniformly, if the regions are populated mainly by low mobility cost firms, both regions want to apply a discriminatory tax policy. When mobility costs are non-uniformly distributed, if the regions are populated mainly by firms with high mobility costs, the larger region favours a preferential tax framework while the smaller one wants to prohibit it.

The second chapter starts from the observation that on average over 12 countries, using country-level data, the ratio of gross real investment in intangible capital to gross real investment in physical capital has been increasing, while at the same time the corporate income tax rate has been decreasing. At first glance this observation is immediately situated within the literature on investment by placing intangible capital alongside physical capital within the neoclassical model of business investment behaviour. Empirical results are obtained using an annual sector-level panel dataset composed of 12 sectors in 12 OECD countries over the period 1995-2015 taken from the EU KLEMS database, the Oxford University Centre for Business Taxation, and the Tax Foundation.

The results of this study show that the equations for the rate of investment in physical capital and the rate of investment in intangible capital are two separate equations. Changes in the corporate income tax rate have a negative impact on both the physical and intangible capital investment rates. The rate of depreciation of intangible capital is more than twice as high as of that of physical capital. This result may explain the increase in intangible capital investments compared to physical capital investments observed in the data. However, the long-run elasticity of capital with respect to the corporate income tax rate is higher for physical capital than for intangible capital.

Finally, the third chapter explores heterogeneity by capital type within the relationship between capital and its user cost, for five types of physical capital asset and two types of intangible capital asset. This study uses an almost similar dataset to that of chapter two. It exploits the existence of a cointegrating relationship between capital, output and the user cost of capital in a model in error-correction form. Since the dataset straddles a long and a short panel, this study can ignore potential dynamic biases by estimating the model using the dynamic fixed-effects (DFE) estimator, or incorporate such biases by using the generalized method of moments (GMM) estimator.

The results using a panel dataset with a large or nearly large time dimension show that the DFE estimation of the relationship between capital and the user cost of capital provides estimates that are most closely consistent with the theoretical and empirical findings of the literature on business investment for all types of capital considered, although to a lesser extent for research and development. However, in terms of the short-run dynamics the DFE and GMM estimation methods yield qualitatively nearly equivalent results. Furthermore, by decomposing the user cost of capital into its price and non-price components, DFE estimation shows that the price component of the user cost of capital (relative prices of capital goods) has an impact on capital accumulation, with the exception of research and development. Changes in the capital stock are influenced by changes in the non-price component of the user cost of capital only for other machinery and equipment. If the model is estimated using the GMM estimator, then changes in the capital stock are affected by changes in relative prices for computing equipment and communications equipment. However, changes in the non-price component of the user cost of capital influence changes in the capital stock for computing equipment and transport equipment. The relationship between capital and the user cost of capital is found to be consistent for capital in the form of computing equipment, regardless of the estimation method applied.

Contents

Chapter 1

Regional Tax Competition with Heterogeneous Mobility Costs of Capital

Abstract

Tax policies that treat distinct tax bases differently, preferential tax regimes, remain a controversial subject. This paper re-examines the issue of whether preferential tax regimes are desirable in a setting where some regions or countries have leadership advantages in selecting tax policy. It concludes that if regions involved in tax competition act sequentially as Stackelberg competitors, they will restrict the use of preferential tax policy. If firms located in small regions face on average higher costs of mobility in comparison to those located in large regions, small regions want to ban preferential tax regimes while large regions tend to support them. If regions are populated with mostly low moving cost firms, they prefer preferential tax treatments. However, are they populated with mostly high moving cost firms, small regions want to restrict preferential tax policies while large ones prefer them.

1.1 Introduction

Two broad forms of discriminatory tax measures are observed in national or regional tax structures. Regions or countries can discriminate in tax treatment between domestically owned firms and foreign-owned ones or by class of asset or industry (Bucovetsky and Haufler, 2007). Often it is the case that the more mobile base receives tax concessions called preferential tax treatments. For example, in many cases foreign-owned firms are granted more favorable tax conditions since they are considered to be more mobile in comparison to domestically owned firms which are less mobile. According to OECD (2017), the existence of preferential tax treatments represents a serious issue for jurisdictional governments. These tax treatments are composed of a plethora of tax incentives that engender enormous loss of tax revenue.

Economic history confirms that preferential regimes are an old story. They have been observed since Catherine the Great of Russia in 1763. However, the economic integration of the world economy over the last few decades has made this subject a very current policy issue (Keen and Konrad, 2013). Application of preferential and non-preferential tax policy is a controversial economic subject.

If two regions compete for two distinct and independent tax bases with different degree of mobility, the restriction to impose a single tax rate on both tax bases, that is applying non-preferential tax regimes, will unambiguously reduce tax revenue in both regions (Keen, 2001). Indeed, given the non-discrimination constraint and by the force of competition, the single tax rate applied on both bases will be lower than the average differentiated tax rates they would apply in the absence of the non-discrimination constraint. Bucovetsky and Haufler (2007) extend Keen (2001) while considering non-symmetric regions that differ in size. They find that imposing a non-discriminatory tax regime or non-preferential tax policy hurts both large and small regions. Those two papers create a general framework in favour of preferential tax regimes. It is for them a more socially desirable tax policy for local governments since they collect more tax revenue under this policy.

An opposite view has emerged from Janeba and Peters (1999) as well as Haupt and Peters (2005). For Janeba and Peters (1999) non-preferential tax policy leads to less tax evasion, thus more tax revenue for local governments. Haupt and Peters (2005), by introducing the assumption of a home-bias effect, meaning that investors have preferences for their home region, have shown that a preferential tax regime accelerates a race to the bottom, and restrictions on preferential tax regimes always increase equilibrium tax revenues. These two papers support the idea that a total ban of preferential tax treatments is optimal from national or regional governments' perspectives.

Other studies try to reconcile this controversy using an integrated approach. This is the case for Razin and Sadka (1991), Janeba and Smart (2003), and Niu (2019), as well as Mongrain and Wilson (2018). Some economic characteristics justify the existence of preferential tax policy, while others justify non-preferential tax policy. For example, non-preferential tax systems are likely to generate more tax revenue for both regions and thus give rise to a higher socially desirable outcome when tax bases are on average highly responsive to a coordinated increase in tax rates by all governments (Janeba and Smart, 2003). By proposing a numerical model that allows firms to be heterogeneous in mobility costs and across regions and assuming that local governments care only about tax revenues, Niu (2019) concludes that preferential tax policy is a dominant strategy if regions are sufficiently asymmetric in terms of firm productivity and population.

Mongrain and Wilson (2018) start off their model by departing from the idea that local governments maximize total tax revenue. Rather, for them, local governments maximize total tax revenue plus a positive share of the surplus generated by the private sector, which is the total after-tax profit less the total costs of mobility involved. Like Haupt and Peters (2005), they consider the home-bias effect, since, in their model, firms are distinguished by their region of origin. In addition, firms differ in the cost they face to relocate from one region to another. Regions are asymmetric in the sense that they differ in size in terms of the number of firms they initially possess (i.e., domestic firms). The costs to relocate from one region to another can be uniformly or non-uniformly distributed. They compare the outcomes where regions apply a non-preferential tax regime with those when they apply a preferential tax regime. The outcomes are scaled by the level of social welfare they provide. The socially desirable outcome is the one that gives rise to the highest social welfare where social welfare is composed of total tax revenue and a positive share of private surplus generated. They conclude that under the assumption of uniformly distributed moving costs, the larger region always prefers a non-preferential tax regime. The smaller region prefers a preferential tax regime when regions are very asymmetric and the weight put on private surplus in the welfare function is high. Under the assumption that regions are identical, when the costs of mobility are non-uniformly distributed, if most of the firms are low moving-cost firms, preferential tax regime will be preferred by both regions. From a policy perspective, since the case where most of the firms have low-moving costs is increasingly thought to be the case in the modern world economy, tax competition between regions will push toward preferential tax regimes. The application of non-preferential tax regimes will have to come from the coordination effort of local governments.

I propose a model of sequential tax competition on the basis of Mongrain and Wilson (2018)'s model. Regional governments, in setting their tax policy, are interacting as Stackelberg tax competitors. This paper departs from their model by allowing firms to be heterogeneous across regions. It analyses tax setting policy when firms located in small regions face on average higher mobility costs in comparison to large regions' firms. The case of a non-uniform distribution of moving costs is divided into two parts. The first is the case where the regions are populated with mostly low moving cost firms, and the second is where regions are populated with mostly high moving cost firms. In both cases, contrary to Mongrain and Wilson (2018), regions are not identical.

By interacting sequentially as Stackelberg tax competitors, regions can limit the race to the bottom in taxation of foreign firms due to Nash-Cournot tax competition on more mobile capital, in this case foreign firms. As a result, regions impose higher tax rates, achieve higher welfare levels, and prefer non-preferential tax policy. Regions have the possibility to take actions that can change the distribution of mobility costs. When this happens in the small region, specifically, domestic firms in the small region face higher mobility costs on average. If the regions choose their tax rates simultaneously as Nash-Cournot tax competitors, the large region favours a preferential tax policy while the small region favours a non-preferential tax regime. Under sequential tax competition, both regions prefer a non-preferential tax setting. When mobility costs, distributed non-uniformly, decline on average in both regions, domestic firms in both regions find it easier to move from one region to another. As a result, the competition to attract foreign firms becomes even more intense, both regions favour preferential tax policies. When mobility costs are distributed non-uniformly, if the regions are populated mainly by firms with high mobility costs, the larger region favours a preferential tax framework while the smaller region wants to prohibit it.

This study highlights Stackelberg tax competition by granting the leader advantage to the large region while the small region is the follower. This approach is inspired by the fact that, first, Wang (1999) claims that it is natural to accept that large regions act as Stackelberg leaders and small regions as followers. Second, empirically, Altshuler and Goodspeed (2015) provides evidence of sequential tax competition between the US (a large country) and European countries (small countries) using data from 1968 to 2008. Their results suggest that, since the 1986 US tax reform, the US has acted as a Stackelberg leader while European nations have acted as followers. Moreover, in several theoretical models of sequential tax competition, results show that regions involved in tax competition sequentially as competitors of Stackelberg impose higher tax rates compared to the case where they choose their tax rates simultaneously (Wang, 1999; Kempf and Rota-Graziosi, 2010; Ogawa, 2013).

The rest of this chapter is organized as follows. In section 1.2, the model is presented. In section 1.3, preferential and non-preferential tax regimes are studied when the costs of mobility are uniformly distributed. In section 1.4, preferential and non-preferential tax regimes are studied when the costs of mobility are uniformly distributed but the distributions differ between regions. In section 1.5, preferential and non-preferential tax regimes are studied when the costs of mobility are non-uniformly distributed. In section 1.6, I conclude.

1.2 The Model

In this economy there are two regions, indexed by $i \in \{1, 2\}$, and a fixed number of firms distributed between the two regions. Each region i possesses N_i domestic firms. Each domestic firm in region i generates before-tax profits of $\gamma_i > 1$ that are taxed where they are earned. Firms are heterogeneous across regions meaning that profit generated by firms initially located in region i is identical but differ from that generated by firms initially located in region j, $(\gamma_i \neq \gamma_j)$. Following Niu (2019), heterogeneity of firms across regions can be explained by differences in productivity. He proposes a numerical model where firms are heterogeneous within and across regions. In this chapter only one side of firm profit heterogeneity is considered. Firms can operate in either their initial location, the domestic region, or move to the foreign region while facing some moving costs c that are distributed between $\underline{\theta}$ and $\overline{\theta}$. Each region i is populated with a fixed number of residents that retain ownership of the firms originally located in that region. Residents consume a numeraire good and have linear preferences. Regional governments care about the provision of public services, but also put some positive weight on surplus generated by private sectors, in their welfare function. Let R_i represent the total tax revenue collected by region i and S_i the private surplus captured by residents of region i from their ownership of firms, including those that are located in region i, and those that are located in region j. The local government in region i wants to maximize its welfare function defined as $\Omega_i = R_i + \omega S_i$, where $\omega \in [0, 1)$ is the weight put on private surplus. This section is similar to Mongrain and Wilson (2018) except that I consider that firms are heterogeneous across regions. The specification of the objective function of regional governments to take into account tax revenues and the surplus generated by the private sector is embodied in the pattern of modelling which assumes that residents consume private goods and public services; and that regional governments are benevolent.

1.2.1 Non-Preferential Tax Regimes

Under a non-preferential tax system, local governments treat distinguishable tax bases similarly. In this precise case, in each region, the tax authority chooses a single tax rate that will be applied to both local and foreign firms. Let t_i and t_j be the tax rates imposed on firms in regions i and j. Whenever $t_i \geq t_j$, a firm in region i stays in that region if its after-tax profits in region i are not lower compared to what it could generate if it moves to region j, that is, if $(1-t_i)\gamma_i \geq (1-t_j)\gamma_i - c$ or $c \geq (t_i - t_j)\gamma_i$. Total tax revenue in region i when both regions apply non-preferential tax regimes is denoted by $R_i^{np,np}(t_i,t_j)$,[1]

$$R_i^{np,np}(t_i,t_j) = \begin{cases} t_i\gamma_i N_i[1-F((t_i-t_j)\gamma_i)], & \text{if } t_i \geq t_j. \\ t_i\gamma_i N_i + t_i\gamma_j N_j F((t_j-t_i)\gamma_j), & \text{if } t_i < t_j. \end{cases} \qquad [1.1]$$

In the first part of [1.1], the total tax revenue is levied only upon profits generated by firms that stay in region i, since the tax rate imposed in that region is higher than the one imposed in the foreign region. In the second part of equation [1.1], the total tax revenue is collected from total profits generated by domestic firms of region i - since $t_i < t_j$, no firms move from region i to region j - plus profits generated by newly arrived foreign firms located in region i for tax purposes.

Let $S_i^{np,np}(t_i,t_j)$ denote the private surplus captured by residents of region i. When $t_i \geq t_j$, total private surplus enjoyed by residents of region i equals the after-tax profits generated by firms that stay in region i plus the after-tax profits generated by firms that had moved from region i to region j less total moving costs. When $t_i < t_j$, no firms move from region i to region j, the total private surplus is equivalent to the total after-tax profits generated in region i. Note that $F(\cdot)$ is the cumulative distribution function (CDF) of the distribution of the moving costs and $f(\cdot)$ is the associated probability density function (PDF).

$$S_i^{np,np}(t_i,t_j) = \begin{cases} (1-t_i)\gamma_i N_i\left[1-F((t_i-t_j)\gamma_i)\right] & \\ +(1-t_j)\gamma_i N_i F((t_i-t_j)\gamma_i) & \\ -N_i \int_{\underline{\theta}}^{(t_i-t_j)\gamma_i} cf(c)dc, & \text{if } t_i \geq t_j. \\ (1-t_i)\gamma_i N_i, & \text{if } t_i < t_j. \end{cases} \qquad [1.2]$$

1.2.2 Preferential Tax Regimes

Under preferential tax systems, regions treat distinguishable tax bases differently. Indeed, the tax authority in region i taxes its existing domestic firms and newly arrived foreign firms at different rates. Let T_i and τ_i be respectively the tax rates on domestic firms and

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[1] The symbols np and p stand for non-preferential and preferential tax regimes.

foreign firms located in region i. Let T_j and τ_j be respectively the tax rates on domestic firms and foreign firms in region j. When $T_i \geq \tau_j$, a firm in region i stays in that region if $(1-T_i)\gamma_i \geq (1-\tau_j)\gamma_i - c$ or $c \geq (T_i - \tau_j)\gamma_i$. Further, when $T_j > \tau_i$ a firm in region j moves to region i if $(1-T_j)\gamma_j < (1-\tau_i)\gamma_j - c$ or $c < (T_j - \tau_i)\gamma_j$. In fact, a local firm in region i that shifts to region j will be taxed at τ_j instead of T_i. Let $R_i^{p,p}(T_i, \tau_i, T_j, \tau_j)$ and $S_i^{p,p}(T_i, \tau_i, T_j, \tau_j)$ denote the total tax revenue and total private surplus in region i when both regions apply preferential tax regimes[2]

$$R_i^{p,p}(\cdot) = \begin{cases} T_i\gamma_i N_i[1 - F((T_i - \tau_j)\gamma_i)], & \text{if } T_i > \tau_j \& \tau_i \geq T_j. \\ T_i\gamma_i N_i[1 - F((T_i - \tau_j)\gamma_i)] & \\ +\tau_i\gamma_j N_j F((T_j - \tau_i)\gamma_j), & \text{if } T_i > \tau_j \& \tau_i < T_j. \\ T_i\gamma_i N_i, & \text{if } T_i \leq \tau_j \& \tau_i \geq T_j. \\ T_i\gamma_i N_i + \tau_i\gamma_j N_j F((T_j - \tau_i)\gamma_j), & \text{if } T_i \leq \tau_j \& \tau_i < T_j. \end{cases} \tag{1.3}$$

$$S_i^{p,p}(\cdot) = \begin{cases} (1 - T_i)\gamma_i N_i \left[1 - F((T_i - \tau_j)\gamma_i)\right] & \\ +(1 - \tau_j)\gamma_i N_i F((T_i - \tau_j)\gamma_i) & \\ -N_i \int_{\underline{\theta}}^{(T_i - \tau_j)\gamma_i} cf(c)dc, & \text{if } T_i \geq \tau_j. \\ (1 - T_i)\gamma_i N_i, & \text{if } T_i < \tau_j. \end{cases} \tag{1.4}$$

1.3 Same uniform moving costs

In this section, regions are assumed to have the same distribution of the costs of mobility and this distribution is uniform between $\underline{\theta} = 0$ and $\overline{\theta} = 1$. In this case, the CDF is $F(c) = c$ and the corresponding PDF is constant and equal to 1, i.e., $f(c) = 1$.

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[2] Preferential tax regimes are tax incentives designed to attract economic activities that can be most easily moved from one country or region to another based on tax differentials. OECD (2017) reported 164 preferential tax regimes in 102 participating jurisdictions, 99 of which required action because they are either harmful or potentially harmful to the economy. A preferential tax regime in one country or region is said to be harmful if it results in an undue risk to the tax base of another country or region. According to the OECD (2017), three elements characterise whether a preferential tax regime is perceived as harmful: ring-fencing (i.e., excluding a portion of a corporation's income from the tax base to reduce its tax liability), a lack of transparency about the regime, and a lack of effective information exchange about the regime. In addition, with respect to intellectual property asset regimes, a so-called nexus approach is also being considered.

The nexus approach presupposes a concrete link between the tax benefits enjoyed by a piece of intellectual property asset and the carrying out of actual activities leading to the creation of that piece of intangible asset (i.e., research and development). To give some examples: the regime granting a reduced tax rate for long-term capital gains and profits from the licensing of intellectual property rights in France has proven to be harmful because it is not in line with the nexus approach. Turkey's Technology Development Zone regime was identified as potentially harmful because it is not in line with the nexus approach in relation to qualified intellectual property assets. The UK patent box is considered not harmful. Preferential tax regimes are at the origin of a series of base erosion and profit shifting (BEPS) strategies. Tax revenue losses due to BEPS are estimated at US$ 100-240 billion per year, equivalent to 4-10% of global corporate tax revenues.

1.3.1 Both Regions Apply Non-Preferential Tax Regimes

Assume that $\gamma_1 > \gamma_2$. From the Appendix (section 1.8.1), we know that $t_1 > t_2$.[3] Let $R_1^{np,np}(t_1, t_2)$ and $R_2^{np,np}(t_1, t_2)$ be the total tax revenue collected in region 1 and region 2. Let $S_1^{np,np}(t_1, t_2)$ and $S_2^{np,np}(t_1, t_2)$ be the total private surplus in region 1 and region 2. We have

$$\begin{aligned}
R_1^{np,np}(t_1, t_2) &= t_1\gamma_1 N_1 \left[1 - F((t_1 - t_2)\gamma_1)\right] = t_1\gamma_1 N_1 \left[1 - (t_1 - t_2)\gamma_1\right] \\
R_2^{np,np}(t_1, t_2) &= t_2\gamma_2 N_2 + t_2\gamma_1 N_1 F((t_1 - t_2)\gamma_1) = t_2\gamma_2 N_2 + t_2\gamma_1 N_1[(t_1 - t_2)\gamma_1] \\
S_1^{np,np}(t_1, t_2) &= (1 - t_1)\gamma_1 N_1 \left[1 - F((t_1 - t_2)\gamma_1)\right] + (1 - t_2)\gamma_1 N_1 F((t_1 - t_2)\gamma_1) \\
&\quad - N_1 \int_0^{(t_1 - t_2)\gamma_1} cf(c)dc \\
S_2^{np,np}(t_1, t_2) &= (1 - t_2)\gamma_2 N_2.
\end{aligned}$$

In case regions involved in tax competition decide their tax policy simultaneously (N) as Nash-Cournot tax competitors. The local government in region i chooses the tax rate t_i that maximizes its welfare function $\Omega_i^{np,np}(t_i, t_j) = R_i^{np,np}(t_i, t_j) + \omega S_i^{np,np}(t_i, t_j)$ for $i, j \in \{1, 2\}$. The reaction functions $t_1(t_2)$ and $t_2(t_1)$ are as follows

$$t_1(t_2) = \frac{(1-\omega)(1+\gamma_1 t_2)}{\gamma_1(2-\omega)} \qquad [1.5]$$

$$t_2(t_1) = \frac{1}{2}t_1 + \frac{(1-\omega)}{2\gamma_1}\frac{\gamma_2 N_2}{\gamma_1 N_1}. \qquad [1.6]$$

Thereafter, the resulting simultaneous Nash-Cournot equilibrium tax rates are found to be

$$t_1^{np,np,N} = \frac{(1-\omega)}{\gamma_1(3-\omega)}\left(2 + (1-\omega)\frac{\gamma_2 N_2}{\gamma_1 N_1}\right) \qquad [1.7]$$

$$t_2^{np,np,N} = \frac{(1-\omega)}{\gamma_1(3-\omega)}\left(1 + (2-\omega)\frac{\gamma_2 N_2}{\gamma_1 N_1}\right). \qquad [1.8]$$

Suppose that regions involved in tax competition interact sequentially (S) as Stackelberg tax competitors. The large region acts as a Stackelberg leader while the small one as a follower. The resolution of the follower's problem gives rise to [1.6]. By substituting region 2's best response function into region 1's objective function, we have

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[3] If the large region contains more productive firms relative to the small region, it will apply higher non-discriminatory tax rate in comparison to the small one, whether they are Nash-Cournot (noted N) or Stackelberg (noted S) tax competitors.

$$\begin{aligned}
R_1(t_1) &= t_1\gamma_1 N_1\left[1-(t_1-t_2(t_1))\gamma_1\right] = t_1\gamma_1 N_1\left[1-\left(\frac{1}{2}t_1-\frac{1-\omega}{2\gamma_1}\frac{\gamma_2 N_2}{\gamma_1 N_1}\right)\right]\\
S_1(t_1) &= (1-t_1)\gamma_1 N_1\left[1-\left(\frac{1}{2}t_1-\frac{1-\omega}{2\gamma_1}\frac{\gamma_2 N_2}{\gamma_1 N_1}\right)\gamma_1\right]\\
&+\left(1-\frac{1}{2}t_1-\frac{1-\omega}{2\gamma_1}\frac{\gamma_2 N_2}{\gamma_1 N_1}\right)\gamma_1 N_1\left(\frac{1}{2}t_1-\frac{1-\omega}{2\gamma_1}\frac{\gamma_2 N_2}{\gamma_1 N_1}\right)\gamma_1\\
&- N_1\int_0^{\left(\frac{1}{2}t_1-\frac{1-\omega}{2\gamma_1}\frac{\gamma_2 N_2}{\gamma_1 N_1}\right)\gamma_1} c dc.
\end{aligned}$$

Resolving region 1's maximization problem and substituting the solution in region 2's best response function, the Stackelberg equilibrium tax rates are

$$t_1^{np,np,S} = \frac{(1-\omega)}{\gamma_1(4-\omega)}\left(4+(2-\omega)\frac{\gamma_2 N_2}{\gamma_1 N_1}\right) \quad [1.9]$$

$$t_2^{np,np,S} = \frac{(1-\omega)}{\gamma_1(4-\omega)}\left(2+(3-\omega)\frac{\gamma_2 N_2}{\gamma_1 N_1}\right). \quad [1.10]$$

Proposition 1. *Under sequential tax competition, if two asymmetric regions are acting as Stackelberg tax competitors and where the large region is a leader while the small one is a follower, then, at equilibrium,*

a. *The tax rates applied are higher than under Nash-Cournot tax competition,*

b. *The tax gap is higher than under Nash-Cournot tax competition,*

c. *The level of welfares are higher than under Nash-Cournot tax competition.*

.

Proof. a. Since $0 \leq \omega < 1$, by using [1.7] and [1.8] and by using [1.9] and [1.10], we have

$$t_1^{np,np,S} - t_1^{np,np,N} = \frac{2(1-\omega)(2-\omega+\frac{\gamma_2 N_2}{\gamma_1 N_1})}{\gamma_1(3-\omega)(4-\omega)} > 0,$$

$$t_2^{np,np,S} - t_2^{np,np,N} = \frac{(1-\omega)(2-\omega+\frac{\gamma_2 N_2}{\gamma_1 N_1})}{\gamma_1(3-\omega)(4-\omega)} > 0.$$

This result is compatible with Keen and Konrad (2013), Wang (1999), Kempf and Rota-Graziosi (2010), as well as Ogawa (2013).

b. The sequential and simultaneous equilibrium tax gaps are $t_1^{np,np,S} - t_2^{np,np,S}$ and $t_1^{np,np,N} - t_2^{np,np,N}$. Indeed,

$$(t_1^{np,np,S} - t_2^{np,np,S}) - (t_1^{np,np,N} - t_2^{np,np,N}) = \frac{(1-\omega)\left(2-\omega+\frac{\gamma_2 N_2}{\gamma_1 N1}\right)}{\gamma_1(3-\omega)(4-\omega)} > 0.$$

Thus $(t_1^{np,np,S} - t_2^{np,np,S}) > (t_1^{np,np,N} - t_2^{np,np,N})$.

c. Let $\Omega_1^{np,np,N}$ and $\Omega_2^{np,np,N}$, and $\Omega_1^{np,np,S}$ and $\Omega_2^{np,np,S}$ be the optimum welfare levels under the simultaneous (N) and sequential (S) tax competition. We have

$$\begin{aligned}\Omega_1^{np,np,S} - \Omega_1^{np,np,N} &= \frac{(1-\omega)^2\left(\gamma_2 N_2 + \gamma_1 N_1(2-\omega)\right)^2}{2\gamma_1^2 N_1(4-\omega)(3-\omega)^2}\\ \Omega_2^{np,np,S} - \Omega_2^{np,np,N} &= (1-\omega)\gamma_2 N_2(t_2^{np,np,S} - t_2^{np,np,N})\\ &\quad + \gamma_1^2 N_1[t_2^{np,np,S}(t_1^{np,np,S} - t_2^{np,np,S}) - t_2^{np,np,N}(t_1^{np,np,N} - t_2^{np,np,N})].\end{aligned}$$

Indeed, $\Omega_1^{np,np,S} > \Omega_1^{np,np,N}$, since $\leq \omega < 1$. Again, $\Omega_2^{np,np,S} > \Omega_2^{np,np,N}$ since $t_2^{np,np,S} > t_2^{np,np,N}$ and $(t_1^{np,np,S} - t_2^{np,np,S}) > (t_1^{np,np,N} - t_2^{np,np,N})$.

$\square$

Parts (a) and (c) of proposition 1 summarize a result that is compatible with Keen and Konrad (2013). Regions involved in sequential tax competition as Stackelberg competitors apply higher tax rates and enjoy higher welfare compared to the case where they are Nash-Cournot tax competitors. Part (b) of this proposition presents a new result that explains that the tax gap is higher under sequential than under simultaneous tax competition. It means under sequential tax competition, the Stackelberg leader increases its tax rate more than the follower does in comparison to the simultaneous equilibrium tax rates. Under sequential Stackelberg tax competition, tax rate differentials are higher than under Nash-Cournot tax competition. Regions stand out more under sequential tax competition compared to Nash-Cournot tax competition because the large region when setting its tax rate is able to anticipate the reaction of the small one.

From the expressions in the part a of this proof, we have $t_1^{np,np,N} - 2t_2^{np,np,N} = t_1^{np,np,S} - 2t_2^{np,np,S} \equiv \alpha$. Under simultaneous and sequential tax competition, the optimum tax rates create a path of equilibrium such that $t_1^* - 2t_2^* = \alpha$ or $t_2^* = (t_1^* - \alpha)/2$. The non-discriminatory equilibrium tax rate in region 1 must be strictly greater than α. By the force of competition, when regions interact simultaneously, the tax rates are $t_1^* = \alpha + \epsilon$ and $t_2^* = \epsilon/2$ for any small $\epsilon \in (0,1)$. When regions interact as sequential tax competitors, the leader, region 1 can increase its level of welfare by imposing an higher tax rate in comparison to the simultaneous equilibrium one. The follower, region 2, will enjoy higher welfare by moving in the same direction, thus imposing an higher tax rate compared to its simultaneous equilibrium one. For example, if region 1 sets its sequential equilibrium tax rate at $t_1^* = \alpha + 2\epsilon$, the tax rate in region 2 will be set at $t_2^* = \epsilon$.

It is of interest to consider the case where the small region is acting as a Stackelberg leader while the large one is a follower. In this case, by solving the follower's problem, its best response function is [1.5]. Thereafter, the Stackelberg equilibrium tax rates would be

$$t_{1'}^{np,np,S} = \frac{(1-\omega)}{2\gamma_1(2-\omega)}\left((3-\omega) + (1-\omega)(2-\omega)\frac{\gamma_2 N_2}{\gamma_1 N_1}\right)$$

$$t_{2'}^{np,np,S} = \frac{1}{2\gamma_1}\left(1 + (2-\omega)\frac{\gamma_2 N_2}{\gamma_1 N_1}\right).$$

Similar to proposition 1 part (a), the Stackelberg equilibrium tax rates are higher than the simultaneous equilibrium ones ([1.7] and [1.8]) in both regions. However, contrary to proposition 1 part (b), the tax gaps are lower under the sequential tax competition than under the simultaneous tax competition. Indeed, when the large region is acting as a Stackelberg follower, at equilibrium, it increases its tax rate less than the small region does. In sum, under sequential tax competition, the regional government that acts as a Stackelberg leader has more leeway to increase its equilibrium tax rate relative to its simultaneous equilibrium tax rate.

In the rest of this chapter, I consider that sequential tax competition grants the large region, region 1, the first-mover advantage. Indeed, this framework proposes equilibrium solutions that are comparable to results from Mongrain and Wilson (2018), even if sequential tax competition is not part of their model. Further, it is unrealistic to envision a case where a small country, under Stackelberg tax competition, increases its equilibrium tax rate more than the large region does, as is the case where the small region moves first. Because of tax competition, I would anticipate that a small region will not increase its equilibrium tax rate more the large region does. Based on these two reasons, I continue the analysis assuming that the large region is granted a Stackelberg leader position in setting tax policy.

1.3.2 Both Regions Apply Preferential Tax Regimes

Let T_1 and τ_1 be the tax rates imposed on domestic firms and foreign firms in region 1 and T_2 and τ_2 the tax rates imposed on domestic and foreign firms in region 2.

Assume that the tax rate imposed on foreign firms in region 1 is higher than the tax rate applied to local firms in region 2, $\tau_1 \geq T_2$ and the tax rate applied to foreign firms in region 2 is higher than the tax rate applied to local firms in region 1, $\tau_2 \geq T_1$. Firms do not move from one region to another. From [1.3] and [1.4], total tax revenue collected in region 1 and total private surplus in region 1 are $R_1^{p,p}(T_1, \tau_1, T_2, \tau_2) = T_1\gamma_1 N_1$ and $S_1^{p,p}(T_1, \tau_1, T_2, \tau_2) = (1 - T_1)\gamma_1 N_1$. In region 2, we have $R_2^{p,p}(T_1, \tau_1, T_2, \tau_2) = T_2\gamma_2 N_2$ and $S_2^{p,p}(T_1, \tau_1, T_2, \tau_2) = (1 - T_2)\gamma_2 N_2$. Each region i chooses T_i and τ_i so as to maximize $\Omega_i^{p,p} = R_i^{p,p} + \omega S_i^{p,p} = T_i\gamma_i N_i + \omega(1 - T_i)\gamma_i N_i$ for $i \in \{1, 2\}$. Under simultaneous (N) and sequential (S) tax competition, at equilibrium, regions apply a confiscatory tax rate, that is $T_1^{p,p,NorS} = \tau_1^{p,p,NorS} = 1$ and $T_2^{p,p,NorS} = \tau_2^{p,p,NorS} = 1$. The equilibrium welfare levels are $\Omega_1^{p,p,NorS} = \gamma_1 N_1$ and $\Omega_2^{p,p,NorS} = \gamma_2 N_2$.[4]

Assume that $T_1 > \tau_2$ and $T_2 > \tau_1$. Total tax revenues and private surplus in region 1 and region 2 are

$$\begin{aligned}
R_1^{p,p}(T_1, \tau_1, T_2, \tau_2) &= T_1\gamma_1 N_1[1 - F((T_1 - \tau_2)\gamma_1)] + \tau_1\gamma_2 N_2 F((T_2 - \tau_1)\gamma_2) \\
&= T_1\gamma_1 N_1[1 - (T_1 - \tau_2)\gamma_1] + \tau_1\gamma_2 N_2 (T_2 - \tau_1)\gamma_2 \\
S_1^{p,p}(T_1, \tau_1, T_2, \tau_2) &= (1 - T_1)\gamma_1 N_1[1 - F((T_1 - \tau_2)\gamma_1)] + (1 - \tau_2)\gamma_1 N_1 F((T_1 - \tau_2)\gamma_1) \\
&\quad - N_1 \int_0^{(T_1 - \tau_2)\gamma_1} cf(c)dc \\
&= (1 - T_1)\gamma_1 N_1[1 - (T_1 - \tau_2)\gamma_1] + (1 - \tau_2)\gamma_1 N_1 (T_1 - \tau_2)\gamma_1 \\
&\quad - N_1 \int_0^{(T_1 - \tau_2)\gamma_1} cdc
\end{aligned}$$

---

[4] This will be also the solution of a tax coordination equilibrium as viewed by Keen and Konrad (2013). Regional governments in region 1 and region 2 would behave as if they formed a single planner that chooses T_1, τ_1, T_2, and τ_2 that maximizes $\Omega^{coordination} = R_1 + R_2 + \omega(S_1 + S_2) = T_1\gamma_1 N_1 + T_2\gamma_2 N_2 + \omega[(1 - T_1)\gamma_1 N_1 + (1 - T_2)\gamma_2 N_2]$. The coordination equilibrium tax rates would be $T_1 = \tau_1 = T_2 = \tau_2 = 1$.

$$\begin{aligned}
R_2^{p,p}(T_1,\tau_1,T_2,\tau_2) &= T_2\gamma_2 N_2[1-F((T_2-\tau_1)\gamma_2)] + \tau_2\gamma_1 N_1 F((T_1-\tau_2)\gamma_1) \\
&= T_2\gamma_2 N_2[1-(T_2-\tau_1)\gamma_2] + \tau_2\gamma_1 N_1 (T_1-\tau_2)\gamma_1 \\
S_2^{p,p}(T_1,\tau_1,T_2,\tau_2) &= (1-T_2)\gamma_2 N_2[1-F((T_2-\tau_1)\gamma_2)] + (1-\tau_1)\gamma_2 N_2 F((T_2-\tau_1)\gamma_2) \\
&- N_2\int_0^{(T_2-\tau_1)\gamma_2} cf(c)dc \\
&= (1-T_2)\gamma_2 N_2[1-(T_2-\tau_1)\gamma_2] + (1-\tau_1)\gamma_2 N_2 (T_2-\tau_1)\gamma_2 \\
&- N_2\int_0^{(T_2-\tau_1)\gamma_2} cdc
\end{aligned}$$

In case regions set their tax policy simultaneously as Nash-Cournot tax competitors, region 1 maximizes $\Omega_1^{p,p} = R_1^{p,p} + \omega S_1^{p,p}$ by selecting the tax rate on the domestic base T_1 and the tax rate on the foreign base τ_1 while region 2 simultaneously maximizes $\Omega_2^{p,p} = R_2^{p,p} + \omega S_2^{p,p}$ by choosing T_2 and τ_2. In this case, the reaction functions for region 1, $T_1(\tau_2)$ and $\tau_1(T_2)$ and for region 2, $T_2(\tau_1)$ and $\tau_2(T_1)$, are as follows

$$T_1(\tau_2) = \frac{(1-\omega)(1+\gamma_1\tau_2)}{\gamma_1(2-\omega)} \tag{1.11}$$

$$\tau_1(T_2) = \frac{T_2}{2} \tag{1.12}$$

$$T_2(\tau_1) = \frac{(1-\omega)(1+\gamma_2\tau_1)}{\gamma_2(2-\omega)} \tag{1.13}$$

$$\tau_2(T_1) = \frac{T_1}{2}. \tag{1.14}$$

Thereafter, the Nash-Cournot tax competition equilibrium tax rates are

$$T_1^{p,p,N} = \frac{2(1-\omega)}{\gamma_1(3-\omega)} \tag{1.15}$$

$$\tau_1^{p,p,N} = \frac{(1-\omega)}{\gamma_2(3-\omega)} \tag{1.16}$$

$$T_2^{p,p,N} = \frac{2(1-\omega)}{\gamma_2(3-\omega)} \tag{1.17}$$

$$\tau_2^{p,p,N} = \frac{(1-\omega)}{\gamma_1(3-\omega)}. \tag{1.18}$$

Now consider the case where regions are interacting sequentially as Stackelberg tax competitors, where the large region, region 1, is a leader and the small one, region 2, is a follower. Region 2's reaction functions, $T_2(\tau_1)$ and $\tau_2(T_1)$, when solving the problem of the follower, are [1.13] and [1.14]. In this case, we have

$$\begin{aligned}
R_1^{p,p}(T_1,\tau_1) &= T_1\gamma_1 N_1\left(1-\frac{\gamma_1 T_1}{2}\right) + \tau_1\gamma_2 N_2\left(\frac{(1-\omega)}{\gamma_2(2-\omega)} - \frac{\tau_1}{2-\omega}\right)\gamma_2 \\
S_1^{p,p}(T_1,\tau_1) &= (1-T_1)\gamma_1 N_1\left(1-\frac{\gamma_1 T_1}{2}\right) + (1-\frac{T_1}{2})\gamma_1 N_1\frac{T_1}{2}\gamma_1 - N_1\int_0^{\frac{T_1}{2}\gamma_1} cdc.
\end{aligned}$$

The sequential tax competition equilibrium tax rates are

$$T_1^{p,p,S} = \frac{4(1-\omega)}{\gamma_1(4-\omega)} \qquad [1.19]$$

$$\tau_1^{p,p,S} = \frac{(1-\omega)}{2\gamma_2} \qquad [1.20]$$

$$T_2^{p,p,S} = \frac{(1-\omega)(3-\omega)}{2\gamma_2(2-\omega)} \qquad [1.21]$$

$$\tau_2^{p,p,S} = \frac{2(1-\omega)}{\gamma_1(4-\omega)}. \qquad [1.22]$$

Let $\Omega_1^{p,p,N}$ and $\Omega_2^{p,p,N}$ denote the optimum welfare levels in region 1 and region 2 when they apply preferential tax regimes and under Nash-Cournot tax competition. Similarly, let $\Omega_1^{p,p,S}$ and $\Omega_2^{p,p,S}$ denote be the optimum welfare levels in region 1 and region 2 when they apply preferential tax regimes and under sequential tax competition where the large region is a Stackelberg leader while the small one a follower. Under simultaneous tax competition, region 1 receives higher welfare levels when it implements a non-preferential tax regime, i.e. $\Omega_1^{np,np,N} - \Omega_1^{p,p,N} > 0$, if $\frac{\gamma_2 N_2}{\gamma_1 N_1} > \frac{2\gamma_1}{\gamma_2(2-\omega)} - 2(2-\omega)$. Similarly, region 2 receives higher welfare levels when it implements a non-preferential tax regime, i.e. $\Omega_2^{np,np,N} - \Omega_2^{p,p,N} > 0$, if $\frac{\gamma_2 N_2}{\gamma_1 N_1} > \frac{\gamma_1(8-3\omega)}{2\gamma_2(2-\omega)^2} - \frac{2}{2-\omega}$. Under sequential tax competition, we have, $\Omega_1^{np,np,S} - \Omega_1^{p,p,S} > 0$, if $\frac{\gamma_2 N_2}{\gamma_1 N_1} > \frac{\gamma_1(4-\omega)}{2\gamma_2(2-\omega)} - 2(2-\omega)$. Similarly, $\Omega_2^{np,np,S} - \Omega_2^{p,p,S} > 0$, if $\frac{\gamma_2 N_2}{\gamma_1 N_1} > \frac{\gamma_1(4-\omega)^2(9-4\omega)}{8\gamma_2(2-\omega)(3-\omega)^2} - \frac{4}{3-\omega}$.

Proposition 2. *Under simultaneous tax competition, if* $(2-\omega)^2 < \frac{\gamma_1}{\gamma_2} < \frac{(2-\omega)(5-2\omega)}{2}$, *region 1 applies non-preferential policy while region 2 applies preferential tax policy. If* $\frac{4(2-\omega)}{8-3\omega} < \frac{\gamma_1}{\gamma_2} < \frac{2(2-\omega)(4-\omega)}{8-3\omega}$ *region 1 applies preferential tax policy while region 2 applies non-preferential tax policy.*

Under sequential tax competition, if $\frac{4(2-\omega)^2}{4-\omega} < \frac{\gamma_1}{\gamma_2} < \frac{2(2-\omega)(5-2\omega)}{4-\omega}$, *region 1 applies non-preferential policy while region 2 applies preferential tax policy. If* $\frac{32(2-\omega)(3-\omega)}{(4-\omega)^2(9-4\omega)} < \frac{\gamma_1}{\gamma_2} < \frac{8(2-\omega)(3-\omega)(7-\omega)}{(4-\omega)^2(9-4\omega)}$ *region 1 applies preferential tax policy while region 2 applies non-preferential tax policy.*

Proof. Under simultaneous tax competition, if $(2-\omega)^2 < \frac{\gamma_1}{\gamma_2} < \frac{(2-\omega)(5-2\omega)}{2}$, since $0 < \frac{\gamma_2 N_2}{\gamma_1 N_1} < 1$ and $0 \leq \omega < 1$, then $\Omega_1^{np,np,N} > \Omega_1^{p,p,N}$. As a result, region 1 applies a non-preferential tax regime while region 2 applies a preferential tax regime. Similarly, if $\frac{4(2-\omega)}{8-3\omega} < \frac{\gamma_1}{\gamma_2} < \frac{2(2-\omega)(4-\omega)}{8-3\omega}$, since $0 < \frac{\gamma_2 N_2}{\gamma_1 N_1} < 1$ and $0 \leq \omega < 1$, $\Omega_2^{np,np,N} > \Omega_2^{p,p,N}$. Therefore, region 1 applies a preferential tax regime while region 2 applies a non-preferential tax regime.

Under sequential tax competition, if $\frac{4(2-\omega)^2}{4-\omega} < \frac{\gamma_1}{\gamma_2} < \frac{2(2-\omega)(5-2\omega)}{4-\omega}$, since $0 < \frac{\gamma_2 N_2}{\gamma_1 N_1} < 1$ and $0 \leq \omega < 1$, then $\Omega_1^{np,np,S} > \Omega_1^{p,p,S}$. As a result, region 1 applies a non-preferential tax regime while region 2 applies a preferential tax regime. Similarly, if $\frac{32(2-\omega)(3-\omega)}{(4-\omega)^2(9-4\omega)} < \frac{\gamma_1}{\gamma_2} < \frac{8(2-\omega)(3-\omega)(7-\omega)}{(4-\omega)^2(9-4\omega)}$, since $0 < \frac{\gamma_2 N_2}{\gamma_1 N_1} < 1$ and $0 \leq \omega < 1$, then $\Omega_2^{np,np,S} > \Omega_2^{p,p,S}$. Therefore, region 1 applies a preferential tax regime while region 2 applies a non-preferential tax regime. $\square$

Indeed, when domestic firms are very heterogeneous; for example $3 < \frac{\gamma_1}{\gamma_2} < 4$ for a fixed weight $\omega = 0.25$; the large region implements non-preferential tax policy while the small one, region 2, implements preferential tax policy. Further, if domestic firms are not very heterogeneous; for example $1 < \frac{\gamma_1}{\gamma_2} < 1.8$ when $\omega = 0.25$; the region 2 applies non-preferential tax policy while region 1 applies preferential tax policy. This result suggests, if firms initially located in region 1 are very productive relative to region 2's firms, the larger region will always implement a non-discriminatory tax regime while the small one applies a discriminatory tax regime. This result is in contrast to Niu (2019) that concludes that preferential tax regime is a dominant strategy if regions are sufficiently asymmetric in terms of firm productivity. In Mongrain and Wilson (2018), the small region prefers a preferential tax regime under asymmetric simultaneous tax competition when regions are very asymmetric and the weight put on the private surplus is high. In this chapter, the introduction of firm heterogeneity brings about a new finding that consists on, if firms initially located in the large region generate larger profit in comparison to firms initially located in the small region, for example $3 < \frac{\gamma_1}{\gamma_2} < 4$, the large region is better off applying a non-preferential tax regime while small region by applying a preferential tax regime.

Under the sequential Stackelberg tax competition, the tax rates applied on domestic and foreign firms are higher than the simultaneous equilibrium ones. Moving from a simultaneous to a sequential equilibrium, the large region increases its tax rate on domestic firms more than the small region does on its foreign firms and its tax rate on foreign firms more than the small region does on its domestic firms; that is

$$(T_1^{p,p,S} - T_1^{p,p,N}) - (\tau_2^{p,p,S} - \tau_2^{p,p,N}) = \frac{(1-\omega)(2-\omega)}{\gamma_1(3-\omega)(4-\omega)} > 0$$

$$(\tau_1^{p,p,S} - \tau_1^{p,p,N}) - (T_2^{p,p,S} - T_2^{p,p,N}) = \frac{(1-\omega)^2}{2\gamma_2(2-\omega)(3-\omega)} > 0.$$

Further, by using [1.15], [1.17], [1.19], and [1.21], $(T_1^{p,p,S} - T_1^{p,p,N}) > (T_2^{p,p,S} - T_2^{p,p,N})$ if $\frac{\gamma_1}{\gamma_2} < \frac{4(2-\omega)^2}{(1-\omega)^2(4-\omega)}$. Similarly, by using [1.16], [1.18], [1.20], and [1.22], $(\tau_1^{p,p,S} - \tau_1^{p,p,N}) > (\tau_2^{p,p,S} - \tau_2^{p,p,N})$ if $\frac{2(2-\omega)}{(1-\omega)(4-\omega)} < \frac{\gamma_1}{\gamma_2}$. Indeed, moving from a simultaneous to a sequential equilibrium, the large region increases its tax rate on domestic and foreign firms more than the small region does if $\frac{2(2-\omega)}{(1-\omega)(4-\omega)} < \frac{\gamma_1}{\gamma_2} < \frac{4(2-\omega)^2}{(1-\omega)^2(4-\omega)}$. When $\frac{\gamma_1}{\gamma_2} > \frac{4(2-\omega)^2}{(1-\omega)^2(4-\omega)}$, the cost of losing domestic firms is very high for the large region. As a result, it will increase its tax rate on domestic firms less than the small region does. Similarly, when $\frac{\gamma_1}{\gamma_2} < \frac{2(2-\omega)}{(1-\omega)(4-\omega)}$, the incentive to attract foreign firms is high for the large region. Therefore, it will increase its tax rate on foreign firms less than region 2 does.

Assume now regions impose positive tax rates on domestic firms but decide to apply a zero tax rate on foreign firms. In this case, total tax revenue and total private surplus expressions in both regions are

$$\begin{aligned}
R_{1'}^{p,p}(T_1) &= T_1\gamma_1 N_1 (1 - \gamma_1 T_1) \\
S_{1'}^{p,p}(T_1) &= (1 - T_1)\gamma_1 N_1 (1 - \gamma_1 T_1) + \gamma_1 N_1(\gamma_1 T_1) - N_1 \int_0^{T_1\gamma_1} cdc \\
R_{2'}^{p,p}(T_2) &= T_2\gamma_2 N_2 (1 - \gamma_2 T_2) \\
S_{2'}^{p,p}(T_2) &= (1 - T_2)\gamma_2 N_2 (1 - \gamma_2 T_2) + \gamma_2 N_2(\gamma_2 T_2) - N_2 \int_0^{T_2\gamma_2} cdc.
\end{aligned}$$

In this case, regional governments apply the same tax rate whether they are interacting simultaneously or sequentially.

$$T_{1'}^{p,p,NorS} = \frac{1}{\gamma_1}\left(\frac{1-\omega}{2-\omega}\right) \ , \ \tau_{1'}^{p,p,NorS} = 0 \ , \ T_{2'}^{p,p,NorS} = \frac{1}{\gamma_2}\left(\frac{1-\omega}{2-\omega}\right) \ , \ \tau_{2'}^{p,p,NorS} = 0.$$

This is not a strategy regions would consider since they collect less tax revenue on domestic firms and no tax revenue on foreign ones compared to the simultaneous (equations [1.15] to [1.18]) or sequential (equations [1.19] to [1.22]) equilibrium solutions. Indeed,

$$T_{1'}^{p,p,NorS} < T_1^{p,p,N} < T_1^{p,p,S}$$

$$\tau_{1'}^{p,p,NorS} < \tau_1^{p,p,N} < \tau_1^{p,p,S}$$

$$T_{2'}^{p,p,NorS} < T_2^{p,p,N} < T_2^{p,p,S}$$

$$\tau_{2'}^{p,p,NorS} < \tau_2^{p,p,N} < \tau_2^{p,p,S}.$$

1.3.3 Non-Preferential and Preferential Tax Regimes

In this case, one region chooses to apply non-preferential tax policy while the other decides to use preferential tax policy. In this section and for the rest of this chapter, since analytical results can not be found, conclusions are derived from analysis of simulation results.[5]

Assume that the large region, region 1, is the one that decides not to discriminate. Indeed, it chooses the tax rate t_1 that will be applied to both domestic and foreign firms. The small region, region 2, chooses a tax rate T_2 to apply to domestic firms and a tax rate τ_2 to apply to foreign firms. If $t_1 \geq T_2$ and $t_1 \leq \tau_2$, by using [1.3] and [1.4], $\Omega_1^{np,p}(t_1, T_2, \tau_2) = t_1\gamma_1 N_1 + \omega(1-t_1)\gamma_1 N_1$ and $\Omega_2^{np,p}(t_1, T_2, \tau_2) = T_2\gamma_2 N_2 + \omega(1-T_2)\gamma_2 N_2$. Under simultaneous and sequential tax competition, the equilibrium tax rates and welfare levels are $t_1^{np,p,NorS} = T_2^{np,p,NorS} = \tau_2^{np,p,NorS} = 1$, $\Omega_1^{np,p,NorS} = \gamma_1 N_1$ and $\Omega_2^{np,p,NorS} = \gamma_2 N_2$.

We assume $t_1 < T_2$ and $t_1 > \tau_2$. In this case, the assumption of the existence of two distinct and independent tax bases does not hold any more (Keen, 2001; Mongrain and Wilson, 2018). The tax bases are dependent, indeed, the reaction functions $t_1(T_2, \tau_2)$, $T_2(t_1)$, and $\tau_2(t_1)$ are

$$t_1(T_2, \tau_2) = \frac{(1-\omega)(1+\gamma_1\tau_2) + \frac{\gamma_2^2 N_2}{\gamma_1 N_1} T_2}{\gamma_1(2-\omega) + 2\frac{\gamma_2^2 N_2}{\gamma_1 N_1}} \qquad [1.23]$$

$$T_2(t_1) = \frac{1}{\gamma_2}\frac{1-\omega}{2-\omega}(1+\gamma_2 t_1) \text{ and } \tau_2(t_1) = \frac{t_1}{2}. \qquad [1.24]$$

---

[5] To characterize the degree of asymmetry between regions, I define the share of firms initially located in region 1, $n > \frac{1}{2}$. As a result, $1-n < \frac{1}{2}$ represents the share of the total number of firms initially located in region 2. The weight put on private surplus in the welfare function is $0 \leq \omega < 1$. Different welfare levels can be obtained by letting vary n and ω. However, comparison will not be very intuitive since several 3D-curves cannot be plotted in the same graph. Therefore, I use two scenarios. One that keeps $\omega = 0.25$ and lets n varies from 0.5 to 1; and the other that sets $n = 0.55$ and lets ω varies from 0 to 1. To create some heterogeneity between the firms initially located in regions 1 and 2, I assume that the ratio of profits is $\frac{\gamma_1}{\gamma_2} = 1.5$. Thus, firms initially located in region 1 are more productive than that of region 2. These parameters are not grounded on any empirical evidence. However, they do help highlight some intuitions from the model.

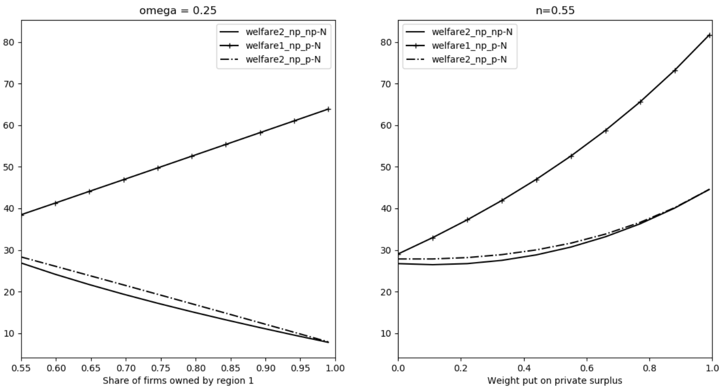
In case regions choose their tax rates simultaneously as Nash-Cournot tax competitors, the solutions are

$$t_1^{np,p,N} = \frac{2}{\gamma_1}\frac{1-\omega}{3-\omega}\left(\frac{2-\omega+\frac{\gamma_2 N_2}{\gamma_1 N_1}}{2-\omega+2\frac{\gamma_2^2 N_2}{\gamma_1^2 N_1}}\right)$$

$$T_2^{np,p,N} = \frac{1}{\gamma_2}\frac{1-\omega}{2-\omega}\left[1+\frac{2\gamma_2}{\gamma_1}\frac{1-\omega}{3-\omega}\left(\frac{2-\omega+\frac{\gamma_2 N_2}{\gamma_1 N_1}}{2-\omega+2\frac{\gamma_2^2 N_2}{\gamma_1^2 N_1}}\right)\right]$$

$$\tau_2^{np,p,N} = \frac{1}{\gamma_1}\frac{1-\omega}{3-\omega}\left(\frac{2-\omega+\frac{\gamma_2 N_2}{\gamma_1 N_1}}{2-\omega+2\frac{\gamma_2^2 N_2}{\gamma_1^2 N_1}}\right).$$

Figure 1.1: Welfare levels, simultaneous move, region 1 does not discriminate while region 2 discriminates



The curves welfare1_np_p-N and welfare2_np_p-N show welfare levels in region 1 and region 2 when region 1 does not discriminate while region 2 discriminates in tax treatment; and regions interact simultaneously. The curve welfare2_np_np-N shows welfare levels in region 2 when both regions do not discriminate. Also $\frac{\gamma_1}{\gamma_2} = 1.5$.

If they choose their tax rates sequentially as Stackelberg tax competitors, the solutions are found to be

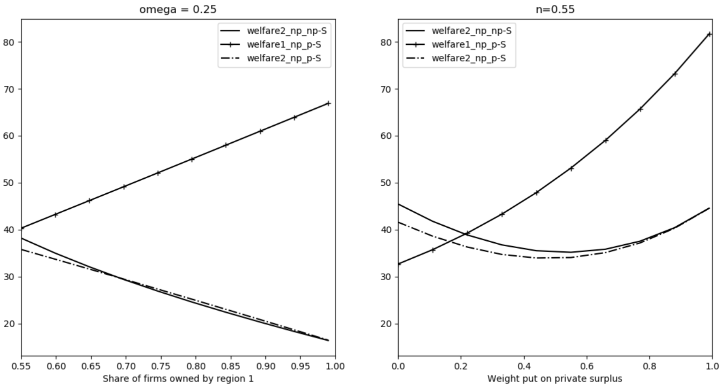
$$t_1^{np,p,S} = \frac{4}{\gamma_1}\frac{1-\omega}{4-\omega}\left(\frac{2-\omega+\frac{\gamma_2 N_2}{\gamma_1 N_1}}{2-\omega+\frac{8}{4-\omega}\frac{\gamma_2^2 N_2}{\gamma_1^2 N_1}}\right)$$

$$T_2^{np,p,S} = \frac{1}{\gamma_2}\frac{1-\omega}{2-\omega}\left[1+\frac{4\gamma_2}{\gamma_1}\frac{1-\omega}{4-\omega}\left(\frac{2-\omega+\frac{\gamma_2 N_2}{\gamma_1 N_1}}{2-\omega+\frac{8}{4-\omega}\frac{\gamma_2^2 N_2}{\gamma_1^2 N_1}}\right)\right]$$

$$\tau_2^{np,p,S} = \frac{2}{\gamma_1}\frac{1-\omega}{4-\omega}\left(\frac{2-\omega+\frac{\gamma_2 N_2}{\gamma_1 N_1}}{2-\omega+\frac{8}{4-\omega}\frac{\gamma_2^2 N_2}{\gamma_1^2 N_1}}\right).$$

Assume now the small region, region 2, is the one that chooses not to discriminate. Region 1 chooses the tax rate T_1 to impose on domestic firms and τ_1 to impose on foreign ones while region

Figure 1.2: Welfare levels, Stackelberg solution, region 1 does not discriminate while region 2 discriminates



The curves welfare1_np_p-S and welfare2_np_p-S show welfare levels when region 1 does not discriminate while region 2 discriminates in tax treatment; and regions are Stackelberg competitors. The curve welfare2_np_np-S shows the welfare levels in region 2 when both regions do not discriminate. Also $\frac{\gamma_1}{\gamma_2} = 1.5$.

2 chooses a single tax rate t_2 to levy upon both domestic and foreign firms. The simultaneous equilibrium tax rates are defined as follows

$$T_1^{p,np,N} = \frac{1}{\gamma_1}\frac{1-\omega}{2-\omega}\left[1 + \frac{2\gamma_1}{\gamma_2}\frac{1-\omega}{3-\omega}\left(\frac{2-\omega+\frac{\gamma_1 N_1}{\gamma_2 N2}}{2-\omega+2\frac{\gamma_1^2 N_1}{\gamma_2^2 N2}}\right)\right]$$

$$\tau_1^{p,np,N} = \frac{1}{\gamma_2}\frac{1-\omega}{3-\omega}\left(\frac{2-\omega+\frac{\gamma_1 N_1}{\gamma_2 N_2}}{2-\omega+2\frac{\gamma_1^2 N_1}{\gamma_2^2 N_2}}\right)$$

$$t_2^{p,np,N} = \frac{2}{\gamma_2}\frac{1-\omega}{3-\omega}\left(\frac{2-\omega+\frac{\gamma_1 N_1}{\gamma_2 N_2}}{2-\omega+2\frac{\gamma_1^2 N_1}{\gamma_2^2 N_2}}\right).$$

If the regions are interacting sequentially, the reaction function of region 2, the follower, $t_2(T_1, \tau_1)$ is defined as

$$t_2(T_1, \tau_1) = \frac{(1-\omega)(1+\gamma_2\tau_1) + \frac{\gamma_1^2 N_1}{\gamma_2 N_2}T_1}{\gamma_2(2-\omega) + 2\frac{\gamma_1^2 N_1}{\gamma_2 N_2}}.$$

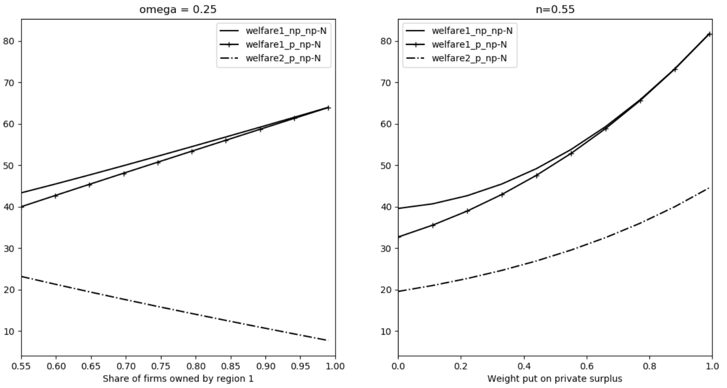
Proposition 3. *Analysis of simulation results shows that if the large region decides to apply non-discriminatory tax policy,*

a. Under simultaneous tax competition, the small region applies discriminatory tax policy;

b. Under Stackelberg tax competition, the small region applies non-discriminatory tax policy.

Proposition 4. *Analysis of simulation results shows that if the small region decides to apply non-discriminatory tax policy,*

Figure 1.3: Welfare levels, simultaneous move, region 2 does not discriminate while region discriminates



The curves welfare1_p_np-N and welfare2_p_np-N show welfare levels when region 1 discriminates while region 2 does not discriminate in tax treatment; and regions act simultaneously. The curve welfare1_np_np-N shows the welfare levels in region 1 when both regions do not discriminate. Also $\frac{\gamma_1}{\gamma_2} = 1.5$.

a. *Under simultaneous tax competition, the large region applies non-discriminatory tax policy;*

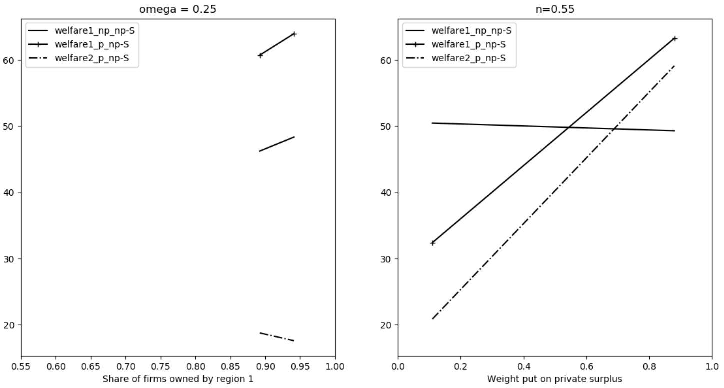
b. *Under Stackelberg tax competition, the large region applies discriminatory tax policy when it possesses a share of domestic firms* $n > 0.90$ *or the weight put on private surplus in the welfare function is* $\omega > 0.60$.

As shown in Figure 1.1 or Table 1.1 and Table 1.2 in Appendix 1.8.2 , when regions choose their tax rates simultaneously, if the small region anticipates that the large region will apply non-preferential tax policy, it is in its best interest to apply preferential tax policy. Under Stackelberg tax competition, as shown in Figure 1.2 or Table 1.3 and Table 1.4 in Appendix 1.8.2, if the follower region, the small one, anticipates that the leader, the large region, will apply non-preferential tax policy, it will also apply non-preferential tax policy. Indeed, tax competition between two asymmetric countries like, for example, the U.S. and Belgium, will most likely be a case where the U.S applies a non-discriminatory tax regime and Belgium applies a discriminatory tax regime if they choose their tax rates simultaneously. Whereas, if they are Stackelberg competitors where the U.S. is a leader while the small one, Belgium, is a follower, we will expect both of them to apply a non-discriminatory tax system if the U.S applies a non-discriminatory tax regime.

As shown in Figure 1.3 or Table 1.5 and Table 1.6 in Appendix 1.8.2, under simultaneous tax competition, if the large region anticipates that the small one will apply a non-preferential tax regime, it will also apply a non-preferential tax regime. Whereas, under Stackelberg tax competition, as shown in Figure 1.4 or Table 1.7 and Table 1.8 in Appendix 1.8.2, if the large region anticipates that the small one will apply non-preferential tax policy, it will apply preferential tax policy if $n > 0.90$ or $\omega > 0.60$.

From proposition 3, under Stackelberg tax competition, I allege that if the large region commits not to use preferential tax policy, it is in the small region's best interest to avoid using preferential tax policy. By doing so, both regions can apply higher tax rates and receive higher welfare levels. Similarly, from proposition 4, if the small region can commit not to use preferential tax policy, the large region will prefer not to apply preferential tax policy for same reason mentioned above. Nevertheless, if regions are extremely asymmetric (for example $n > 0.90$), due to the fact the small

Figure 1.4: Welfare levels, Stackelberg solution, region 2 does not discriminate while region 1 discriminates



The curves welfare1_p_np-S and welfare2_p_np-S show welfare levels when region 1 discriminates while region 2 does not discriminates in tax treatment; and regions are Stackelberg competitors. The curve welfare1_np_np-N shows the welfare levels in region 1 when both regions do not discriminate. Also $\frac{\gamma_1}{\gamma_2} = 1.5$.

region will have a huge incentive to lower its tax rates in order to attract more foreign firms, the large region will prefer to implement preferential tax policy.

1.4 Different uniform moving costs

In this section, I assume that firms in the small region face a different distribution of the costs of mobility while the large region's firms are still facing moving costs uniformly distributed between 0 and 1. This situation can be interpreted as aftermaths of actions limiting capital outflows taken by the small region. The aim of those actions is to maintain within the country or the region a tax base to finance public services. There are many examples of capital outflow controls such as the U.S interest equalization tax of 1963-1974, Chile, Brazil, Argentina, Mexico, and Malaysia in the 1990s, as well as the Czech Republic, Hungry and Poland before their EU accessions (Giovannini and de Melo, 1993; Aizenman and Guidotti, 1994; Reinhart and Rogoff, 2011; Aizenman and Pasricha, 2013). This extension is new with regard to Mongrain and Wilson (2018). It allows to interpret the configuration of tax policy when firms from one region face a different distribution of costs of mobility in comparison to the other region.

Assume that the mobility costs in region 1 are distributed uniformly between 0 and 1 such that the distribution function is $F_1(c) = c$ and the corresponding density function is $f_1(c) = 1$. The moving costs in region 2 are now distributed uniformly between $\underline{\theta} > 0$ and $\overline{\theta} = 1$. As a result, in region 2, the distribution function becomes $F_2(c) = \frac{c-\underline{\theta}}{1-\underline{\theta}}$ with the corresponding density function $f_2(c) = \frac{1}{1-\underline{\theta}}$.[6]

From Appendix 1.8.3, if

$$0 < \underline{\theta} < \frac{\frac{\gamma_1 N_1}{\gamma_2 N_2} - 1}{\frac{\gamma_1 N_1}{\gamma_2 N_2} + \frac{1}{1-\omega}},$$

---

[6] In this situation, the average costs of mobility in region 1 is $\mu_1 = \frac{1}{2}$ while the average of cost of mobility in region 2 is $\mu_2 = \frac{1+\underline{\theta}}{2} > \mu_1$.

we have $t_1^{np,np,N} > t_2^{np,np,N}$ and the solutions are the ones provided by [1.7] and [1.8]. Indeed, when firms initially located in the small region face a different distribution of the costs of mobility, if the lower bound of this distribution is above the threshold of $(\frac{\gamma 1 N_1}{\gamma_2 N_2} - 1)/(\frac{\gamma 1 N_1}{\gamma_2 N_2} + \frac{1}{1-\omega})$, i.e. $(\frac{\gamma 1 N_1}{\gamma_2 N_2} - 1)/(\frac{\gamma 1 N_1}{\gamma_2 N_2} + \frac{1}{1-\omega}) < \underline{\theta} < 1$, we have $t_2^{np,np,N} > t_1^{np,np,N}$ and the simultaneous Nash-Cournot equilibrium tax rates are

$$t_1^{np,np,N} = \frac{(1-\omega)}{\gamma_2(3-\omega)} \left(1 - \frac{\underline{\theta}(2-\omega)}{1-\omega} + (1-\underline{\theta})(2-\omega)\frac{\gamma_1 N_1}{\gamma_2 N_2}\right) \qquad [1.25]$$

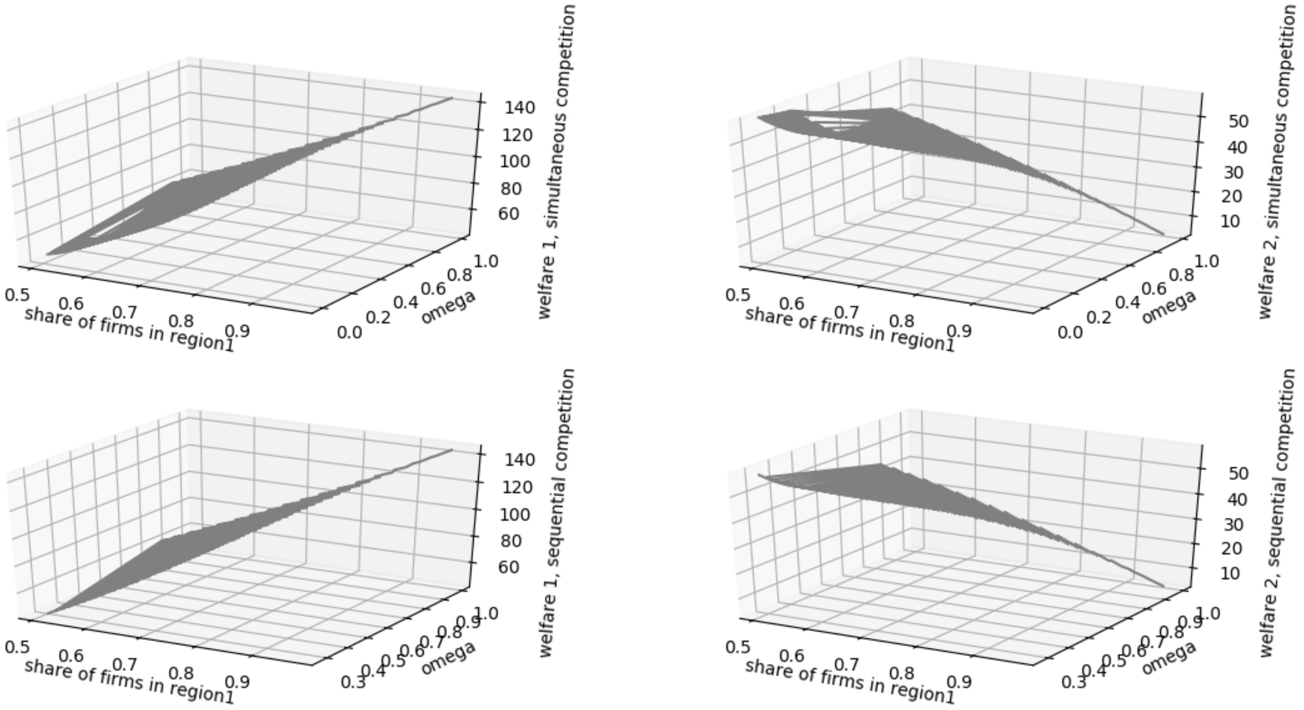
$$t_2^{np,np,N} = \frac{(1-\omega)}{\gamma_2(3-\omega)} \left(2 - \underline{\theta} + (1-\underline{\theta})(1-\omega)\frac{\gamma_1 N_1}{\gamma_2 N_2}\right). \qquad [1.26]$$

If regions are interacting sequentially, the Stackelberg equilibrium tax rates are

$$t_1^{np,np,S} = \frac{(2-\omega)}{2\gamma_2} \left(\frac{1-\omega}{2-\omega} - \underline{\theta} + (1-\underline{\theta})(1-\omega)\frac{\gamma_1 N_1}{\gamma_2 N_2}\right) \qquad [1.27]$$

$$t_2^{np,np,S} = \frac{(1-\omega)}{\gamma_2(2-\omega)} \left(1 + \frac{(2-\omega)}{2}\left(\frac{1-\omega}{2-\omega} - \underline{\theta} + (1-\underline{\theta})(1-\omega)\frac{\gamma_1 N_1}{\gamma_2 N_2}\right)\right). \qquad [1.28]$$

Figure 1.5: Welfare levels, non-preferential, $[\underline{\theta} = \frac{1}{3}, 1]$-uniform distribution in region 2



When firms in the small region face a different distribution of mobility costs, for example a $[\underline{\theta} = \frac{1}{3}, 1]$-uniform distribution instead of [0,1]-uniform distribution, domestic firms in the small region can shift less easily to the large region. Results of simulations shown in Tables 1.9 and 1.10 of Appendix 1.8.3, confirm that region 2 applies higher tax rate in comparison to the case where its domestic firms face a $[0, 1]$-uniform distribution of moving costs. As shown in 1.5, when regions decide their tax rate simultaneously, welfare levels increase in region 2 and decrease in region 1, if $n < 0.62$ and $\omega < 0.66$. In case regions are Stackelberg tax competitors, welfare levels increase in region 2 and decrease in region 1, if $n < 0.51$ and $\omega < 0.44$. Further, if $n > 0.62$ and $\omega > 0.66$, region 1 will benefit higher welfare levels while region 2 lower welfare levels in comparison to the case firms in both regions face $[0, 1]$-uniform distribution.

Assume that both regions apply preferential tax regimes. If $T_1 > \tau_2$ and $T_2 > \tau_1$, total tax revenue and total private surplus expressions in region 1 and region 2 are

$$\begin{aligned}
R_1^{p,p}(T_1, \tau_1, T_2, \tau_2) &= T_1\gamma_1 N_1 \left[1 - F_1((T_1 - \tau_2)\gamma_1)\right] + \tau_1\gamma_2 N_2 F_2((T_2 - \tau_1)\gamma_2) \\
&= T_1\gamma_1 N_1 \left[1 - (T_1 - \tau_2)\gamma_1\right] + \tau_1\gamma_2 N_2 \frac{(T_2 - \tau_1)\gamma_2 - \underline{\theta}}{1 - \underline{\theta}} \\
S_1^{p,p}(T_1, \tau_1, T_2, \tau_2) &= (1 - T_1)\gamma_1 N_1 \left[1 - F_1((T_1 - \tau_2)\gamma_1)\right] + (1 - \tau_2)\gamma_1 N_1 F_1((T_1 - \tau_2)\gamma_1) \\
&\quad - N_1 \int_0^{(T_1-\tau_2)\gamma_1} c f_1(c) dc \\
&= (1 - T_1)\gamma_1 N_1 \left[1 - (T_1 - \tau_2)\gamma_1\right] + (1 - \tau_2)\gamma_1 N_1 (T_1 - \tau_2)\gamma_1 \\
&\quad - N_1 \int_0^{(T_1-\tau_2)\gamma_1} c dc \\
R_2^{p,p}(T_1, \tau_1, T_2, \tau_2) &= T_2\gamma_2 N_2 \left[1 - F_2((T_2 - \tau_1)\gamma_2)\right] + \tau_1\gamma_1 N_1 F_1((T_1 - \tau_2)\gamma_1) \\
&= T_2\gamma_2 N_2 \left[1 - \frac{(T_2 - \tau_1)\gamma_2 - \underline{\theta}}{1 - \underline{\theta}}\right] + \tau_1\gamma_1 N_1 (T_1 - \tau_2)\gamma_1 \\
S_2^{p,p}(T_1, \tau_1, T_2, \tau_2) &= (1 - T_2)\gamma_2 N_2 \left[1 - F_2((T_2 - \tau_1)\gamma_2)\right] + (1 - \tau_1)\gamma_2 N_2 F_2((T_2 - \tau_1)\gamma_2) \\
&\quad - N_2 \int_{\underline{\theta}}^{(T_2-\tau_1)\gamma_2} c f_2(c) dc \\
&= (1 - T_2)\gamma_2 N_2 \left[1 - \frac{(T_2 - \tau_1)\gamma_2 - \underline{\theta}}{1 - \underline{\theta}}\right] + (1 - \tau_1)\gamma_2 N_2 \frac{(T_2 - \tau_1)\gamma_2 - \underline{\theta}}{1 - \underline{\theta}} \\
&\quad - N_2 \int_{\underline{\theta}}^{(T_2-\tau_1)\gamma_2} \frac{c}{1 - \underline{\theta}} dc
\end{aligned}$$

In case regions involve in tax competition choose their tax rates as Nash-Cournot, the reaction functions $T_1(\tau_2)$, $\tau_1(T_2)$, $T_2(\tau_1)$, and $\tau_2(T_1)$ are derived as follows

$$T_1(\tau_2) = \frac{(1 - \omega)(1 + \gamma_1\tau_2)}{\gamma_1(2 - \omega)} \text{ and } \tau_1(T_2) = \frac{T_2}{2} - \frac{\underline{\theta}}{2\gamma_2}$$

$$T_2(\tau_1) = \frac{(1 - \omega)(1 + \gamma_2\tau_1)}{\gamma_2(2 - \omega)} \text{ and } \tau_2(T_1) = \frac{T_1}{2}$$

Thereafter, the equilibrium tax rates are

$$T_1^{p,p,N} = \frac{2(1 - \omega)}{\gamma_1(3 - \omega)} \qquad [1.29]$$

$$\tau_1^{p,p,N} = \frac{(1 - \omega) - \underline{\theta}(2 - \omega)}{\gamma_2(3 - \omega)} \qquad [1.30]$$

$$T_2^{p,p,N} = \frac{(1-\omega)(2-\underline{\theta})}{\gamma_2(3-\omega)} \tag*{[1.31]}$$

$$\tau_2^{p,p,N} = \frac{(1-\omega)}{\gamma_1(3-\omega)}. \tag*{[1.32]}$$

If regions are interacting sequentially as Stackelberg competitors where the large region is a leader and the small is a follower, the equilibrium tax rates are found to be

$$T_1^{p,p,S} = \frac{4(1-\omega)}{\gamma_1(4-\omega)} \tag*{[1.33]}$$

$$\tau_1^{p,p,S} = \frac{(1-\omega)-\underline{\theta}(2-\omega)}{2\gamma_2} \tag*{[1.34]}$$

$$T_2^{p,p,NS} = \frac{(1-\omega)}{(2\gamma_2)}\left(\frac{3-\omega}{2-\omega}-\underline{\theta}\right) \tag*{[1.35]}$$

$$\tau_2^{p,p,S} = \frac{2(1-\omega)}{\gamma_1(4-\omega)}. \tag*{[1.36]}$$

In comparison to the case where both countries had [0,1]-uniformly distributed moving costs, when both regions decide their tax rates à la Nash-Cournot, the equilibrium tax rate on domestic firms in region 2 has decreased by $(\underline{\theta}(1-\omega))/(\gamma_2(3-\omega))$ ([1.17] and [1.31]) while the tax rate on foreign firms in region 1 has decreased by $(\underline{\theta}(2-\omega))/(\gamma_2(3-\omega))$ ([1.16] and [1.30]). When domestic firms in the small region face a higher distribution of mobility costs, in relation to the case where both regions have the same uniform distribution of moving costs, the tax rate applied to domestic firms in region 2 and to foreign firms in region 1 decrease.

Under Stackelberg competition, the equilibrium tax rate on domestic firms in region 2 has decreased by $(\underline{\theta}(1-\omega))/(2\gamma_2)$ ([1.21] and [1.35]) while the equilibrium tax rate on foreign firms in region 1 has decreased by $(\underline{\theta}(2-\omega))/(2\gamma_2)$ ([1.22] and [1.36]). The equilibrium tax rates on domestic firms in region 1 and foreign firms in region 2 do not change.

In all cases, when regions apply a discriminatory tax regime, if firms in the small region face a higher distribution of mobility costs, then the small region reduces its equilibrium tax rate on its domestic firms because it is able to maintain a significant part of its tax base within its borders. The local government in region 1 has to reduce even more its equilibrium tax rate on foreign firms because it has to incentivize them more, since on average their mobility costs have increased. As the weight put on private surplus in the welfare function increases, the ratio of tax reduction of region 2 to region 1 can go up to 1:10. For example, if $\omega = 0.90$, under Nash-Cournot tax competition, local government in region 2 reduces its tax rate on domestic firms by 4.7% of $\frac{\underline{\theta}}{\gamma_2}$ while regional government in region 1 reduces its tax rate on foreign firms by 52.4% of $\frac{\underline{\theta}}{\gamma_2}$. Under Stackelberg tax competition, regional government in region 2 reduces its tax rate on domestic firms by 5.0% of $\frac{\underline{\theta}}{\gamma_2}$ while local government in region 1 reduces its tax rate by 55.0% of $\frac{\underline{\theta}}{\gamma_2}$.

Proposition 5. *Results based on simulations show, if domestic firms of the small region face on average higher costs of mobility in comparison to the large region's firms, then*[7]

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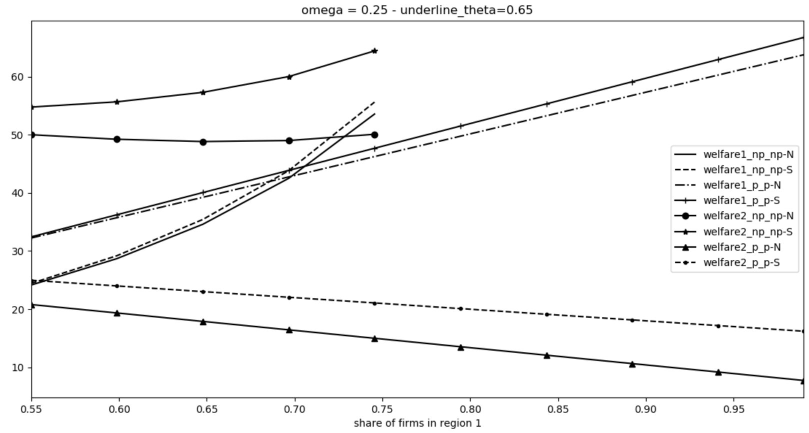
[7] Figure 1.6 is used to produce proposition 5.

a. When both regions apply non-discriminatory tax policy, the small region always increases the equilibrium tax rate imposed in comparison to the case where moving costs are uniformly distributed between 0 and 1 in both regions.

b. When both regions apply discriminatory tax policy, the tax rate on domestic firms in the large region and the tax rate on foreign firms in the small region will not be affected, however, the small region reduces slightly its tax rate on domestic firms while the large region reduces significantly its tax rate on foreign firms in comparison to the case where moving costs are uniformly distributed between 0 and 1 in both regions.

c. When both regions decide their tax rates à la Nash-Cournot, if the share of domestic firms initially located in the large region is lower than 0.70, the large region prefers preferential tax policy while the small one favours non-preferential tax policy. However, under Stackelberg tax competition, both regions prefer non-preferential tax regime.

Figure 1.6: Welfare levels, preferential, $[\underline{\theta}, 1]$-uniform distribution in region 2.



The curves welfare1_np_np-N and welfare2_np_np-N show welfare levels when regions apply non-preferential tax regimes and act simultaneously. The curves welfare1_np_np-S and welfare2_np_np-S show welfare levels when regions apply non-preferential tax regimes and act sequentially. The curves welfare1_p_p-N and welfare2_p_p-N show welfare levels when regions apply preferential tax regimes and act simultaneously. The curves welfare1_p_p-S and welfare2_p_p-S show welfare levels when regions apply preferential tax regimes and act sequentially. Also $\frac{\gamma_1}{\gamma_2} = 1.5$.

1.5 Same non-uniform moving costs

In this section, I assume that regions have same but non-uniform distribution of moving costs. This approach is divided into two cases: when regions are populated with mostly low moving cost firms; and when regions are populated with mostly high moving cost firms. This section allows to reassess one of the results from Mongrain and Wilson (2018) under more general assumptions; since, in this model, regions are not identical and firms are heterogeneous. Further, it proposes a new result that considers the case where regions are populated with mostly firms with high costs of mobility.

When regions have mostly firms with low moving costs, I assume a density function of $f(c) = 2(1-c)$ with a corresponding distribution function of $F(c) = 2c - c^2$ over [0,1]. Observe in this case, the average cost of mobility is $\mu(c) = \int_0^1 cf(c) = \frac{1}{3} < \frac{1}{2}$.

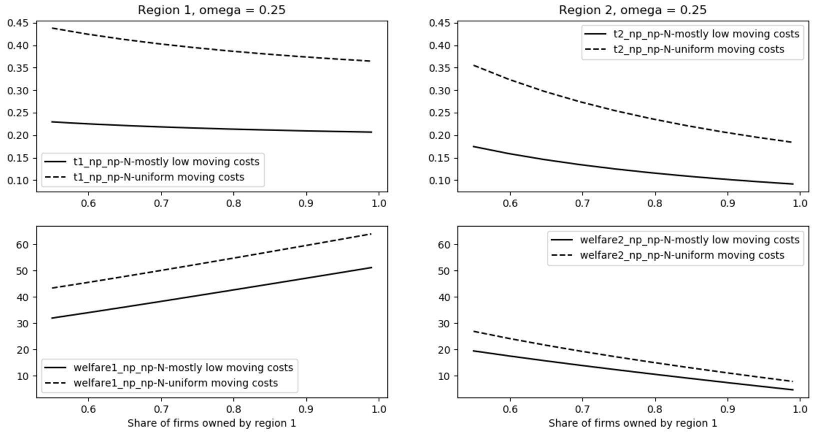
If both regions apply a non-preferential tax regime, suppose they decide their tax policy simultaneously as Nash-Cournot tax competitors, the reaction functions $t_1(t_2)$ and $t_2(t_1)$ are derived implicitly as follows

$$(1-\omega)\left[1+\gamma_1^2(t_1-t_2)^2\right] - 2\gamma_1\left[(2t_1-t_2)-\omega(t_1-t_2)\right] + 2\gamma_1^2 t_1(t_1-t_2) = 0 \qquad [1.37]$$

$$(1-\omega)\frac{\gamma_2 N_2}{\gamma_1 N_1} + 2\gamma_1(t_1-2t_2) - \gamma_1^2(t_1-t_2)^2 + 2\gamma_1^2 t_2(t_1-t_2) = 0. \qquad [1.38]$$

The equilibrium tax rates are found by solving simultaneously the system formed by equations [1.37] and [1.38]. As shown in Figure 1.7, in comparison to the case where moving costs have a [0,1]-uniform distribution in both regions, the non-discriminatory equilibrium tax rates are lower. Since firms can move more easily from one region another and by the force of competition, regions are forced to impose lower tax rates. Regions receive lower welfare.

Figure 1.7: Welfare levels, non-preferential, low costs of mobility



The curves t1_np_np-N-mostly low moving costs, t2_np_np-N-mostly low moving costs, welfare1_np_np-N-mostly low moving costs, and welfare2_np_np-N-mostly low moving costs show non-preferential tax rates and welfare levels when regions are populated with mostly low moving cost firms; and are involved in simultaneous tax competition. The curves t1_np_np-N-uniform moving costs, t2_np_np-N-uniform moving costs, welfare1_np_np-N-uniform moving costs and welfare2_np_np-N-uniform moving costs show non-preferential tax rates and welfare levels when moving costs are distributed uniformly between 0 and 1; and regions are involved in simultaneous tax competition. Also $\frac{\gamma_1}{\gamma_2} = 1.5$.

If, regions apply a preferential tax regime, the reaction functions $T_1(\tau_2)$, $\tau_1(T_2)$, $T_2(\tau_1)$, and $\tau_2(T1)$ are defined implicitly as follows

$$(1-\omega)\left[1+\gamma_1^2(T_1-\tau_2)^2\right] - 2\gamma_1\left[(2T_1-\tau_2)-\omega(T_1-\tau_2)\right] + 2\gamma_1^1 T_1(T_1-\tau_2) = 0 \qquad [1.39]$$

$$2(T_2-2\tau_1) - \gamma_2(T_2-\tau_1)(T_2-3\tau_1) = 0 \qquad [1.40]$$

$$(1-\omega)\left[1+\gamma_2^2(T_2-\tau_1)^2\right]-2\gamma_2\left[(2T_2-\tau_1)-\omega(T_2-\tau_1)\right]+2\gamma_2^2T_2(T_2-\tau_1)=0 \qquad [1.41]$$

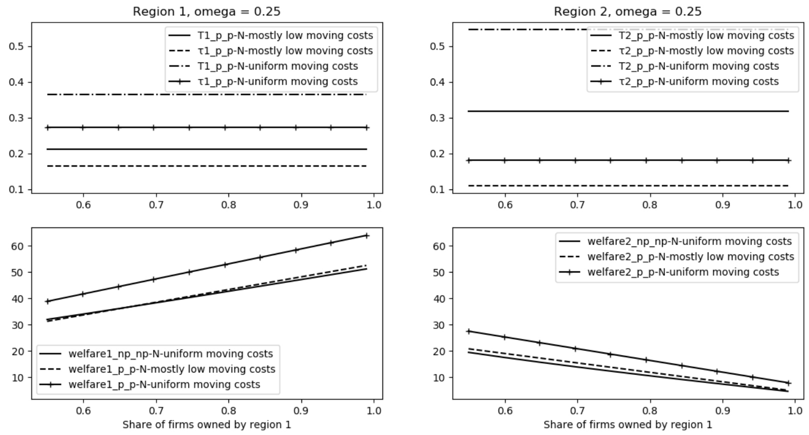
$$2(T_1-2\tau_2)-\gamma_1(T_1-\tau_2)(T_1-3\tau_2)=0. \qquad [1.42]$$

The equilibrium tax rates are found by solving simultaneously the system created by equations [1.39] to [1.42]. As shown in Figure 1.8 , in both regions, the equilibrium tax rates on domestic firms and the equilibrium tax rates on foreign firms are reduced in comparison to the case where firms in both regions have $[0,1]$-uniformly distributed moving costs. Both regions prefer to implement preferential tax policy.

Proposition 6. *Results from simulations show when asymmetric regions are populated mostly with firms with low moving costs, they apply lower tax rates on domestic and foreign firms in comparison to the case where firms in both regions have* $[0,1]$*-uniformly distributed moving costs; and regions prefer preferential tax policy.*

This result is consistent with Mongrain and Wilson (2018). However, in this chapter, it is found on more general assumptions. In Mongrain and Wilson (2018)'s paper, regions are identical and firms are homogeneous. In this paper, regions are not identical and firms are heterogeneous across regions. The interpretation is the same as in their paper: as the integration in the world economy increases, the costs of mobility will be lower for all firms. According to this model, the use of preferential tax policy will be a dominant strategy for national or regional tax authorities.

Figure 1.8: Welfare levels, preferential, low costs of mobility



The curves T1_p_p-N-mostly low moving costs, τ1_p_p-N-mostly low moving costs, T2_p_p-N-mostly low moving costs, τ2_p_p-N-mostly low moving costs, welfare1_p_p-N-mostly low moving costs, and welfare2_p_p-N-mostly low moving costs show preferential tax rates and welfare levels when regions are populated with mostly low moving cost firms; and involved in tax competition simultaneously. The curves T1_p_p-N-uniform moving costs, τ1_p_p-N-uniform moving costs, T2_p_p-N-uniform moving costs, τ2_p_p-N-uniform moving costs, welfare1_p_p-N-uniform moving costs, and welfare2_p_p-N-uniform moving costs show preferential tax rates and welfare levels when moving costs are uniformly distributed between 0 and 1; and involved in tax competition simultaneously. The curves welfare1_np_np-N-uniform moving costs, and welfare2_np_np-N-uniform moving costs show welfare levels when regions apply non-preferential regimes; and involved in tax competition simultaneously. Also $\frac{\gamma_1}{\gamma_2}=1.5$.

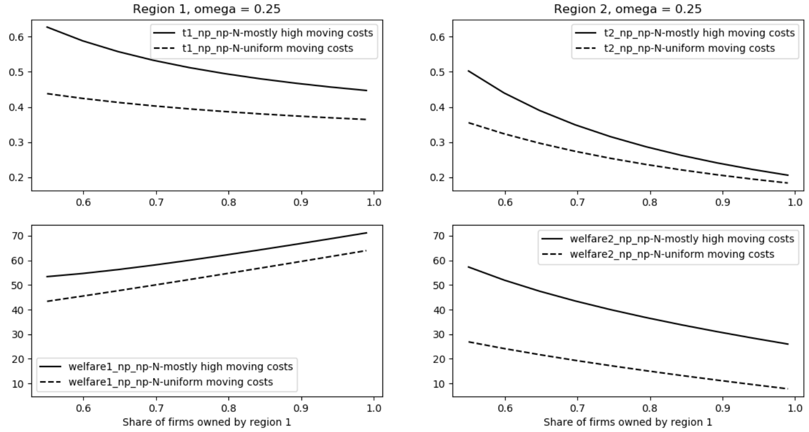
When regions have mostly high moving cost firms, I assume a density function of $f(c)=\frac{e^c}{e-1}$ and a corresponding distribution function of $F(c)=\frac{e^c-1}{e-1}$ over [0,1]. Note that, the average cost of mobility is $\mu = \int_0^1 cf(c)dc = \frac{1}{e-1} > \frac{1}{2}$. If both regions apply non-preferential tax policy, the reaction functions $t_1(t_2)$ and $t_2(t_1)$ are derived implicitly as follows

$$(1-\omega)\left(e - e^{\gamma_1(t_1-t_2)}\right) - \gamma_1 t_1 e^{\gamma_1(t_1-t_2)} = 0 \qquad [1.43]$$

$$(1-\omega)(e-1)\frac{\gamma_2 N_2}{\gamma_1 N_1} + (1-\gamma_1 t_2)e^{\gamma_1(t_1-t_2)} - 1 = 0. \qquad [1.44]$$

When regions are populated with high mobility cost firms, in comparison to the case where the costs of mobility are [0,1]-uniformly distributed, if both regions apply non-discriminatory tax policy, as shown in Figure 1.9, the equilibrium tax rates are higher in both regions. Knowing that domestic firms can not easily shift to the other region, regional governments can tax them at a higher rate.

Figure 1.9: Welfare levels, non-preferential, high costs of mobility



The curves t1_np_np-N-mostly high moving costs, t2_np_np-N-mostly high moving costs, welfare1_np_np-N-mostly high moving costs, and welfare2_np_np-N-mostly high moving costs show non-preferential tax rates and welfare levels when regions are populated with mostly high moving cost firms; and involved in tax competition simultaneously. The curves t1_np_np-N-uniform moving costs, t2_np_np-N-uniform moving costs, welfare1_np_np-N-uniform moving costs and welfare2_np_np-N-uniform moving costs show non-preferential tax rates and welfare levels when moving costs are distributed uniformly between 0 and 1; and involved in tax competition simultaneously. Also $\frac{\gamma_1}{\gamma_2} = 1.5$.

If regions apply preferential tax policy, the reaction functions $T_1(\tau_2)$, $\tau_1(T_2)$, $T_2(\tau_1)$, and $\tau_2(T1)$ are defined implicitly as follow

$$(1-\omega)e - (1-2\omega+\gamma_1 T_1)e^{\gamma_1(T_1-\tau_2)} = 0 \qquad [1.45]$$

$$(1-\gamma_2\tau_1)e^{\gamma_2(T_2-\tau_1)} - 1 = 0 \qquad [1.46]$$

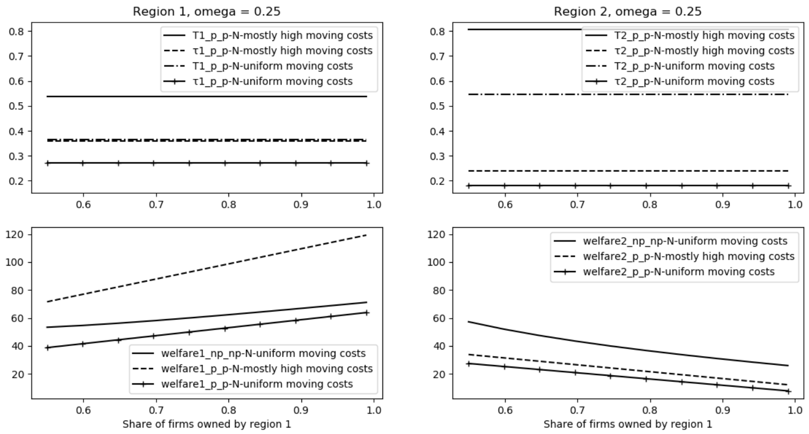
$$(1-\omega)e - (1-2\omega+\gamma_2 T_2)e^{\gamma_2(T_2-\tau_1)} = 0 \qquad [1.47]$$

$$(1-\gamma_1\tau_2)e^{\gamma_1(T_1-\tau_2)} - 1 = 0. \qquad [1.48]$$

As shown in Figure 1.10, the equilibrium tax rates on domestic firms and on foreign firms are higher relative to the case of a [0,1]-uniformly distributed costs of mobility. In this case, the large region prefers a preferential tax regime for all levels of country asymmetry while the small region always prefers non-preferential tax policy. In a world where all countries restrict capital outflows or pull back from world economic integration, according to this model, it can be expected to observe higher tax rates and large countries will prefer to implement discriminatory tax policy while small countries will prefer to apply non-discriminatory tax policy.

Proposition 7. *Analysis of simulation results suggest that when asymmetric regions are populated mostly with firms with high costs of mobility, in comparison to the case where firms in both regions have* $[0, 1]$*-uniformly distributed moving costs, the equilibrium tax rates applied are higher. The large region always prefers a preferential tax regime while the small region always prefers non-preferential tax regime.*

Figure 1.10: Welfare levels, preferential, high costs of mobility



The curves T1_p_p-N-mostly high moving costs, τ1_p_p-N-mostly high moving costs, T2_p_p-N-mostly high moving costs, τ2_p_p-N-mostly high moving costs, welfare1_p_p-N-mostly high moving costs, and welfare2_p_p-N-mostly high moving costs show preferential tax rates and welfare levels when regions are populated with mostly high moving cost firms; and involved in tax competition simultaneously. The curves T1_p_p-N-uniform moving costs, τ1_p_p-N-uniform moving costs, T2_p_p-N-uniform moving costs, τ2_p_p-N-uniform moving costs, welfare1_p_p-N-uniform moving costs, and welfare2_p_p-N-uniform moving costs show preferential tax rates and welfare levels when moving costs are uniformly distributed between 0 and 1; and involved in tax competition simultaneously. The curves welfare1_np_np-N-uniform moving costs, and welfare2_np_np-N-uniform moving costs show welfare levels when regions apply non-preferential regimes; and involved in tax competition simultaneously. Also $\frac{\gamma_1}{\gamma_2} = 1.5$.

This result is new in comparison to Mongrain and Wilson (2018). It is an interesting case since it can help understand countries' tax setting as moving costs increase in all countries. Indeed, if regions are pulling back from world economic integration, the costs of mobility will be higher in all regions. As a result, it can be expected to see higher tax rates are imposed but also small regions would want to ban preferential tax policies while large regions favour them.

1.6 Conclusion

This chapter analyses when it is optimal for countries or regions to apply non-preferential or preferential tax policy. It extends Mongrain and Wilson (2018) to include sequential Stackelberg tax competition while allowing firms to be heterogeneous across regions. It also considers the case where firms in small regions face on average higher costs of mobility than large regions' firms. Under the assumption of non-uniformly distributed costs of mobility, this chapter finds additional and more general results since regions are not identical and firms are heterogeneous.

Under the assumption of uniformly distributed costs of mobility between 0 and 1, the fact that both regions implement non-preferential tax policy is welfare dominant, if regions involved in tax competition act as Stackelberg tax competitors where the large one is a leader while the small one is a follower. Indeed, in this case, both regions want to restrict the use of preferential tax policies that have been called harmful tax practices by OECD (2017). If firms in the small region face on average higher costs of mobility than the large region's firms, under simultaneous Nash-Cournot and sequential tax competition, the small region wants to implement a non-preferential tax regime while the large region prefers to implement a preferential tax regime.

Under the assumption of non-uniformly distributed costs of mobility, if regions are populated with mostly firms with low moving costs, regions impose lower tax rates on both domestic and foreign firms and they both prefer to apply preferential tax policy. The expansion of world economic integration creates an environment where firms can move more easily. According to this model, more economic integration will give rise to lower tax rates imposed and regions or countries will not want to restrict the use of preferential tax treatments. When regions are populated with mostly firms with high costs of mobility, regions apply higher tax rates. In this case, small regions want to implement non-preferential tax policy while large regions prefer preferential tax regimes. As regions pull back from world economic integration, according to this model, it could be expected to observe higher tax rates and small regions pushing for a ban of preferential tax policies while large regions support them. This is an interesting case to investigate further, specially in the current context of Brexit.

1.7 References

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1.8 Appendix

1.8.1 Structure of tax rates in case both regions apply non-preferential regimes

Let $N_1 > N_2$ and $\gamma_1 > \gamma_2$. Assume that $t_1 < t_2$. In this case, in region 1, the total tax revenue and private surplus are

$$\begin{aligned} R_1^{np,np}(t_1,t_2) &= t_1\gamma_1 N_1 + t_1\gamma_2 N_2 F((t_2-t_1)\gamma_2) = t_1\gamma_1 N_1 + t_1\gamma_2 N_2 (t_2-t_1)\gamma_2 \\ S_1^{np,np}(t_1,t_2) &= (1-t_1)\gamma_1 N_1. \end{aligned}$$

In region 2, we have

$$\begin{aligned} R_2^{np,np}(t_1,t_2) &= t_2\gamma_2 N_2 \left[1 - F((t_2-t_1)\gamma_2)\right] = t_2\gamma_2 N_2 [1-(t_2-t_1)\gamma_2] \\ S_2^{np,np}(t_1,t_2) &= (1-t_2)\gamma_2 N_2 \left[1 - F((t_2-t_1)\gamma_2)\right] + (1-t_1)\gamma_2 N_2 F((t_2-t_1)\gamma_2) \\ &\quad - N_2 \int_0^{(t_2-t_1)\gamma_2} c dc. \end{aligned}$$

In case regions involved in tax competition choose their equilibrium tax rate simultaneously (N) à la Nash-Cournot model. The local government in region i chooses the tax rate t_i that maximizes its welfare function $\Omega_i^{np,np} = R_i^{np,np}(t_i,t_j) + \omega S_i^{np,np}(t_i,t_j)$ for $i,j \in \{1,2\}$. The reaction functions $t_1(t_2)$ and $t_2(t_1)$ are found to be as follows:

$$t_1(t_2) = \frac{1}{2}t_2 + \frac{(1-\omega)}{2\gamma_2}\frac{\gamma_1 N_1}{\gamma_2 N_2} \quad [1.49]$$

$$t_2(t_1) = \frac{(1-\omega)(1+\gamma_2 t_1)}{\gamma_2(2-\omega)}. \quad [1.50]$$

Thereafter, the resulting equilibrium tax rates are

$$t_1^N = \frac{(1-\omega)}{\gamma_2(3-\omega)}\left(1 + (2-\omega)\frac{\gamma_1 N_1}{\gamma_2 N_2}\right) \quad [1.51]$$

$$t_2^N = \frac{(1-\omega)}{\gamma_2(3-\omega)}\left(2 + (1-\omega)\frac{\gamma_1 N_1}{\gamma_2 N_2}\right). \quad [1.52]$$

Now, suppose that regions involved in tax competition interact sequentially (S) as Stackelberg tax competitors. The large region acts as a Stackelberg leader while the small one as a follower. The resolution of the follower's problem give rise to [1.50]. By solving the leader's problem while taking into account the follower's best response function, the sequential equilibrium tax rates are expressed as

$$t_1^S = \frac{(1-\omega)}{2\gamma_2}\left(1 + (2-\omega)\frac{\gamma_1 N1}{\gamma_2 N_2}\right) \quad [1.53]$$

$$t_2^S = \frac{(1-\omega)}{2\gamma_2}\left(\frac{3-\omega}{2-\omega} + (1-\omega)\frac{\gamma_1 N1}{\gamma_2 N_2}\right). \quad [1.54]$$

We note that

$$0 < t_2^N - t_1^N = \frac{(1-\omega)}{\gamma_2(3-\omega)} \left(1 - \frac{\gamma_1 N_1}{\gamma_2 N_2}\right) < 0,$$

and

$$0 < t_2^S - t_1^S < \frac{(1-\omega)}{2\gamma_2} \left(\frac{1}{2-\omega} - \frac{\gamma_1 N_1}{\gamma_2 N_2}\right) < 0,$$

which are contradictions since $0 \leq \omega < 1$ and $\frac{\gamma_1 N1}{\gamma_2 N_2} > 1$. Indeed, in presence of asymmetric regions such that $N_1 > N_2$, if before-tax profits are higher in the large region than in the small region, i.e. $(\gamma_1 > \gamma_2)$, then the tax rate is higher in the large region than in the smaller one, i.e. $t_1 > t_2$. Regardless that regions engaged in tax competition decide their tax policy simultaneously or act sequentially as Stackelberg tax competitors.

1.8.2 Tables of simulation results: preferential and non-preferential regimes

Table 1.1: Figure[3] part I

n	$t_1^{np,np,N}$	$t_2^{np,np,N}$	$\Omega_2^{np,np,N}$	$t_1^{np,p,N}$	$T_2^{np,p,N}$	$\tau_2^{np,p,N}$	$\Omega_1^{np,p,N}$	$\Omega_2^{np,p,N}$
0.55	0.44	0.36	26.88	0.34	0.57	0.17	38.47	28.33
0.60	0.42	0.32	24.16	0.34	0.57	0.17	41.27	26.10
0.65	0.41	0.30	21.68	0.34	0.58	0.17	44.09	23.86
0.70	0.40	0.27	19.37	0.35	0.58	0.17	46.90	21.61
0.75	0.39	0.25	17.20	0.35	0.58	0.18	49.72	19.35
0.79	0.39	0.24	15.15	0.35	0.58	0.18	52.55	17.08
0.84	0.38	0.22	13.20	0.36	0.58	0.18	55.38	14.80
0.89	0.37	0.21	11.33	0.36	0.58	0.18	58.21	12.51
0.94	0.37	0.20	9.53	0.36	0.58	0.18	61.04	10.21
0.99	0.36	0.18	7.79	0.36	0.58	0.18	63.88	7.91

$\gamma_1 = 1.5$, $\gamma_2 = 1.0$, $N = 50$, $N_1 = 2nN$, $N_2 = 2(1-n)N$, $\omega = 0.25$.

Table 1.2: Figure[3] part II

ω	$t_1^{np,np,N}$	$t_2^{np,np,N}$	$\Omega_2^{np,np,N}$	$t_1^{np,p,N}$	$T_2^{np,p,N}$	$\tau_2^{np,p,N}$	$\Omega_1^{np,p,N}$	$\Omega_2^{np,p,N}$
0.00	0.57	0.46	26.72	0.41	0.71	0.21	29.04	27.84
0.11	0.51	0.42	26.46	0.38	0.65	0.19	32.97	27.84
0.22	0.45	0.37	26.72	0.35	0.59	0.17	37.24	28.17
0.33	0.40	0.32	27.50	0.31	0.53	0.15	41.89	28.88
0.44	0.34	0.27	28.82	0.27	0.46	0.13	46.99	30.02
0.55	0.27	0.22	30.70	0.22	0.38	0.11	52.59	31.64
0.66	0.21	0.17	33.18	0.18	0.30	0.09	58.76	33.82
0.77	0.15	0.11	36.28	0.12	0.21	0.06	65.59	36.63
0.88	0.08	0.06	40.06	0.07	0.11	0.03	73.19	40.16
0.99	0.01	0.01	44.55	0.01	0.01	0.00	81.68	44.55

$\gamma_1 = 1.5$, $\gamma_2 = 1.0$, $N = 50$, $N_1 = 2nN$, $N_2 = 2(1-n)N$, $n = 0.55$.

Table 1.3: Figure[4] part I

n	$t_1^{np,np,S}$	$t_2^{np,np,S}$	$\Omega_2^{np,np,S}$	$t_1^{np,p,S}$	$T_2^{np,p,S}$	$\tau_2^{np,p,S}$	$\Omega_1^{np,p,S}$	$\Omega_2^{np,p,S}$
0.55	0.66	0.47	38.20	0.48	0.64	0.24	40.29	35.78
0.60	0.64	0.43	34.99	0.49	0.64	0.25	43.23	33.70
0.65	0.62	0.40	32.08	0.50	0.64	0.25	46.17	31.60
0.70	0.60	0.37	29.40	0.50	0.64	0.25	49.11	29.48
0.75	0.59	0.35	26.92	0.51	0.65	0.25	52.06	27.34
0.79	0.57	0.33	24.59	0.51	0.65	0.26	55.02	25.19
0.84	0.56	0.31	22.40	0.52	0.65	0.26	57.98	23.02
0.89	0.55	0.30	20.31	0.52	0.65	0.26	60.95	20.84
0.94	0.54	0.28	18.31	0.53	0.65	0.26	63.92	18.65
0.99	0.53	0.27	16.38	0.53	0.66	0.27	66.89	16.45

$\gamma_1 = 1.5$, $\gamma_2 = 1.0$, $N = 50$, $N_1 = 2nN$, $N_2 = 2(1-n)N$, $\omega = 0.25$.

Table 1.4: Figure[4] part II

ω	$t_1^{np,np,S}$	$t_2^{np,np,S}$	$\Omega_2^{np,np,S}$	$t_1^{np,p,S}$	$T_2^{np,p,S}$	$\tau_2^{np,p,S}$	$\Omega_1^{np,p,S}$	$\Omega_2^{np,p,S}$
0.00	0.85	0.61	45.45	0.62	0.81	0.31	32.67	41.58
0.11	0.77	0.55	41.77	0.56	0.74	0.28	35.72	38.60
0.22	0.68	0.48	38.86	0.50	0.66	0.25	39.25	36.29
0.33	0.60	0.42	36.75	0.44	0.58	0.22	43.28	34.71
0.44	0.51	0.36	35.50	0.37	0.49	0.19	47.88	33.95
0.55	0.42	0.29	35.17	0.30	0.40	0.15	53.11	34.05
0.66	0.32	0.22	35.82	0.23	0.31	0.12	59.02	35.10
0.77	0.22	0.15	37.53	0.16	0.22	0.08	65.69	37.16
0.88	0.12	0.08	40.41	0.08	0.12	0.04	73.21	40.29
0.99	0.01	0.01	44.56	0.01	0.01	0.00	81.68	44.55

$\gamma_1 = 1.5$, $\gamma_2 = 1.0$, $N = 50$, $N_1 = 2nN$, $N_2 = 2(1-n)N$, $n = 0.55$.

Table 1.5: Figure[5] part I

n	$t_1^{p,np,N}$	$t_2^{p,np,N}$	$\Omega_1^{np,np,N}$	$T_1^{p,np,N}$	$\tau_1^{p,np,N}$	$t_2^{p,np,N}$	$\Omega_1^{p,np,N}$	$\Omega_2^{p,np,N}$
0.55	0.44	0.36	43.35	0.40	0.13	0.27	40.00	23.21
0.60	0.42	0.32	45.47	0.40	0.13	0.26	42.71	21.33
0.65	0.41	0.30	47.66	0.39	0.12	0.25	45.40	19.50
0.70	0.40	0.27	49.90	0.39	0.12	0.23	48.08	17.71
0.75	0.39	0.25	52.18	0.38	0.11	0.22	50.74	15.97
0.79	0.39	0.24	54.49	0.38	0.11	0.22	53.40	14.27
0.84	0.38	0.22	56.83	0.37	0.10	0.21	56.04	12.60
0.89	0.37	0.21	59.19	0.37	0.10	0.20	58.68	10.96
0.94	0.37	0.20	61.57	0.37	0.10	0.19	61.31	9.35
0.99	0.36	0.18	63.97	0.36	0.09	0.18	63.93	7.76

$\gamma_1 = 1.5$, $\gamma_2 = 1.0$, $N = 50$, $N_1 = 2nN$, $N_2 = 2(1-n)N$, $n = 0.55$.

Table 1.6: Figure[5] part II

ω	$t_1^{p,np,N}$	$t_2^{p,np,N}$	$\Omega_1^{np,np,N}$	$T_1^{p,np,N}$	$\tau_1^{p,np,N}$	$t_2^{p,np,N}$	$\Omega_1^{p,np,N}$	$\Omega_2^{p,np,N}$
0.00	0.57	0.46	39.60	0.50	0.17	0.34	32.70	19.59
0.11	0.51	0.42	40.71	0.46	0.16	0.31	35.57	21.02
0.22	0.45	0.37	42.67	0.41	0.14	0.28	38.97	22.70
0.33	0.40	0.32	45.49	0.37	0.12	0.25	42.96	24.66
0.44	0.34	0.27	49.19	0.31	0.11	0.21	47.57	26.93
0.55	0.27	0.22	53.79	0.26	0.09	0.17	52.84	29.55
0.66	0.21	0.17	59.31	0.20	0.07	0.13	58.83	32.56
0.77	0.15	0.11	65.78	0.14	0.05	0.09	65.58	36.02
0.88	0.08	0.06	73.22	0.08	0.03	0.05	73.18	39.99
0.99	0.01	0.01	81.68	0.01	0.00	0.00	81.68	44.55

$\gamma_1 = 1.5$, $\gamma_2 = 1.0$, $N = 50$, $N_1 = 2nN$, $N_2 = 2(1-n)N$, $n = 0.55$.

Table 1.7: Figure[6] part I

n	$t_1^{p,np,S}$	$t_2^{p,np,S}$	$\Omega_1^{p,np,S}$	$T_1^{p,np,S}$	$\tau_1^{p,np,S}$	$t_2^{p,np,S}$	$\Omega_1^{p,np,S}$	$\Omega_2^{p,np,S}$
0.89	0.53	0.27	46.23	0.52	0.01	0.27	60.72	18.77
0.94	0.53	0.27	48.34	0.53	0.04	0.27	63.95	17.60

$\gamma_1 = 1.5$, $\gamma_2 = 1.0$, $N = 50$, $N_1 = 2nN$, $N_2 = 2(1-n)N$, $n = 0.55$.

Table 1.8: Figure[6] part II

ω	$t_1^{p,np,S}$	$t_2^{p,np,S}$	$\Omega_1^{p,np,S}$	$T_1^{p,np,S}$	$\tau_1^{p,np,S}$	$t_2^{p,np,S}$	$\Omega_1^{p,np,S}$	$\Omega_2^{p,np,S}$
0.11	0.01	0.01	50.46	0.44	0.00	0.27	32.41	20.87
0.88	0.01	0.01	49.30	0.52	0.00	0.21	63.27	59.11

$\gamma_1 = 1.5$, $\gamma_2 = 1.0$, $N = 50$, $N_1 = 2nN$, $N_2 = 2(1-n)N$, $n = 0.55$.

1.8.3 Firms in the small region face on average higher cost of mobility

Let $N_1 > N_2$ and $\gamma_1 > \gamma_2$. In case where regions apply non-discriminatory tax regimes, let t_1 be the tax applied in region 1 and t_2 the tax rate applied in region 2. Assume $t_2 > t_1$. In this case, in region 1, the total tax revenue and total private surplus expressions are

$$\begin{aligned} R_1^{np,np}(t_1,t_2) &= t_1\gamma_1 N_1 + t_1\gamma_2 N_2 F_2((t_2-t_1)\gamma_2) = t_1\gamma_1 N_1 + t_1\gamma_2 N_2\left(\frac{(t_2-t_1)\gamma_2-\underline{\theta}}{1-\underline{\theta}}\right) \\ S_1^{np,np}(t_1,t_2) &= (1-t_1)\gamma_1 N_1. \end{aligned}$$

In region 2, the total tax revenue and total private surplus expressions are

$$\begin{aligned} R_2^{np,np}(t_1,t_2) &= t_2\gamma_2 N_2\left(1-F_2((t_2-t_1)\gamma_2)\right) = t_2\gamma_2 N_2\left(1-\frac{(t_2-t_1)\gamma_2-\underline{\theta}}{1-\underline{\theta}}\right) \\ S_2^{np,np}(t_1,t_2) &= (1-t_2)\gamma_2 N_2\left(1-F_2((t_2-t_1)\gamma_2)\right) + (1-t_1)\gamma_2 N_2 F_2((t_2-t_1)\gamma_2) \\ &\quad - N_2\int_{\underline{\theta}}^{(t_2-t_1)\gamma_2} c f_2(c)dc \\ &= (1-t_2)\gamma_2 N_2\left(1-\frac{(t_2-t_1)\gamma_2-\underline{\theta}}{1-\underline{\theta}}\right) + (1-t_1)\gamma_2 N_2\frac{(t_2-t_1)\gamma_2-\underline{\theta}}{1-\underline{\theta}} \\ &\quad - N_2\int_{\underline{\theta}}^{(t_2-t_1)\gamma_2}\frac{c}{1-\underline{\theta}}dc. \end{aligned}$$

In the case where regions involved in tax competition decide their tax rate simultaneously, the equilibrium tax rates are

$$t_1^N = \frac{(1-\omega)}{\gamma_2(3-\omega)}\left(1-\frac{\underline{\theta}(2-\omega)}{1-\omega}+(1-\underline{\theta})(2-\omega)\frac{\gamma_1 N_1}{\gamma_2 N_2}\right)$$

$$t_2^N = \frac{(1-\omega)}{\gamma_2(3-\omega)}\left(2-\underline{\theta}+(1-\underline{\theta})(1-\omega)\frac{\gamma_1 N_1}{\gamma_2 N_2}\right).$$

Hence, $t_2^N > t_1^N$ if

$$\frac{\frac{\gamma 1 N_1}{\gamma_2 N_2}-1}{\frac{\gamma 1 N_1}{\gamma_2 N_2}+\frac{1}{1-\omega}} < \underline{\theta} < 1. \qquad [1.55]$$

Table 1.9: Non-preferential, Nash equilibrium, ([0,1],[$\underline{\theta}$,1])-uniformly distributed moving costs

		Uniform distribution ([0,1],[0,1])				Uniform distribution ([0,1],[$\underline{\theta} = \frac{1}{3}$,1])			
n	ω	$t_1^{np,np,N}$	$t_2^{np,np,N}$	$\Omega_1^{np,np,N}$	$\Omega_2^{np,np,N}$	$t_1^{np,np,N}$	$t_2^{np,np,N}$	$\Omega_1^{np,np,N}$	$\Omega_2^{np,np,N}$
0.51	0.33	0.41	0.35	43.34	29.93	0.48	0.59	42.08	45.76
0.51	0.44	0.34	0.29	46.40	31.31	0.37	0.49	43.77	43.46
0.56	0.55	0.28	0.24	50.37	36.66	0.33	0.41	53.61	40.03
0.56	0.66	0.21	0.18	55.27	36.06	0.21	0.31	58.54	39.20
0.56	0.77	0.15	0.12	61.11	39.46	0.08	0.21	65.52	39.65
0.62	0.66	0.21	0.18	55.27	36.06	0.27	0.32	65.17	36.14
0.67	0.77	0.15	0.12	61.11	39.46	0.12	0.21	72.10	35.69
0.67	0.88	0.08	0.06	67.93	43.60	0.01	0.11	88.44	31.92
0.78	0.88	0.08	0.06	67.93	43.60	0.10	0.12	102.86	22.69

$\gamma_1 = 1.5$, $\gamma_2 = 1.0$, $N = 50$, $N_1 = 2nN$, $N_2 = 2(1-n)N$, $0.50 < n < 1$ and $0 \leq \omega < 1$.

Table 1.10: Non-preferential, Stackelberg equilibrium, ([0,1],[$\underline{\theta}$,1])-uniformly distributed moving costs

		Uniform distribution ([0,1],[0,1])				Uniform distribution ([0,1],[$\underline{\theta} = \frac{1}{3}$,1])			
n	ω	$t_1^{np,np,S}$	$t_2^{np,np,S}$	$\Omega_1^{np,np,S}$	$\Omega_2^{np,np,S}$	$t_1^{np,np,S}$	$t_2^{np,np,S}$	$\Omega_1^{np,np,S}$	$\Omega_2^{np,np,S}$
0.51	0.33	0.62	0.45	45.67	39.57	0.64	0.66	43.21	54.17
0.51	0.44	0.52	0.38	48.06	38.28	0.47	0.53	44.27	48.18
0.56	0.55	0.43	0.31	51.46	38.00	0.40	0.44	53.86	42.83
0.56	0.66	0.33	0.24	55.90	38.81	0.24	0.31	58.60	40.29
0.56	0.77	0.23	0.16	61.40	40.77	0.09	0.20	65.52	39.88
0.62	0.66	0.33	0.24	55.90	38.81	0.31	0.33	65.26	37.51
0.67	0.77	0.23	0.16	61.40	40.77	0.20	0.22	78.95	32.30
0.67	0.88	0.12	0.09	68.01	43.97	0.01	0.11	88.44	31.93
0.78	0.88	0.12	0.09	68.01	43.97	0.11	0.12	102.86	22.78

$\gamma_1 = 1.5$, $\gamma_2 = 1.0$, $N = 50$, $N_1 = 2nN$, $N_2 = 2(1-n)N$, $0.50 < n < 1$ and $0 \leq \omega < 1$.

Chapter 2

Corporate Taxation and Expansion of Intangible Capital Assets

Abstract

This paper uses an annual sector-level panel dataset composed of 12 sectors in 12 OECD countries over the period 1995-2015, and adopts the neoclassical theory of investment to model the rate of investment in physical and intangible capital. The data used come from the EU KLEMS database, the Oxford University Centre for Business Taxation, and the Tax Foundation. The results show that the rate of investment equations for physical and intangible capital are distinct. Corporate tax incentives affect the rates of investment in both physical and intangible capital, but differently. The higher rate of depreciation of intangible capital compared to physical capital seems likely to explain the increasing ratio of investment in intangible to physical capital.

2.1 Introduction

This empirical investigation begins with the observation that on average over 12 countries, using country-level data, the ratio of gross real investment in intangible capital to gross real investment in physical capital has been increasing (see Figure 2.1, left panel). According to van Ark and Jäger (2017) and Jäger (2017), in the EU KLEMS database investment in intangible capital consists of real gross fixed capital formation in knowledge-based assets such as computer software and databases, research and development, and other intellectual property products. Real investment in physical capital is composed of expenditures on computing equipment, communications equipment, transport equipment, other machinery and equipment, non-residential investment, and cultivated assets. As shown in Figure 2.1 (left panel), over the period 1995-2015 the ratio of intangible to physical capital investment increased from 0.45 to 0.70. Moreover, this ratio reached 0.72 in 2010.[1]

At first glance, one may ask what might have caused this increase in the ratio of investment in intangible to physical capital? One possible explanation is that it may be related to changes in the corporate income tax rate. Since intangible assets are more mobile than physical capital assets, it is possible for countries to increase their attractiveness as a destination of intangible capital investment by lowering their corporate income tax rate. Two empirical studies have shown the existence of a strong negative correlation between the location of intangible capital and the evolution of the corporate income tax rate. In Dischinger and Riedel (2011), the lower a subsidiary's corporate tax rate relative to those of other affiliates of the multinational group, the higher is its level of intangible capital investment. Similarly, Karkinsky and Riedel (2012) present evidence that the corporate income tax rate exerts a negative effect on the number of patent applications filled by a multinational affiliate.

This observation can immediately be placed within the literature on investment. After a review of the literature on three salient theoretical models of investment behaviour, it is clear that the literature has ignored intangible capital. Evidence has shown that businesses invest approximately the same amount in intangible capital as in physical capital (Corrado et al., 2005, 2009, 2013).[2] According to Whitwell et al. (2007), intangible capital assets are an important source of corporate wealth and increase consistently shareholder value. Governments have shown increasing interest in intangible capital assets (Hejazi, 2006).

This study contributes to the literature by placing investment in intangible capital, alongside physical capital, within the framework of the neoclassical model of investment behaviour. Two estimating equations with the same functional form are derived, one for the rate of investment in physical capital, and one for the rate of investment in intangible capital. To capture the effect of intellectual property regimes (the so-called "patent box"), a dummy variable is included in the equation for the rate of investment in intangible capital. The long-run elasticities are derived with the help of an autoregressive distributed lag model in error-correction form.

The results show that the equations for the rate of investment in physical capital and the rate of investment in intangible capital are two separate equations. While assuming that the equations for investment rates in physical and intangible capital share the same functional form, the estimated

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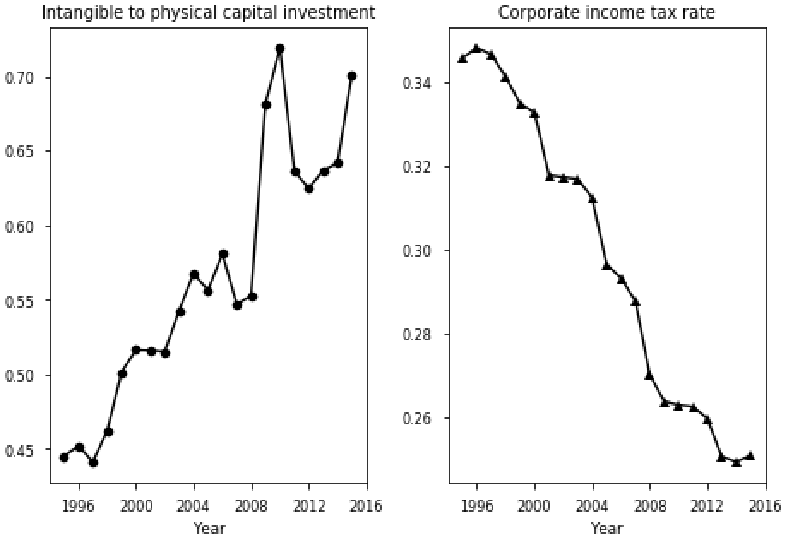
[1] The increase in the ratio looks even larger when the ratio is computed by averaging over country-sector pairs. It ranges from 0.5 to 1.25 over the period.

[2] These papers present a wider view of intangible capital. According to them, such assets are grouped in three broad categories: computerized information that includes computer software and databases; innovative property that is composed of R&D, design, mineral exploration, and financial innovation; and economic competencies that combine advertising, marketing research, organisational capital, and training. For the time being, the first two categories are taken into account in the national accounts.

Figure 2.1: Ratios of investment in intangible to physical capital, and corporate income tax rate: annual average, 1995-2015.



Intangible to physical capital investment

Corporate income tax rate

Notes: This figure gives, in the left panel, the trend of the ratio of intangible to physical capital real gross investment. This graph is created with yearly-country panel data provided by the EU KLEMS database. The right panel shows the evolution of the annual average of the statutory corporate income tax rate. Corporate tax data come from the Oxford University Centre for Business Taxation.

coefficients of these two equations are statistically distinct and do not share confidence interval bands. Changes in the corporate income tax rate impact negatively the rates of investment in both physical and intangible capital. The rate of depreciation of intangible capital is more than twice as high as that of physical capital. This result can explain the behaviour of the data observed in Figure 2.1 (left panel). However, the long-run elasticity of capital with respect to the corporate income tax rate is larger for physical than for intangible capital.

The remaining part of this paper is as organized follows. In section 2, some theoretical considerations that guide the empirical modelling are presented. Section 3 presents the data. Section 4 deals with the empirical testing and estimation results. Section 5 provides a sensitivity analysis. In section 6, I conclude.

2.2 Models of investment

In any study of investment behaviour, three well-known theoretical models are considered points of departure: the flexible accelerator model, the neoclassical model of investment, and the securities-value or Tobin's q model. Originating in the work of Samuelson (1939), Chenery (1952), and Koyck (1954), the flexible accelerator model of investment behaviour is based on the flexible acceleration principle, which hypothesizes that changes in investment are caused by changes in aggregate demand. The neoclassical model of investment behaviour is based on the neoclassical theory of optimal capital accumulation. Finally, the securities-value or Tobin's q model of investment behaviour, proposed by Tobin (1969) and Hayashi (1982), assumes that changes in investment levels are explained by changes in the valuations of physical capital assets relative to their replacement costs. This section provides a brief overview of these models of business investment behaviour and discusses how they can be extended to incorporate intangible capital.

2.2.1 The flexible accelerator model

The flexible accelerator model of investment behaviour assumes that the economy's desired level of capital stock is proportional to the current level of output (Jorgenson, 1971; Bischoff et al., 1971; Bernanke et al., 1988; Kopp, 2018). If capital is not homogeneous, then the economy's desired levels of both physical and intangible capital can be assumed to be proportional to the current level of output; i.e., $K_t^{phy*} = \gamma^{phy} Y_t$ and $K_t^{int*} = \gamma^{int} Y_t$, where γ^{phy} and γ^{int} are the physical and intangible capital stocks per unit of output. Consequently, following Jorgenson and Siebert (1968), investment equations can be specified as follows

$$I_t^{phy} = \alpha^{phy} + \sum_{s=0}^{N} \beta_s^{phy} \Delta Y_{t-s} + \delta^{phy} K_{t-1}^{phy} + u_t^{phy} \qquad [2.1]$$

$$I_t^{int} = \alpha^{int} + \sum_{s=0}^{N} \beta_s^{int} \Delta Y_{t-s} + \delta^{int} K_{t-1}^{int} + u_t^{int}, \qquad [2.2]$$

where I_t^{phy} and I_t^{int} are the current levels of gross investment in physical and intangible capital; N is the lag length; α^{phy}, α^{int}, β_s^{phy}, and β_s^{int}, for $s = 0, ..., N$, are scalar parameters to be estimated; Δ is the first-difference operator; δ^{phy} and δ^{int} are the rates of depreciation of physical and intangible capital assets; and u_t^{phy} and u_t^{int} are the disturbances. The problem of reverse causality can be handled by omitting current-dated explanatory variables in [2.1] and [2.2]; i.e., by setting $s = 1, ..., N$. In many empirical tests, the dependent variable is redefined as I_t/K_{t-1} to avoid the issue of nonstationarity, as suggested by Oliner et al. (1995) and Kopp (2018). If net investment is modelled instead of gross investment, as in Bernanke et al. (1988), the investment equations are similar to [2.1] and [2.2], but without the K_{t-1} terms.

On the basis of the flexible accelerator model of investment behaviour, the observed difference in investment in physical and intangible capital, shown in Figure 2.1 (left panel), can be explained by differences in the values of depreciation rates and/or the other parameters in [2.1] and [2.2]. Indeed, since the change in output variables are identical for both equations, under this theory differences in the values of depreciation and/or the other parameters are the only remaining factors that could justify the observed difference in investment in physical and intangible capital.

2.2.2 The neoclassical model of investment

According to the neoclassical theory of firm investment behaviour, if the production function combines only two inputs, labour and capital, is Cobb-Douglas, and exhibits constant returns to scale, then the economy's desired capital stock is the level at which the marginal product of capital services equals their rental price (Jorgenson, 1963, 1967, 1971; Bernanke et al., 1988; Bond and Xing, 2015). Under the assumption that intangible capital is treated in the same manner as physical capital, the economy's desired physical and intangible capital stocks will be determined by the level at which the marginal products of physical and intangible capital services equal their rental prices; i.e., $K_t^{phy*} = \zeta^{phy}(Y_t/c_t^{phy})$ and $K_t^{int*} = \zeta^{int}(Y_t/c_t^{int})$, where ζ^{phy} and ζ^{int} are the elasticities of output with respect to physical and intangible capital, Y_t is the level of output, and c_t^{phy} and

c_t^{int} are the user costs of physical and intangible capital services. Indeed, following Jorgenson and Siebert (1968), investment equations can be specified as follows:

$$I_t^{phy} = \alpha^{phy} + \sum_{s=0}^{N} \beta_s^{phy} \Delta \left(\frac{Y}{c^{phy}} \right)_{t-s} + \delta^{phy} K_{t-1}^{phy} + u_t^{phy} \qquad [2.3]$$

$$I_t^{int} = \alpha^{int} + \sum_{s=0}^{N} \beta_s^{int} \Delta \left(\frac{Y}{c^{int}} \right)_{t-s} + \delta^{int} K_{t-1}^{int} + u_t^{int}, \qquad [2.4]$$

where I_t^{phy} and I_t^{int} are the current levels of gross investment in physical and intangible capital; N is the lag length; α^{phy}, α^{int}, β_s^{phy}, and β_s^{int}, for $s = 0, ..., N$, are scalar parameters to be estimated; Δ is the first-difference operator; δ^{phy} and δ^{int} are the rates of depreciation of physical and intangible capital assets; and u_t^{phy} and u_t^{int} are the disturbances.

Following Devereux and Griffith (1999) and Devereux and Griffith (2003) and assuming that new investment is financed by retained earnings,[3] the user costs of physical and intangible capital can be written as

$$c_t^{phy} = \frac{P_t^{phy}}{p_t} \left[\frac{(1 - A_t^{phy})(r_t^{phy} + \delta^{phy})}{(1 - \tau_t)} - \delta^{phy} \right] \qquad [2.5]$$

$$c_t^{int} = \frac{P_t^{int}}{p_t} \left[\frac{(1 - A_t^{int})(r_t^{int} + \delta^{int})}{(1 - \tau_t)} - \delta^{int} \right], \qquad [2.6]$$

where P_t^{phy}/p_t and P_t^{int}/p_t are the prices of physical and intangible capital investment goods relative to the price of output, A_t^{phy} and A_t^{int} are the net present values of current and future tax depreciation allowances associated with one dollar of investment in physical and intangible capital in year t, r_t^{phy} and r_t^{int} are the real discount rates of physical and intangible capital, δ^{phy} and δ^{int} are the rates of depreciation of physical and intangible capital assets, and τ_t is the corporate income tax rate.[4]

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[3] In the general definition of the user cost of capital, when the additional costs of raising external finances are zero, according to Devereux and Griffith (1999) and Devereux and Griffith (2003) the user cost of capital formula is the one shown in [2.5] and [2.6]. This is a reasonable approximation since, according to Fazzari et al. (1988), financing through retained earnings is the primary source of finances in corporations. In fact, they account for 71.1% of total sources of funds.

[4] Under similar assumptions, Bond and Xing (2015) and Fatica (2018) proposed alternative measures of the user cost of capital. In Bond and Xing (2015), the user cost of capital is expressed as

$$c_t = \frac{P_t^K}{P_t \left(1 - \frac{1}{\eta}\right)} \frac{(1 - A_t)}{(1 - \tau_t)} \frac{(r_t + \delta)}{(1 + r_t)},$$

where P_t^K is the price of capital investment goods, P_t is the price of output, and η is the price elasticity of demand. According to Fatica (2018), the user cost of capital is

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

where P_{ij} is the price of capital asset relative to the price of output and Ψ_{ij} is the replacement cost recovery of capital (this variable is called the net present value of depreciation allowances in Fatica (2018) but labelled the replacement cost recovery of capital by the Tax Foundation). A comparison of these two formulas indicates that the net present value of depreciation allowances is $A = \tau\Psi$. With regard to her definition of the user cost, the tax component of the user cost of capital is expressed as $(1 - \tau\Psi_{ij})/(1 - \tau)$.

Following Bond and Xing (2015), the expressions $(1 - A_t^{phy})/(1 - \tau_t)$ and $(1 - A_t^{int})/(1 - \tau_t)$ are called the tax components of the user cost of physical and intangible capital. Again, the problem of reverse causality can be handled by omitting current-dated explanatory variables from [2.3] and [2.4] (Bond and Xing, 2015; Kopp, 2018). The problem of nonstationarity can be handled by scaling [2.3] and [2.4] by K_{t-1}^{phy} and K_{t-1}^{int}, respectively (Oliner et al., 1995; Kopp, 2018).

The neoclassical model of investment behaviour offers many potential avenues of explanation of the observed difference in investment in physical and intangible capital illustrated in Figure 2.1 (left panel). According to the definition of the user cost of capital, elements of the explanation lie in the relative prices, the rates of depreciation, the discount rates, and/or changes in the corporate income tax rate that affect differently investment in physical and intangible capital. Also, this difference can be explained by distinct parameters in the rate of investment equations.

2.2.3 The securities-value or Tobin's *q* model

The securities-value or Tobin's q model assumes that the rate of investment, I_t/K_{t-1}, depends on the Tobin q, which is the ratio of the firm's market value of capital to its replacement cost (Tobin, 1969; Hayashi, 1982; Bernanke et al., 1988). Peters and Taylor (2017) extend the Tobin's q model of investment to the case of firms that invest in both physical and intangible capital by introducing the idea of total-q. Let V_{it} be the value of firm i at time t. Let the firm's total capital stock be defined as the sum of its physical and intangible capital stocks, i.e., $K_{it}^{tot} = K_{it}^{phy} + K_{it}^{int}$. The total-$q$ is then defined as the ratio of the firm's market value to its total stock of physical and intangible capital. The first of prediction of Peters and Taylor's (2017, 254) model is

> physical and intangible capital share the same marginal q; marginal q equals average q; and the ratio of the firm value to its total capital stock is derived as
>
> $$\frac{\partial V_{it}}{\partial K_{it}^{phy}} = \frac{\partial V_{it}}{\partial K_{it}^{int}} = \frac{\partial V_{it}}{\partial K_{it}^{tot}} = \frac{V_{it}}{K_{it}^{tot}} = \frac{V_{it}}{K_{it}^{phy} + K_{it}^{int}} \equiv q_{it}^{tot}.$$

Using the idea of the total-q model and following Bernanke et al. (1988), Oliner et al. (1995), and Peters and Taylor (2017), the rate of investment equations are as follows

$$\frac{I_{it}^{phy}}{K_{t-1}^{phy}} = \alpha^{phy} + \sum_{s=0}^{N} \beta_s^{phy} q_{it}^{tot} + u_{it}^{phy} \qquad [2.7]$$

$$\frac{I_{it}^{int}}{K_{t-1}^{int}} = \alpha^{int} + \sum_{s=0}^{N} \beta_s^{int} q_{it}^{tot} + u_{it}^{int}, \qquad [2.8]$$

where N is the lag length; α^{phy}, α^{int}, the β_s^{phy}, and the β_s^{int} are scalar parameters to be estimated; and u_t^{phy} and u_t^{int} are the disturbances.

On the basis of the securities-value or Tobin's q model, the observed difference in investment in physical and intangible capital shown in Figure 2.1 (left panel) can be explained by differences in the parameters α^{phy}, α^{int}, β_s^{phy}, and β_s^{int}. Indeed, as shown in [2.7] and [2.8], since the total-q is the same in both equations, under this theory, differences in investment in physical and intangible capital are explained entirely by differences in the parameters.

2.2.4 Empirical evidence

The theory of the flexible accelerator model of investment behaviour was tested by Jorgenson and Siebert (1968). They compare the performance of both the accelerator and neoclassical models of investment using firm-level data (a sample of 15 firms selected from the *Fortune* Directory of the 500 largest U.S. industrial corporations for 1962) as well as aggregate U.S. data. They find modest support for the neoclassical model of investment, but little support for the accelerator model of investment behaviour. Using quarterly data for US manufacturing for the period 1948-1960, Jorgenson (1963) and Jorgenson (1971) conclude that the neoclassical model of investment behaviour provides the best explanation of firm and industry investment. Further, Jorgenson and Stephenson (1967) and Jorgenson and Stephenson (1969) attest that this model provides a highly satisfactory explanation of both actual and future business investment in comparison to the accelerator model of investment behaviour.

Recently, with the help of the newly updated EU KLEMS database,[5] Bond and Xing (2015) test this theory using sector-level panel data for 14 OECD countries. They find that the ratios of capital to output are strongly influenced by changes in corporate tax incentives. Fatica (2018) uses a panel of 23 sectors in 10 OECD countries over the period 1984-2007 from the EU KLEMS database to show that investment is significantly responsive to the tax-adjusted user cost of capital. These elements of the recent literature on business investment have also implemented autoregressive or simple distributed lag models and error correction models with logarithmic transformation of the variables. Fatica's model (2018) enriches the neoclassical conception of the determinants of investment by analysing the short-run dynamics and the long-run equilibrium relationship between capital and the user cost of capital. This model in error-correction form offers the possibility of estimating the long-run elasticities of capital with respect to the user cost of capital or with respect to the different components of the user cost of capital.[6]

Using quarterly data for aggregate private business in the US over the period 1952-1992, Oliner et al. (1995) conclude that an Euler-type investment equation does not outperform the accelerator, the neoclassical, or the Tobin's q models of investment behaviour in terms of forecasting capacity. When the Euler-type investment equation is updated with a time-to-build constraint, its performance improves but remains worse than that of the traditional models of investment. Bernanke et al. (1988) allege there is modest support for investment models that add capacity utilization variables such as output or sales, but little support for models that include user cost or q-variables. Kopp (2018), considering a log-log model where the dependent variable is the logarithm of non-residential private fixed investment, shows that most of the changes in U.S. business investment can be explained by changes in aggregate demand, which provides strong support for the accelerator model of investment behaviour.

In the aftermath of the recent financial crisis, the slowdown of aggregate investment has led to the emergence of the idea of a modified accelerator model of investment which consists of updating the accelerator-style model with additional country variables (Rabanal and Lee, 2010; Pinto and Tevlin, 2014; Banerjee et al., 2015; Barkbu et al., 2015). The aim of these models is to investigate how much of the weakness in aggregate investment can be explained by weakness in output. The evidence supports the argument that output, together with many other economic and financial variables, can explain a large part of the observed slowdown in U.S. investment.

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[5] EU KLEMS is a research project originally financed by the European Commission. It aims to produce industry level data on output, capital, employment, and other intermediate inputs. EU KLEMS stands for EU level analysis of capital (K), labour (L), energy (E), materials (M) and service (S) inputs.

[6] A review of the empirical approach in Bond and Xing (2015) and Fatica (2018) is given in the appendix (section 2.8.2).

Peters and Taylor (2017) tested their alternative Tobin's q model of investment behaviour based on their idea of a total-q using a large sample of firm-level data from the Compustat database, as well as aggregate data for the U.S. economy. They scale the investment levels in physical and intangible capital by the total stock of capital ($K_{it}^{tot} = K_{it}^{phy} + K_{it}^{int}$) to construct the rates of investment in physical and intangible capital. Each rate of investment is regressed on the total-q variable. They conclude that, compared to physical capital, intangible capital adjusts more slowly to changes in investment opportunities captured by the total-q. Their evidence suggests a reverse pattern compared to the one shown in Figure 2.1 (left panel).

2.2.5 Empirical strategy

The neoclassical model of investment behaviour offers a wide range of analytical elements to deepen our understanding of the origin of the observed difference in investment in physical and intangible capital. For this reason, this empirical investigation adopts the framework of the neoclassical model of investment behaviour. As in Jorgenson and Siebert (1968), Oliner et al. (1995), Dwenger (2014), and IMF (2015), the dependent and independent variables in [2.3] and [2.4] are scaled by $K_{i,j,t-1}^{phy}$ or $K_{i,j,t-1}^{int}$ (depending on the equation), for each country i and sector j. The estimating equations are

$$\frac{I_{ij,t}^{phy}}{K_{ij,t-1}^{phy}} \quad = \quad \frac{\alpha^{phy}}{K_{ij,t-1}^{phy}} \; + \; \sum_{s=1}^{2} \beta_s^{phy} \frac{\Delta\left(\frac{Y}{c^{phy}}\right)_{ij,t-s}}{K_{ij,t-1}^{phy}} \; + \; \lambda_{ij}^{phy} \; + \; \mu_{ij}^{phy} t \; + \; \omega_t^{phy} \; + \; u_{ij,t}^{phy} \qquad [2.9]$$

$$\frac{I_{ij,t}^{int}}{K_{ij,t-1}^{int}} \quad = \quad \frac{\alpha^{int}}{K_{ij,t-1}^{int}} \; + \; \sum_{s=1}^{2} \beta_s^{int} \frac{\Delta\left(\frac{Y}{c^{int}}\right)_{ij,t-s}}{K_{ij,t-1}^{int}} \; + \; \gamma pb_{it} \; + \; \lambda_{ij}^{int} \; + \; \mu_{ij}^{int} t \; + \; \omega_t^{int} \; + \; u_{ij,t}^{int}. \qquad [2.10]$$

Note that the starting point of the lag index s is one. As discussed earlier, this approach is taken to avoid having current-dated variables on the right-hand side of the rate of investment equations, so as to control for the issue of endogeneity or reverse causality that might emerge when current-dated variables are included on the right-hand side of the equation. The empirical setting controls for time-invariant unobserved heterogeneity by integrating country-sector pair-specific fixed effects, λ_{ij}^{phy} and λ_{ij}^{int}, and year-specific fixed effects, ω_t^{phy} and ω_t^{int}. In addition, it includes country-sector pair-specific time trends, $\mu_{ij}^{phy} t$ and $\mu_{ij}^{int} t$. Other parameters to be estimated are α^{phy} and α^{int}, β_s^{phy} and β_s^{int} for $s = 1, 2$, and γ. The disturbances are $u_{ij,t}^{phy}$ and $u_{ij,t}^{int}$. The lag length is fixed at two.[7] The user costs of physical and intangible capital, c_{ij}^{phy} and c_{ij}^{int}, are as defined in [2.5] and [2.6].

Five out of the twelve countries in the sample offer preferential tax concessions on profits derived from intangible assets (the so-called "patent box").[8] This is the case for France, Italy, the

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[7] Based on the neoclassical theory of investment behaviour and using US aggregate data from 1949I to 1960IV, Jorgenson and Stephenson (1967) found that investment expenditure lagged behind its determinants by 6 to 12 quarters or from a year and half to three years on average. In this study the lag length is not optimized, rather fixed at $N = 2$, following Jorgenson and Stephenson (1967). Note that Bond and Xing (2015) and Fatica (2018) also opt for a lag length of 2.

[8] Information about the existence of intellectual property box regimes (the patent boxes) is taken from Evers et al. (2015) and Alstadsæter et al. (2018). The most recent regimes were implemented in Italy and in

Netherlands, Spain, and the United Kingdom. The existence of an intellectual property regime (IPbox), by allowing profits derived from intellectual property assets to be taxed at a lower rate, increases a territory's attractiveness as a destination for intangible investment. Thus, it is expected to increase the rate of investment in intangible capital. To capture the effect of this tax practice, let pb_{it} be a dummy variable that takes the value 1 if an IPbox is in place in country i at time t, and zero otherwise. This variable is included as an additional explanatory variable in the equation for the rate of investment in intangible capital. In this study, 17.8% of the observations have an intellectual property regime.

Equations [2.9] and [2.10] differ in several aspects. First, physical and intangible capital assets have different prices, depreciate differently, and are impacted differently by tax policy. As a result, they should have different enough trajectories of capital accumulation to make unique both rate of investment equations. Further, if physical and intangible capital are equally productive and have the same rate of depreciation, the introduction of the IPbox variable in the equation for the rate of investment in intangible capital will be the only remaining factor that would differentiate the equations. Finally, if both types of capital are equally productive but with distinct rates of depreciation, the equations will be distinct even if some parameters are similar.

One may wonder whether presenting separate rate of investment equations does not neglect the elasticity of substitution between physical and intangible capital assets. Although this is a legitimate concern, according to Fatica (2018), this is the simplest way to accommodate different types of capital goods in a single-level constant elasticity of substitution (CES) production function. In the current empirical exercise, the Cobb-Douglas production function is sufficient and corresponds well to the original idea of modelling the determinants of investment behaviour put forward by Jorgenson (1963). In addition, it is possible that the error terms of the equations for physical and intangible capital are jointly distributed. This would give rise to a potential relationship between the two equations. In fact, this possibility has been ignored in the literature. For example, Fatica (2018) has set up four investment equations to investigate the relationship between capital and the tax-adjusted user cost of capital for four different types of capital goods such as computing equipment, communications equipment, transport equipment, and other machinery and equipment. Each equation was estimated independently.

2.3 Data description

This empirical investigation is based on sector-level panel data on capital and output from the EU KLEMS database,[9] corporate taxation information compiled by the Oxford University Centre for

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the United Kingdom in 2015 and 2013 respectively. The respective rates are 13.95% and 10.00%. The least recent regime was implemented in France in 2000. It applies a rate of 15.50%. The Netherlands offers the most generous regime by allowing a tax rate of 5.00% to be applied to profits generated from intellectual property assets. When an IPbox is in place in country i at time t, it is considered to be in place in all sectors j in country i.

[9] The data on capital and output come from the EU KLEMS database (July 2018 release). This version, which covers the time period 1995-2015, conforms with the adoption of the new European System of National Accounts 2010 (ESA 2010, which replaces ESA 1995). Under the new ESA 2010, the definition of gross fixed capital formation has undergone some modifications, where those concerning intangible capital are worth recalling. First, knowledge-based assets are now referred to as intellectual property products and include, for the first time, expenditure on research and development. Second, computer software is combined with databases to create another sub-group labelled computer software and databases. Finally, mineral exploration and artistic originals form the sub-group of other intellectual property product (OIPP) (Jäger, 2017; van

Business Taxation,[10] and replacement cost values of capital calculated by the Tax Foundation.[11] The sample contains information on twelve sectors in twelve OECD countries and covers the period 1995-2015.[12] The resulting panel dataset is slightly unbalanced. Tables 2.1 and 2.2 provide summary statistics for the variables related to physical and intangible capital. Levels of investment and the capital stock are expressed in real terms.

Table 2.1: Descriptive Statistics, variables related to physical capital.

Variables	Obs.	Mean	Std.	Min	Max
Rate of investment in physical capital	2,431	9.077	4.324	0.097	71.741
Inverse of lag of physical capital stock, $\frac{1}{K^{phy}_{t-1}}$	2,431	0.137	0.252	0.0006	3.621
Relative price of physical capital assets	2,431	0.995	0.258	-0.087	5.539
Tax component of the user cost of physical capital	2,431	1.104	0.054	-0.499	1.321
User cost of physical capital	2,431	0.065	0.018	0.008	0.350
Corporate income tax rate	2,431	0.289	0.054	0.150	0.450
$\frac{\Delta\left(\frac{Y}{c^{phy}}\right)_{t-1}}{K^{phy}_{t-1}}$	2,431	0.166	2.089	-48.213	50.922
$\frac{\Delta\left(\frac{Y}{c^{phy}}\right)_{t-2}}{K^{phy}_{t-1}}$	2,431	0.152	2.156	-53.460	53.545

Table 2.2: Descriptive Statistics, variables related to intangible capital.

Variables	Obs.	Mean	Std.	Min	Max
Rate of investment in intangible capital	2,431	26.896	10.147	3.656	96.755
Inverse of lag of intangible capital stock, $\frac{1}{K^{int}_{t-1}}$	2,431	2.565	6.558	0.002	73.268
Relative price of intangible capital assets	2,431	0.982	0.273	0.266	4.772
Tax component of the user cost of intangible capital	2,431	1.088	0.054	1.013	1.309
User cost of intangible capital	2,431	0.074	0.026	0.017	0.457
Corporate income tax rate	2,431	0.289	0.054	0.150	0.450
$\frac{\Delta\left(\frac{Y}{c^{int}}\right)_{t-1}}{K^{int}_{t-1}}$	2,431	4.523	95.352	-974.394	2252.359
$\frac{\Delta\left(\frac{Y}{c^{int}}\right)_{t-2}}{K^{int}_{t-1}}$	2,431	3.630	88.028	-894.524	1843.233
Intellectual property regime	2,431	0.178	0.382	0	1

Ark and Jäger, 2017).

[10] The Oxford University Centre for Business Taxation is an independent research centre which aims to promote effective policies for the taxation of corporations.

[11] The Tax Foundation is a leading independent tax policy non-profit located in the DC area in the United States. Established in 1937, it aims to promote smarter tax policy at the federal, state, and global levels.

[12] The countries are Austria, Czech Republic, Denmark, Finland, France, Germany, Italy, the Netherlands, Spain, Sweden, the United Kingdom, and the United States. Further information about the sectors can be found in Table 2.10 in the appendix 2.8.1.5.

2.3.1 Gross investment rate

The rates of investment in physical and intangible capital are obtained, for each sector in each country, by dividing the flow of investment in year t by the stock of capital in year $t-1$, both in millions of US dollars measured in purchasing power parity.[13] The rates of investment are transformed into percentages by multiplying them by 100. As shown in Tables 2.1 and 2.2, the average rates of investment, over all sectors during the sample period 1995-2015, in physical and intangible capital are found to be, respectively, 9.08% and 26.90%. Over the sample period, on average, the rate of investment in intangible capital is almost three times higher than that in physical capital (see Figure 2.2).

The maximum rate of investment in physical capital, 71.74% (seen in Table 2.1), is observed in the United Kingdom in 2005 in the sector "basic metals and fabricated metal products, except machinery and equipment." In national currency, this sector increased its investment in other machinery and equipment assets from £1,418.9 in 2004 to £19,645.4 million in 2005. Note that the annual average of this sector's investment in other machinery and equipment assets is £2,334.81 million. The maximum investment rate in intangible capital, 96.75% (seen in Table 2.2), is observed in the United States in 1999 in the sector "mining and quarrying." Indeed, this sector increased its investment in research and development from \$758.32 million US in 1998 to \$3,895.29 million US in 1999. Note that the annual average of this sector's investment in research and development is \$1,114.83 million US. More information about the composition of physical and intangible investment flows and stocks of capital is provided in the appendix 2.8.1.1.

2.3.2 Relative price, corporate tax, and user cost

As seen in Figure 2.3 (left-top panel), the average over all cross-sections of the relative price of intangible capital increased by more than 15% during the 1995-2015 period, while the average relative price of physical capital decreased slightly. The relative price of physical capital is obtained by dividing the price index of physical capital goods by the price index of real value-added. The price index of physical capital investment goods is the weighted average of the price indices of computing equipment, communications equipment, transport equipment, other machinery and equipment, non-residential buildings, and cultivated assets. The weight associated with each asset corresponds to its share of total investment in physical capital.

The ratio of the price index of intangible capital investment goods to the price index of real value-added determines the relative price of intangible capital. The price index of intangible capital investment goods is the weighted average of the price indices of computer software and databases, research and development, and other intellectual property products. The weights are the shares of total investment in intangible capital of investment in each asset. All price indices equal 100.0 in the base year of 2010, leading to the result that the relative prices of physical and intangible capital are both equal to one in 2010. This observation explains the similarity of the two relative prices around 2010. Further details on the construction of relative prices can be found in the appendix 2.8.1.2.

The corporate income tax rate, averaged over all countries, has decreased from 35% in 1995 to 25% in 2015 (Figure 2.1, right panel). Many national tax authorities have implemented a tremendous reduction in their corporate tax rates (Auerbach, 2007; Loretz, 2008). As seen in

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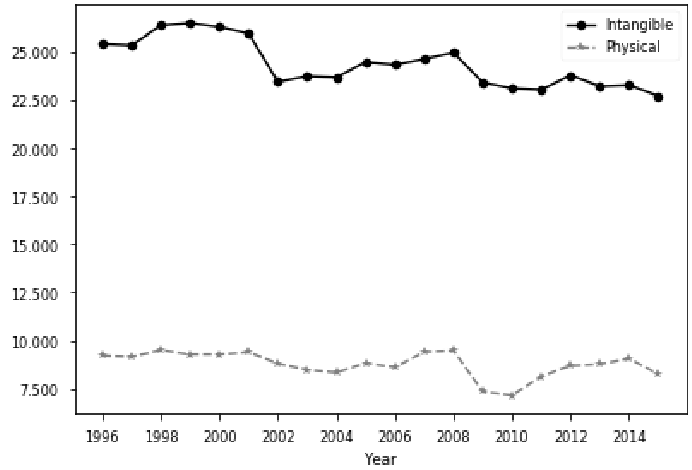
[13] Purchasing power parity (PPP) measures the amount of national currency per US dollar. The value of the purchasing power parity for the base year 2010 is used to convert the variables expressed in national currency to US dollars. The PPP data are taken from OECD (2020c).

Figure 2.2: Rates of Investment in physical and intangible capital in percentage: annual average across all sectors, 1995-2015.



Notes: This figure provides a graphical illustration of the evolution of rates of investment in physical and intangible capital. For each sector j in country i, the rate of investment is obtained by dividing investment measured in millions of US dollars in purchasing power parity in year t by the stock of capital measured in millions of US dollars in purchasing power parity in year $t-1$, multiplied by 100.

Tables 2.1 and 2.2, the minimum and the maximum corporate income tax rates are 15% and 45%. Moreover, from 1995 to 2015 the Czech Republic, Germany, and the United Kingdom decreased their corporate tax rates from 41% to 19%, 45% to 15%, and 33% to 21%, respectively.[14] The corporate tax rate is the same for all sectors within a country for a given year, but varies across countries and/or time. Further information about the evolution of the corporate tax rates can be found in the appendix 2.8.1.3.

Over the entire sample, the average user cost of intangible capital of 0.074 is higher than the average user of physical capital, which is 0.065. Also, the user cost of intangible capital remains above the user cost of physical capital in every year of the sample period (Figure 2.3, top-right panel). It exhibits higher variability than the user cost of physical capital (Tables 2.1 and 2.2). An inverse pattern is observed when visualizing the tax component of the user cost of capital shown in Figure 2.3 (bottom-left panel). On average, the tax component of the user cost of intangible capital (1.088) is lower than the tax component of physical capital (1.104). Over the sample period, the tax components of the user cost of physical and intangible capital have decreased. The tax components of the user cost of capital have decreased because the replacement cost values of physical and intangible capital have increased. The tax component of the user cost is lower for intangible capital in comparison to physical capital because the replacement cost for intangible capital is higher than that for physical capital.

The evolution of the user costs of physical and intangible capital shows that, over the sample

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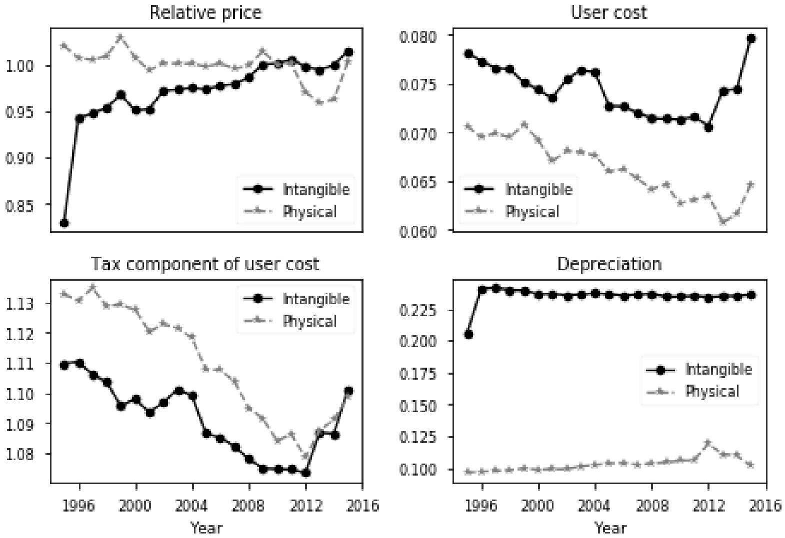
[14] The Oxford University Centre for Business Taxation database offers other corporate tax measures such as the effective average tax rate and the effective marginal tax rate. This study uses the statutory corporate income tax rate, which is positively correlated with the effective average and marginal tax rates. Note that the corporate tax measures do not differentiate between physical and intangible capital.

Figure 2.3: Relative prices, user cost, tax component of user cost, and the rate of depreciation: annual average, 1995-2015.



Notes: This figure gives the evolution of the relative prices, the user costs, the tax components of the user costs, and the rates of depreciation of physical and intangible capital. The relative price of physical/intangible capital is the price index of physical/intangible capital assets divided by the price index of gross value-added. The user costs of physical and intangible capital are defined following Devereux and Griffith (1999) and Devereux and Griffith (2003). The tax components of the user costs of physical and intangible capital are defined following Bond and Xing (2015). The rates of depreciation are calculated with the help of data from the EU KLEMS database.

period, the user cost of intangible capital has remained higher than that of physical capital. This is an observation that needs further investigation, since for two components of the user cost of capital, i.e., the relative price and the tax component of the user cost, the values for intangible capital are generally lower than for physical capital. Under the assumption of the same real discount rate (5%)[15] for both physical and intangible capital, this difference is explained by the evolution of the rates of depreciation of intangible and physical capital assets. Indeed, Figure 2.3 (bottom-right panel) shows that, over the sample period, the rate of depreciation of intangible capital remains significantly higher than that of physical capital.[16] On average, it is more than twice the rate of depreciation of physical capital. The useful life of each type of capital (physical and intangible) affects the calculation of the rates of depreciation. Indeed, intangible capital is depreciated throughout a useful life of two to ten years. However, physical capital assets are depreciated throughout a useful life of twenty to fifty years for non-residential buildings and seven to twenty years for machinery

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[15] Clark and Sichel (1993) used a constant discount rate of 5%. A discount rate of 5% is an appropriate benchmark, according to ZEW (2014). It is acknowledged that Fatica (2018) used a floating discount rate which is a weighted average of the cost of equity and the cost of debt. Bond and Xing (2015) allow it to vary across time, but avoid the problem of measurement by letting this component of the user cost of capital to be captured by fixed effects and time trends.

[16] The depreciation rates in the EU KLEMS database are calculated from a geometric pattern and vary by asset, but are held constant over time and across countries. The idea of estimating implicit depreciation rates from capital stock data was rejected. Although an implicit depreciation rate would align well with the evolution of national statistics, it happens that these estimates are sometimes very volatile and even negative (O'Mahony and Timmer, 2009).

Table 2.3: Serial correlation tests, investment rate equations.

	Physical		Intangible	
Serial correlation tests	Statistic	p-value	Statistic	p-value
IS(1)	42.25	0.001	39.18	0.002
IS(2)	68.33	0.000	64.48	0.001
IS(all)	142.40	0.720	141.10	0.746
Q(1)	9.78	0.002	29.70	0.000
Q(2)	11.35	0.003	30.15	0.000
LM(1)	3.15	0.002	5.45	0.000
LM(2)	0.39	0.700	2.89	0.004

Notes: Physical: equation [2.9]. Intangible: equation [2.10].

and equipment (Devereux and Bilicka, 2017).

2.4 Empirical results

This section begins with some diagnostic testing and continues with the analysis of the regression results. Serial correlation can bias standard errors and give rise to less efficient estimates, so it is important to identify its existence and correctly account for it. The IS test proposed by Inoue and Solon (2006) and the Q and LM tests proposed by Born and Breitung (2016) are used to detect serial correlation in this fixed effects panel data regression model (equations [2.9] and [2.10]). The IS(1), Q(1) and LM(1) test results, shown in Table 2.3, indicate that the null hypothesis of no serial correlation of order 1 is strongly rejected for the physical and intangible capital equations. Regarding second-order autocorrelation, based on IS(2) and Q(2), the null hypothesis is strongly rejected for both equations. However, the LM(2) test fails to reject the null hypothesis for the rate of investment in physical capital equation, but rejects the null for the rate of investment in intangible capital equation. Finally, the IS(all) test indicates that the null hypothesis of no serial autocorrelation of any order is not rejected.

Thus the IS(1), Q(1), and LM(1) tests confirm the presence of first-order serial correlation. Even though the IS(all) test does not reject the null hypothesis of no serial correlation of any order, it is acceptable to assume the presence of first-order autocorrelation since the IS(all) test is a less powerful test, according to Wursten (2018). Further, almost all the tests reject the null hypothesis of no second-order serial correlation at the 1% level of significance. As a result, standard errors that are adjusted to account for serial correlation are used.[17]

In addition, common unobservable factors or patterns might affect the cross-sectional units, in this case, the country-sector pairs. A convincing example of such a factor is the 2007 financial crisis.

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[17] Wursten (2018) creates the Stata codes to implement the IS, Q and LM tests. Further, the Wooldridge test, implemented in Stata by Drukker (2003) and appropriate to detect the first-order autocorrelation in the one-way panel data regression model, rejects at the 5% level of significance the null hypothesis of no first-order autocorrelation for the rate of investment in physical capital (F(1,142)=4.335 and p-value=0.0391). For the rate of investment in intangible capital equation, with an F statistic of F(1,142)=31.899 and p-value 0.000, the null hypothesis that there is no first-order autocorrelation is strongly rejected.

Such common factors will make the residuals cross-sectionally dependent and invalidate statistical inference. Since the model contains common time effects and the number of cross-sections is large relative to the number of periods, according to Hoyos and Sarafidis (2006) the Frees test (Frees, 1995, 2004) is the appropriate test. For $T \leq 30$, the critical values at the 10%, 5%, and 1% levels of significance are 0.2136, 0.2838, and 0.4252, respectively. Since the values of Frees' statistic for the rate of investment equations in physical and intangible capital are respectively 5.998 and 5.149, at the 1% level of significance, under this test, the null of hypothesis of cross-sectional independence is strongly rejected. Indeed, Frees' test confirms the presence of cross-sectional correlation.

Given the presence of autocorrelation and cross-sectional dependence, statistical inference will be made with the help of Driscoll and Kraay (1998) standard errors. Hoechle (2006) suggests that these standard errors are well calibrated when cross-sectional correlations are present.

Table 2.4 presents the estimation results for equations [2.9] and [2.10]. For the rate of investment in physical capital, the estimates are strongly significant with the expected signs. These results can be compared to those of Bond and Xing (2015) and Fatica (2018) for total capital (see appendix 2.8.2). For the rate of investment in intangible capital equation, the estimate associated with the inverse of the lagged stock of intangible capital is significant at the 1% level of significance. The coefficient estimates for the variables $\Delta\left(\frac{Y}{c^{int}}\right)_{t-1}/K^{int}_{t-1}$ and $\Delta\left(\frac{Y}{c^{int}}\right)_{t-2}/K^{int}_{t-2}$ are significant at the 10% and 5% levels of significance, respectively. Note that the intellectual property box variable does not have a significant coefficient. All estimates except the one associated with the intellectual property box have the correct signs.

These results confirm a negative relationship between the rates of investment and the user cost for both physical and intangible capital. Indeed, lower values of the user cost of physical and intangible capital induce higher values of $\Delta\left(\frac{Y}{c^{phy}}\right)_{ij,t-s}/K^{phy}_{ij,t-1}$ and $\Delta\left(\frac{Y}{c^{int}}\right)_{ij,t-s}/K^{int}_{ij,t-1}$, for $s = 1, 2$. Therefore, higher rates of investment in both physical and intangible capital will occur.

The regression results show different estimated coefficients for the two types of capital. It is important to investigate whether this result is due to chance or to idiosyncratic characteristics of the rate of investment equations for physical and intangible capital. Dufour and Torrès (1998) propose a confidence intervals intersection test which helps answer this question. Let $\hat{\theta}_i$ be an estimate of θ_i. The lower and upper confidence limits of θ_i are $\hat{\theta}_{iL} = \hat{\theta}_i - c_{iL}(y_i, \alpha_i)$ and $\hat{\theta}_{iU} = \hat{\theta}_i + c_{iU}(y_i, \alpha_i)$, where y_i is the sample and $1 - \alpha_i$ is the confidence coefficient. Usually, but not always, we have $c_{iL}(y_i, \alpha_i) = c_{iU}(y_i, \alpha_i) = t_{\alpha_i/2} \cdot \sigma_{\hat{\theta}_i}$. Therefore, the confidence intervals are written as

$$C_i(y_i, \alpha_i) = \left[\hat{\theta}_{iL}, \hat{\theta}_{iU}\right] = \left[\hat{\theta}_i - t_{\frac{\alpha_i}{2}} \cdot \sigma_{\hat{\theta}_i}, \hat{\theta}_i + t_{\frac{\alpha_i}{2}} \cdot \sigma_{\hat{\theta}_i}\right].$$

Suppose we compare m models. Consider the null hypothesis

$$H_o : \theta_1 = \theta_2 = \cdots = \theta_m,$$

where θ_i is the parameter in model i. At the $\alpha = \sum_{i=1}^{m} \alpha_i$ level of significance, the null hypothesis is rejected if and only if

$$max\left[\frac{\left|\hat{\theta}_k - \hat{\theta}_j\right|}{c_{jU}(y_j, \alpha_j) + c_{kL}(y_k, \alpha_k)}\right] > 1, \text{ for j, k} \in \{1, 2, \cdots, m\}.$$

In this case, there are two models ($m = 2$) and the following null hypotheses are tested:

$$H_{1o} : \alpha^{phy} = \alpha^{int} \quad , \quad H_{2o} : \beta_1^{phy} = \beta_1^{int},$$

Table 2.4: Regression results, rate of investment equations in physical and intangible capital.

Rate of investment	Physical capital	Intangible capital
$\frac{1}{K_{t-1}^n}$	14.821***	1.044***
	(4.062)	(0.151)
$\frac{\Delta\left(\frac{Y}{c^n}\right)_{t-1}}{K_{t-1}^n}$	0.200***	0.0044*
	(0.042)	(0.0022)
$\frac{\Delta\left(\frac{Y}{c^n}\right)_{t-2}}{K_{t-1}^n}$	0.129***	0.0072**
	(0.045)	(0.0026)
Intellectual property box		-0.377
		(0.950)
Constant	8.258***	24.662***
	(0.581)	(0.848)
Country-sector fixed-effects	Yes	Yes
Country-sector trends	Yes	Yes
Time trends	Yes	Yes
F statistic	278.5	2244.9
Number of groups	143	143
Observations	2431	2431
R^2	0.3988	0.3288

Notes: The letter $n \in \{\text{phy, int}\}$ represents the type of capital (physical or intangible). Driscoll and Kraay standard errors are in parentheses, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. The coefficients of $1/K_{t-1}^n$ have been scaled by 1000. The estimated constants show the rates of depreciation and have been multiplied by 100.

Table 2.5: Confidence intervals intersection test of Dufour and Torrès (1998)

Estimate	Coef. Phy.	$t_{\frac{2.5\%}{2}} \cdot \sigma^{phy}$	Coef. Intan.	$t_{\frac{2.5\%}{2}} \cdot \sigma^{phy}$	$\frac{\lvert Coef^{phy} - Coef^{int} \rvert}{t_{\frac{2.5\%}{2}} \cdot \sigma^{phy} + t_{\frac{2.5\%}{2}} \cdot \sigma^{int}}$
α	14.821	9.448	1.044	0.350	1.406
β_1	0.200	0.098	0.004	0.005	1.891
β_2	0.129	0.104	0.007	0.006	1.110
Constant	8.258	1.351	24.662	1.972	4.935

Notes: The constant is the estimated rate of depreciation multiplied by 100. We note that the values of 8.258 for physical capital and 24.662 for intangible capital are close to average rates of depreciation for physical (10.4) and intangible (23.6) capital used in the calculation of the user cost of capital.

$$H_{3o} : \beta_2^{phy} = \beta_2^{int} \quad , \text{and} \quad H_{4o} : Constant^{phy} = Constant^{int}.$$

The test is done for the first three estimated parameters and the constant terms in each investment equation (Table 2.4). As shown in the fifth column of Table 2.5, at the $\alpha_1 + \alpha_2 = 2.5\% + 2.5\% = 5\%$ level of significance, the null hypotheses are rejected, since all the values in this column are larger than one. Consequently, the rate of investment in physical capital and the rate of investment in intangible capital are explained by two separate equations. Thus, they will respond differently to changes in the same factor, such as the corporate income tax rate, for example. Besides the fact that the fixed effects may differ, the confidence intervals intersection test reinforces the differences between [2.9] and [2.10] by showing that the parameters are also statistically different.

The empirical results confirm, keeping everything else fixed, that changes in the corporate income tax rate impact negatively the rates of investment in both physical and intangible capital. This result is consistent with the conclusions of Hall and Jorgenson (1967), Bond and Xing (2015), and Fatica (2018) under the assumption of a homogeneous type of capital asset, physical capital. When the corporate income tax rate decreases, the user costs of both physical and intangible capital are reduced, causing the rates of investment in both physical and intangible capital to increase. Changes in corporate tax policy thus create incentives that affect investment in both physical and intangible capital.

However, the response time of the rate of investment to changes in corporate tax policy differs, everything else remaining unchanged, between physical and intangible capital. Indeed, in this setting, the response of rate of investment in physical capital is stronger in the first period than in the second period. Inversely, in the case of intangible capital, the response of the rate of investment is weaker in the first period but becomes stronger in the second period. Furthermore, the estimate capturing the impact of the implementation of an intellectual property regime is not significant. This evidence suggests that the existence of a patent box does not have a positive impact on the rate of investment in intangible capital in this dataset.

The coefficient estimates shown in Table 2.4 imply the following two equations for predicted gross investment in physical and intangible capital, [2.11] and [2.12]:

$$\hat{I}_{ij,t}^{phy} = 14.8 + 0.2\Delta\left(\frac{Y}{C^{phy}}\right)_{ij,t-1} + 0.13\Delta\left(\frac{Y}{C^{phy}}\right)_{ij,t-2} + 8.3K_{ij,t-1}^{phy} \quad [2.11]$$

$$\hat{I}_{ij,t}^{int} = 1.04 + 0.0044\Delta\left(\frac{Y}{C^{int}}\right)_{ij,t-1} + 0.0072\Delta\left(\frac{Y}{C^{int}}\right)_{ij,t-2} - 0.38pb_{it} + 24.7K_{ij,t-1}^{int} \quad [2.12]$$

Evaluated at sample means, the terms $0.2\Delta\left(Y/c^{phy}\right)_{ij,t-1}$ and $0.13\Delta\left(Y/c^{phy}\right)_{ij,t-2}$ in equation [2.11], and $0.0044\Delta\left(Y/c^{int}\right)_{ij,t-1}$, $0.0072\Delta\left(Y/c^{int}\right)_{ij,t-2}$, and $-0.38pb_{it}$ in equation [2.12], are small (close to zero). As a result we can write:

$$\hat{I}^{phy}_{ij,t} \approx 14.8 + 8.3K^{phy}_{ij,t-1} \quad \text{and} \quad \hat{I}^{int}_{ij,t} \approx 1.04 + 24.7K^{int}_{ij,t-1}.$$

Thus the model of investment formed by equations [2.9] and [2.10] gives a central role to the rates of depreciation in explaining the increasing ratio of investment in intangible to physical capital. Under this model, the higher rate of depreciation of intangible relative to physical capital explains the increasing ratio of investment in intangible to physical capital. Nonetheless, it should be noted that the estimated constant terms in equations [2.9] and [2.10] may reflect other elements in addition to the estimated depreciation rates. Therefore, this is a result that should be treated with caution; although the estimated constant terms are very close to the physical and intangible capital depreciation rates obtained from the data.

2.5 Sensitivity analysis

This section puts the emphasis on some sensitivity analysis. In the first part, the same model formed by [2.9] and [2.10] is re-estimated while some features of the dataset are modified. Later, an alternative empirical model in error-correction form based on Fatica (2018) is tested.

2.5.1 Changes in the dataset

First, the structure of the dataset is modified to create a balanced panel dataset of twelve sectors in twelve countries that covers the period 2000-2014. Second, the alternative formulas for the user cost of capital proposed by Bond and Xing (2015) and Fatica (2018) are used. Finally, the weighting scheme used in the construction of the price indices, the rates of depreciation, and the replacement cost recovery value of capital is changed. Instead of using the share of each asset in total investment as its weight, a simple average approach is used.

First, Table 2.6, in columns 1 and 2, shows the regression results of the model of [2.9] and [2.10] estimated using a balanced panel dataset (period 2000-2014). The estimates are equally statistically significant, but larger in magnitude than the ones shown in Table 2.4. The results keep their qualitative and quantitative interpretations, such as: the rate of investment equations in physical and intangible capital are two separate equations, changes in corporate tax incentives affect the rates of investment in both physical and intangible capital, and the response of the rate of investment in physical capital is stronger in the first period while this response is weaker in the first period for intangible capital.

Second, the user cost of capital formula proposed by Bond and Xing (2015) is tried (Table 2.6, in columns 3 and 4). The estimates are equally significant. While almost identical estimated coefficients are found for the variable $1/K^n_{t-1}$ for $n \in \{\text{phy, int}\}$, and for the constants, the estimates associated with $\Delta\left(\frac{Y}{c^n}\right)_{t-1}/K^n_{t-1}$ and $\Delta\left(\frac{Y}{c^n}\right)_{t-2}/K^n_{t-1}$ are significantly larger than the ones shown in Table 2.4. Indeed, they increase by a factor of 3 for physical capital and a factor of almost 4 for intangible capital. Qualitatively, the estimates have similar interpretations. Furthermore, the user cost of capital formula proposed by Fatica (2018) is used (Table 2.6, in columns 5 and 6). The results are almost identical to the ones found with the user cost formula of Bond and Xing (2015) (Table 2.6, in columns 3 and 4). There is a small increase in the estimates associated with the variables $\Delta\left(\frac{Y}{c^n}\right)_{t-1}/K^n_{t-1}$ and $\Delta\left(\frac{Y}{c^n}\right)_{t-2}/K^n_{t-1}$ when $n = phy$. Again, the estimates keep their qualitative interpretations.

Finally, instead of using a weighted average, where the weights are the shares of total investment, to construct the price indices, the rates of depreciation, and replacement cost recovery values for physical and intangible capital, a simple average is used. This new weighting scheme keeps unchanged the results for physical capital (Table 2.6, in columns 7 and 8) in comparison to the ones shown in Table 2.4. For intangible capital, while the estimates keep their respective signs, the magnitude of the coefficients associated with $\Delta\left(\frac{Y}{c^n}\right)_{t-1}/K^n_{t-1}$ and $\Delta\left(\frac{Y}{c^n}\right)_{t-2}/K^n_{t-1}$ for $n = int$ change considerably. These estimates are not significant and are lower in magnitude in comparison to the results shown in Table 2.4 for intangible capital. These results suggest that the use of a simple average is less appropriate to derive the price indices of investment goods, the rates of depreciation and the replacement cost recovery of capital.

Table 2.6: Other regression results: restricted balanced panel dataset, other user cost formulas, and other weighting scheme: model of investment formed by [2.9] and [2.10].

	Balanced panel		New user cost, BX		New user cost, Fatica		New weighting scheme	
Rate of investment	Physical	Intangible	Physical	Intangible	Physical	Intangible	Physical	Intangible
$\frac{1}{K^n_{t-1}}$	22.737***	1.060***	14.474***	1.052***	14.474***	1.052***	14.483***	1.008***
	(5.472)	(0.164)	(3.190)	(0.156)	(3.190)	(0.156)	(3.635)	(0.127)
$\frac{\Delta(\frac{Y}{c^n})_{t-1}}{K^n_{t-1}}$	0.216***	0.0042*	0.592***	0.020**	0.622***	0.021**	0.205***	0.0025
	(0.052)	(0.0021)	(0.175)	(0.0087)	(0.183)	(0.0092)	(0.044)	(0.0015)
$\frac{\Delta(\frac{Y}{c^n})_{t-2}}{K^n_{t-1}}$	0.199*	0.0073**	0.433*	0.028***	0.454*	0.029***	0.140**	0.0032
	(0.101)	(0.0025)	(0.217)	(0.0068)	(0.227)	(0.0071)	(0.064)	(0.0019)
Intellectual property box		-1.014		-0.335		-0.335		-0.388
		(1.490)		(0.953)		(0.953)		(0.970)
Constant	7.693***	23.628***	8.279***	24.652***	8.279***	24.652***	8.227***	24.627***
	(0.706)	(.492)	(0.501)	(0.876)	(0.501	(0.876)	(0.540)	(0.732)
Country-sector fixed-effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country-sector trends	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time trends	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
F statistic	1144.9	48.5	3408.7	329.5	3408	329.5	4659.3	4704.44
Number of groups	143	143	143	143	143	143	143	143
Observations	2109	2109	2431	2431	2431	2431	2431	2431
R^2	0.3945	0.3460	0.3948	0.3298	0.3948	0.3298	0.3917	0.3203

Notes: Driscoll and Kraay standard errors in parentheses, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$, n $\in$ {phy, int}. The estimation method is the fixed effects regression.

2.5.2 Alternative model in error-correction form

The investment model in the form of equations [2.9] and [2.10] is usually estimated to forecast the level of investment. However, this model has an important drawback in that it does not allow estimation of the long-run impact of changes in the user cost of capital. Following Fatica (2018), this drawback can be overcome by estimating an error-correction model of the level of the capital stock.

Let n be the type of capital, which can be physical or intangible; i.e., $n \in \{\text{phy}, \text{int}\}$. Recall that under the neoclassical model of investment, we have $K^{n*}_{ij,t} = \zeta^n(Y_{ij,t}/c^n_{ij,t})$. Using a logarithmic transformation, this expression can be written as

$$k^{n*}_{ij,t} = z^n + y_{ij,t} - \vartheta^n_{ij,t}, \tag{2.13}$$

where $k^{n*}_{ij,t}$, z^n, $y_{ij,t}$, and $\vartheta^n_{ij,t}$ represent the logs of the desired level of the stock of capital, the elasticity of output with respect to capital, the output level, and the user cost of capital. Following Caballero et al. (1995), in any period the observed level of the stock of capital deviates from its desired level, such that we have $k^n_{ij,t} = k^{n*}_{ij,t} + e_{ij,t}$. The term $e_{ij,t}$ represents deviations between the desired and actual capital stock at the sector level. Following Fatica (2018), if we opt for an autoregressive distributed lag model of length 2, ADL(2,2), the estimating equation in error-correction form becomes

$$\begin{aligned}\Delta k^n_{ij,t} = \alpha^n + \pi^n_0 \Delta k^n_{ij,t-1} + \pi^n_1 \Delta y_{ij,t} + \pi^n_2 \Delta y_{ij,t-1} + \pi^n_3 \Delta \vartheta^n_{ij,t} \\ + \pi^n_4 \Delta \vartheta^n_{ij,t-1} + \varphi^n[(k^n_{ij,t-2} - y_{ij,t-2}) + \theta^n \vartheta^n_{ij,t-2}] + u^n_{ij,t},\end{aligned} \tag{2.14}$$

.

where the parameter θ^n is the long-run elasticity of capital with respect to the user cost of capital; φ^n is the speed of adjustment; and α^n, π^n_0, π^n_1, π^n_2, π^n_3, and π^n_4 are other parameters to be estimated. Further details about the derivation of equation [2.14] can be found in appendix 2.8.3. Given the estimate $\hat{\theta}^n$ and the sample data, the long-run elasticities of capital with respect to the tax component of the user cost of capital, the relative price, and the corporate income tax rate, respectively denoted ε_1, ε_2, and ε_3, can be calculated as follows:

$$\varepsilon_{1t} = \hat{\theta}^n \cdot \frac{P^n_t(1 - A^n_t)(r^n_t + \delta^n)}{p_t c^n_t (1 - \tau_t)},$$

$$\varepsilon_2 = \hat{\theta}^n,$$

$$\varepsilon_{3t} = \hat{\theta}^n \cdot \frac{P^n_t(1 - B^n_t)(r^n_t + \delta^n)\tau_t}{p_t c^n_t (1 - \tau_t)^2},$$

where $A^n_t = \tau_t B^n_t$.

As in Fatica (2018), we estimate a dynamic fixed effects error-correction model (DFE model) in which the short-run and long-run coefficients are restricted to be identical across all country-sector pairs as explained in Blackburne and Frank (2007). The estimation results for the model formed by equation [2.14] are presented in Table 2.7. The estimates for the speed of adjustment of physical and intangible capital ($\varphi^{phy} = -0.045$ and $\varphi^{int} = -0.055$) are strongly significant with the expected signs. Indeed, if the stocks of physical and intangible capital in period t are higher than their desired levels, then they are expected to be lower than their desired levels in period t+1.

Hence, the speeds of adjustment are negative. Note that intangible capital adjusts to its desired level faster than does physical capital. This could perhaps explain, among other things, higher growth of investment in intangible capital relative to physical capital.

The long-run elasticity of capital with respect to its user cost is $\theta^{phy} = -1.414$ for physical capital, and $\theta^{int} = -0.660$ for intangible capital. These elasticities are strongly significant with the correct signs. We note that physical capital responds more strongly to changes in its own user cost in comparison to intangible capital. The long-run elasticity of physical capital with respect to its user cost is almost 2.14 times larger than the one for intangible capital. Indeed, a 1% decrease in the user cost of physical capital causes the stock of physical capital to increase by 1.41% in the long-run. However, the same percentage change in the user cost of intangible capital induces the stock of intangible capital to increase by only 0.66%. Intangible capital does not react as quickly to changes in the user cost of capital in comparison to physical capital. Note that, as shown in section 5.2, the long-run elasticity with respect to the user cost is the same as the one with respect to the relative price.

The model formed by [2.9] and [2.10] and the alternative specification in error-correction form are not directly comparable. It is possible, however, to make some comparisons. For example, the negative relationship between capital and the user cost of capital expressed in the alternative model (equation [2.14]) is also present in the initial model (equations [2.9] and [2.10]). The estimated coefficient involving the stock of capital is positive in both models. It is also possible to compare the results of the error-correction model for physical capital with those of Fatica (2018) for total capital. In both cases, the estimated coefficients have the correct signs and are equally significant. The alternative specification model gives larger coefficients in magnitude compared to Fatica (2018). We recall that Fatica (2018) used a different sample period (1984-2007) and worked with 23 sectors constituting the whole market economy in 10 OECD countries (see appendix 2.8.2). The speed of adjustment of -0.045 for physical capital is higher in absolute value than that obtained by Fatica (2018) for total capital (-0.029). The long-run elasticity of capital with respect to the cost of capital is -0.729 in Fatica (2018), but -1.414 in this study.

To compute the long-run elasticities that are not directly estimated, i.e., the long-run elasticities of capital with respect to the tax component of the user cost of capital and with respect to the corporate income tax rate, we use the average marginal effect. These long-run elasticities are shown in Table 2.8. The long-run elasticities by country are averaged over all sectors and years within each country. Overall, the long-run elasticity of capital with respect to the tax component of the user cost of capital is higher for physical than for intangible capital, except in Italy. Overall, a 1% decrease in the tax component of the user cost of physical capital causes the stock of physical capital to increase by 3.63%. However, the stock of intangible capital increases by 2.79% as the tax component of the user cost of intangible capital decreases by 1%. The long-run elasticity of physical capital with respect to the tax component of the user cost of physical capital is above the overall average in the Czech Republic, Finland, Germany, the Netherlands, and Sweden. The long-run elasticity of intangible capital with respect to the tax component of its user cost is above the overall average in the Czech Republic, Denmark, France, Germany, Italy, Sweden, and the United Kingdom. Countries that have relatively higher ratios of investment in intangible to physical capital have an above average overall elasticity of intangible capital with respect to the tax component of its user cost, for example Denmark, Finland, France, and Sweden (Figure 2.4). The overall and within country elasticities are statistically different from zero at the 1% level of significance.

Overall, the long-run elasticities of physical and intangible capital with respect to the corporate income tax rate are respectively -0.49 and -0.31. Thus, changes in the corporate income tax rate induce a higher impact on physical capital accumulation than on intangible capital. Indeed, a

1% decrease in the corporate income tax rate causes physical and intangible capital to increase by 0.49% and 0.31%, respectively. The long-run elasticity of physical capital with respect to the corporate income tax rate is above the overall average in Austria, France, Italy, Spain, the United Kingdom, and the United States. The long-run elasticity of intangible capital with respect to the corporate income tax is above the overall average in the Czech Republic, the Netherlands, Spain, and the United States. At the 1% level of significance, the overall and within country long-run elasticities of capital with respect to the corporate income tax rate are statistically different from zero.

Finally, before concluding the analysis, it is worth estimating the long-run change in the capital stock based on Chirinko et al. (1999) and Wen et al. (2020). Recall that $\vartheta^n = ln(c^n)$. Thus, the corporate income tax semi-elasticity of capital (CSE) is given by the formula:[18]

$$CSE^n = -\widehat{\theta^n} * \frac{\partial \vartheta^n}{\partial \tau}.$$

Thus, the long-run change in the capital stock is obtained as follows

$$\frac{\Delta K^n}{K^n} \approx 100 * CSE^n * \Delta\tau.$$

During the period under study (1995-2015), the average corporate income tax rate decreased by 10 percentage points, from 35% to 25%. Thus, $\Delta\tau = -0.10$. This 10 percentage point decrease in the average corporate income tax rate led to a predicted long-run rise in physical capital of about 16.4% (100*(-1.636)*(-0.10)). As for intangible capital, a predicted long-run rise of about 10.1% (100*(-1.009)*(-0.10)) is expected when the average corporate income tax rate decreases by 10 percentage points. In summary, the long-run change in the capital stock is expected to be higher for physical capital than for intangible capital as a result of a same reduction in the corporate income tax rate.

The analysis of the estimation results of the investment model of equations [2.9] and [2.10] and that of the alternative specification in error-correction form [2.14] leads to the conclusion that the rate of depreciation is the convincing element which explains the increasing ratio of investment in intangible to physical capital. The higher rate of depreciation of intangible relative to physical capital explains why investment in intangible capital has been increasing faster than investment in physical capital.

So far this difference in depreciation rates seems to offer the best explanation for the increasing ratio of investment in intangible to physical capital. But if this was the only explanatory element, one would not observe an increasing ratio of the stock of intangible capital relative to physical capital. In fact, this is the case: the ratio of stock of intangible capital relative to the stock of physical capital is increasing (see Figure 2.5). Thus, there may be some other explanatory elements. The only things left that could explain faster growth of the stock of intangible capital relative to physical capital would be the fixed effects and the time trends.

The time trends seem like the most likely other contributor, because it is question of explaining a trend. The estimated time trends in the initial model do not offer any clear pattern. However, for

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[18] The derivative of the logarithm of the user cost of capital with respect to the corporate income tax rate is

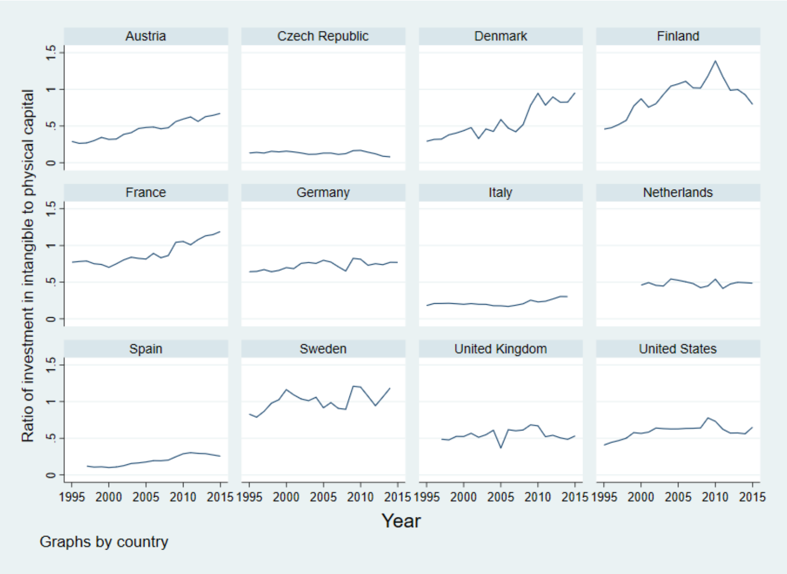
$$\frac{\partial \vartheta^n}{\partial \tau} = \frac{(1-B^n)(r^n+\delta^n)}{(1-\tau)[(1-A^n)(r^n+\delta^n)-(1-\tau)\delta^n]}.$$

Using the data, the derivatives of the logarithm of the user cost of capital with respect to corporate income tax rate are averaged to find $\partial\vartheta^{phy}/\partial\tau = 1.157$ for physical capital and $\partial\vartheta^{int}/\partial\tau = 1.528$ for intangible capital. Thereafter, the corporate income tax semi-elasticity of physical capital is $CSE^{phy} = -1.414*1.157 = -1.636$. For intangible capital, it's $CSE^{int} = -0.660 * 1.528 = -1.009$.

the alternative model, the estimated time trends are almost all negative for both types of capital. They are larger in absolute value for intangible capital for the sub-period 1995-2004 and are larger for physical capital in the sub-period 2004-2015. Thus the time trends may contribute to the explanation of faster growth of intangible capital, especially after 2004. Further, the data show that the logs of the capital-output ratios have been increasing for intangible capital, while they remained almost constant for physical capital. This evidence reinforces the role of the time trends in explaining the relatively rapid growth of investment in intangible compared to physical capital. It is possible that over time the production function has changed so as to combine more intangible capital with a given amount of physical capital. This is a very reasonable assertion, since for more than two decades information and communication technologies have represented an increasingly important part of productive structures.

Finally, it is worth noting that a limitation of the dataset used here is that the number of years per cross-sectional unit varies between 14 and 19. Thus this dataset is on the border line between a short and a long panel. To evaluate the potential dynamic panel bias in the error correction model, the generalized method-of-moments (GMM) estimator of Arellano and Bond (1991) might be worth future exploration.

Figure 2.4: Ratio of investment in intangible to physical capital, by country, 1995-2015.



Notes: This figure shows the evolution of the ratio of gross real investment in intangible to physical capital using country-level data.

Table 2.7: Estimates of equation [2.14].

	Physical capital	Intangible capital
Dependent variable: Δk_t^n	DFE model	DFE model
Δy_t	0.074*** (0.016)	0.097*** (0.022)
Δy_{t-1}	0.071*** (0.015)	0.066*** (0.020)
$\Delta \vartheta_t^n$	-0.049*** (0.015)	-0.061** (0.021)
$\Delta \vartheta_{t-1}^n$	-0.070*** (0.011)	-0.043** (0.017)
Δk_{t-1}^n	0.117** (0.060)	0.334*** (0.053)
Constant	-0.137*** (0.027)	-0.174*** (0.034)
Speed of ajustment (φ^n)	-0.045*** (0.011)	-0.055*** (0.009)
Long-run elasticity of capital w.r.t. the user cost (θ^n)	-1.414*** (0.302)	-0.660*** (0.158)
Country-sector fixed-effects	Yes	Yes
Country-sector trends	Yes	Yes
Year dummy	Yes	Yes
Number of groups	143	143
Observations	2,574	2,575

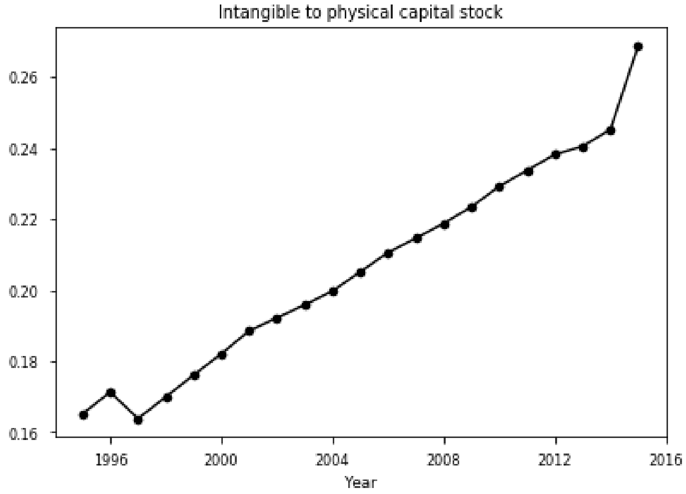
Notes: The letter $n \in \{\text{phy, int}\}$ represents the type of capital (physical or intangible). Standard errors adjusted with cluster(country-sector) are in parentheses; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. DFE model: dynamic fixed effects regression estimation.

Table 2.8: Long-run elasticities of capital with respect to the tax component of the user cost of capital and with respect to the corporate income tax rate.

	Tax component		Corporate tax rate	
	Physical	Intangible	Physical	Intangible
Overall	-3.627 (0.775)	-2.790 (0.670)	-0.493 (0.105)	-0.306 (0.074)
Austria	-3.586 (0.766)	-2.613 (0.628)	-0.523 (0.112)	-0.365 (0.088)
Czech Republic	-3.841 (0.820)	-2.862 (0.688)	-0.465 (0.099)	-0.294 (0.071)
Denmark	-3.622 (0.774)	-2.830 (0.680)	-0.480 (0.103)	-0.281 (0.068)
Finland	-3.703 (0.791)	-2.621 (0.630)	-0.372 (0.080)	-0.301 (0.072)
France	-3.526 (0.753)	-3.008 (0.722)	-0.512 (0.109)	-0.275 (0.066)
Germany	-3.862 (0.825)	-2.824 (0.678)	-0.431 (0.092)	-0.227 (0.055)
Italy	-3.416 (0.730)	-3.705 (0.890)	-0.584 (0.125)	-0.162 (0.039)
Netherlands	-3.636 (0.777)	-2.593 (0.623)	-0.471 (0.101)	-0.352 (0.085)
Spain	-3.214 (0.687)	-2.416 (0.580)	-0.671 (0.143)	-0.410 (0.099)
Sweden	-3.933 (0.840)	-2.894 (0.695)	-0.365 (0.078)	-0.190 (0.046)
United Kingdom	-3.617 (0.773)	-2.999 (0.720)	-0.499 (0.106)	-0.273 (0.065)
United States	-3.568 (0.762)	-2.117 (0.509)	-0.540 (0.115)	-0.538 (0.129)

Notes: Tax component - Physical/Intangible: we have the long-run elasticity of physical/intangible capital with respect to the tax component of the user cost of physical/intangible capital. Corporate tax rate - Physical/Intangible: we have the long-run elasticity of physical/intangible capital with to respect the corporate income tax rate. The standard deviations are in parentheses.

Figure 2.5: Ratios of the stock of capital in intangible to physical, annual average, 1995-2015.



Notes: This figure shows the ratio of the gross real stock of capital in intangible to physical capital.

2.6 Conclusion

This paper, with the objective of explaining the increasing ratio of investment in intangible to physical capital (Figure 2.1, left panel, and Figure 2.4), places intangible capital alongside physical capital within the framework of the neoclassical model of investment behaviour. This approach makes it possible to confirm that the equations for the rate of investment in physical and intangible capital are two separate equations. It concludes that corporate taxation incentives impact the rates of investment in both physical and intangible capital. However, corporate tax policy has a stronger impact on the accumulation process of physical capital than of intangible capital.

After the analysis of the estimation results of several regression equations, a specific explanation is found to explain the behaviour of the data: the higher rate of depreciation of intangible capital in comparison to physical capital. The rate of depreciation is more than twice as high as for intangible capital than for physical capital. The results are consistent after being subjected to a set of sensitivity analysis elements such as the restriction of dataset to a balanced panel, the use of alternative user cost of capital definitions, using a new weighting scheme, and estimating an alternative specification model in error-correction form.

A possible limitation of this study is the potential dynamic panel bias due to the short time dimension of the sample for some cross-sectional units (country-sector pairs). This limitation can be rectified by the arrival of new information to make the cross-sections longer. There is also the possibility trying the generalized methods-of-moments estimator of Arellano and Bond (1991). Of course, finding the right instruments and the right number of instruments will be a major challenge of this approach.

2.7 References

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2.8 Appendix

2.8.1 Data collection

2.8.1.1 Rates of investment

The dependent variables are the rates of investment in physical and intangible capital in country i, sector j, and year t. The rate investment is obtained by dividing the flow of investment in country i, sector j, and year t by the stock of capital in country i, sector j, and year $t-1$. The flows of investment and stocks of capital in physical and intangible capital assets, the rates of depreciation, the price indices of investment goods, and the real value-added and its price index are taken from the EU KLEMS database (July 2018 release).

Physical capital is composed of computing equipment (IT), communications equipment (CT), transport equipment (TraEq), other machinery and equipment (OMach), non-residential investment (OCon), and cultivated assets (Cult). They are measured in millions of US dollars in purchasing power parity. The sum of gross real investment in IT, CT, TraEq, OMach, OCon, and Cult forms the flow of investment in physical capital, I^{phy}. Similarly, the sum of the stocks of IT, CT, TraEq, OMach, OCon, and Cult constitutes the total stock of physical capital, K^{phy}.[19] The rate of investment in physical capital is expressed as $I^{phy}_{ij,t}/K^{phy}_{ij,t-1}$.

Intangible capital consists of computer software and databases (Soft_DB), research and development (RD), and other intellectual property products assets (OIPP). All components of intangible capital assets are measured in millions of US dollars in purchasing power parity. The sum of investment in Soft_DB, RD, and OIPP constitutes the total investment in intangible capital, I^{int}. Further, the sum of the stocks of capital in the form of Soft_DB, RD, and OIPP constitutes the total stock of intangible capital, K^{int}.[20] The rate of investment in intangible capital is expressed as $I^{int}_{ij,t}/K^{int}_{ij,t-1}$.

2.8.1.2 Relative prices

The price indices of all investment goods by assets and that of the gross value-added are accessible in EU KLEMS database. All price indices are 100.0 for the base year of 2010. The price index of physical capital investment goods is the weighted average of the price indices of IT, CT, TraEq, OMach, OCon, and Cult, where the weights are the respective shares in gross investment in physical capital.[21] For example, the weight associated with commuting equipment is Iq_CT/I^{phy}. The

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[19] In the EU KLEMS database the real gross fixed investments in physical assets are labelled Iq_IT for computing equipment, Iq_CT for communications equipment, Iq_TraEq for transport Equipment, Iq_OCon for total non-residential investment, and Iq_Cult for cultivated assets. Similarly, the real fixed capital stocks in physical capital assets are labelled Kq_IT for computing equipment, Kq_CT for communications equipment, Kq_TraEq for transport Equipment, Kq_OCon for total non-residential investment, and Kq_Cult for cultivated assets. These are real variables expressed in 2010 prices.

[20] In the EU KLEMS database the real gross fixed investments in intangible capital assets are labelled Iq_Soft_DB for computer software and databases, Iq_RD for research and development, Iq_OIPP for other intellectual property products. Similarly, the real fixed capital stocks in intangible capital assets are labelled Kq_Soft_DB for computer software and databases, Kq_RD for research and development, and Kq_OIPP for other intellectual property products. These are real variables expressed 2010 prices.

[21] In the EU KLEMS database the price indices of physical capital investment goods are labelled Ip_IT for computing equipment, Ip_CT for communications equipment, Ip_TraEq for transport Equipment, Ip_OCon for total non-residential investment, and Ip_Cult for cultivated assets. The price indices take the value 100.0 for the base year 2010.

relative price of physical capital is obtained by dividing the price index of physical capital by the price index of gross value-added. Similarly, the price index of intangible capital goods is calculated by taking the weighted average of the price indices of Soft_DB, RD, and OIPP, where their weights are the respective shares in gross investment in intangible capital.[22] For example, the weight associated with computer software and databases is Iq_Soft_DB/I^{int}. Thereafter, the relative price of intangible capital goods is the ratio of the price index of intangible capital to the price index of gross value-added in sector i in country j and year t.

2.8.1.3 Corporate income tax rate

Data on the corporate income tax rate are obtained from the Oxford University Centre for Business Taxation database (Devereux and Bilicka, 2017).[23] The database provides several corporate tax measures such as the corporate income tax rate, the statutory corporate income tax rate, the effective average tax rate, and the effective marginal tax rate. The corporate income tax rate is the top marginal tax on corporate income. The statutory corporate income tax rate is corporate income tax rate plus all applicable surcharges and the local profit tax (Devereux et al., 2008; Loretz, 2008). All corporate tax measures are positively correlated (see Table 2.9). Indeed, Loretz (2008) observed a clear downward trend in all measures of corporate income tax rate.

Table 2.9: Correlations between statutory corporate tax rate, effective average and effective marginal tax rates.

Variables	Correlations
Statutory Corporate income tax rate and effective average tax rate	0.7933
Statutory Corporate income tax rate and effective marginal tax rate	0.5109
Effective average tax rate and effective marginal tax rate	0.7012

2.8.1.4 User cost and tax component of user cost

Following Devereux and Griffith (1999) and Devereux and Griffith (2003) the expressions for user costs of physical and intangible capital are

$$c_t^{phy} = \frac{P_t^{phy}}{p_t}\left[\frac{(1-A_t^{phy})(r^{phy}+\delta^{phy})}{(1-\tau_t)} - \delta^{phy}\right]$$

$$c_t^{int} = \frac{P_t^{int}}{p_t}\left[\frac{(1-A_t^{int})(r^{int}+\delta^{int})}{(1-\tau_t)} - \delta^{int}\right].$$

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[22] In the EU KLEMS database the price indices of intangible capital assets are labelled Ip_Soft_DB for computer software and databases, Ip_RD for research and development, and Ip_OIPP for other intellectual property products. The price indices take the value 100.0 for the base year 2010.

[23] CBT Tax Database, http://eureka.sbs.ox.ac.uk/4635/.

The expressions P_t^{phy}/p_t and P_t^{int}/p_t are the relative price of physical and intangible capital and are explained in Appendix 2.8.1.2. Following Bond and Xing (2015) the expressions $(1 - A_t^{phy})/(1 - \tau_t)$ and $(1 - A_t^{int})/(1 - \tau_t)$ and are designated the tax components of the user cost of physical and intangible capital. In the numerators, A_t^{phy} and A_t^{int} are the net present value of depreciation allowances for physical and intangible capital, which are calculated by multiplying the statutory corporate tax rate by the replacement cost recovery of physical and intangible capital, respectively. With the help of data provided by the Tax Foundation, the replacement cost recovery of physical capital is the weighted average of replacement cost recovery of machinery and building structures. The replacement cost recovery for intangible capital assets is directly taken from the Tax Foundation database.

The rate of depreciation of physical capital assets, δ^{phy}, is the weighted average of the rates of depreciation of IT, CT, TraEq, OMach, OCon, and Cult, where the weights are the respective shares in gross investment in physical capital.[24] The rate of depreciation of intangible capital assets, δ^{int}, is the weighted average of the depreciation rates of Soft_DB, RD, and OIPP, where the weights are the respective shares in gross investment in intangible capital.[25] The rates of depreciation vary across sectors, but remain fixed across countries and over time. The expressions r^{phy} and r^{int} are the real discount rates of physical and intangible capital. Fatica (2018) used a weighted average of the cost of equity and the debt to obtain a real discount rate applied to physical capital. According to ZEW (2014), a nominal interest rate of 7.1% is a consistent benchmark for nominal discount rate. Considering an inflation rate of 2%, the cost of capital is on average equal to 5%. In this study, the real discount rates of physical and intangible are fixed at 5%. They are fixed across all country-sector pairs and over time.

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[24] In the EU KLEMS database, the rates of depreciation of gross investment in physical capital assets are labelled dpr_IT for computing equipment, dpr_CT for communications equipment, dpr_TraEq for transport Equipment, dpr_OMach for other machinery and equipment, dpr_OCon for total non-residential investment, and dpr_Cult for cultivated assets.

[25] In the EU KLEMS database, the rates of depreciation of intangible capital assets are labelled dpr_Soft_DB for computer software and databases, dpr_RD for research and development, and dpr_OIPP for other intellectual property products.

2.8.1.5 Cross-sections

Table 2.10: Countries, sectors , and period under study.

Countries	Period of available data
Austria	1995-2015
Czech Republic	1995-2014
Denmark	1995-2015
Finland	1995-2015
France	1995-2015
Germany	1995-2015
Italy	1995-2014
Netherlands	2000-2015
Spain	1997-2015
Sweden	1995-2014
The United Kingdom	1997-2015
The United States	1995-2015

Sectors[1]
Agriculture, forestry, and fishing
Mining and quarrying
Food products, beverages and tobacco
Textiles, wearing apparel, leather and related prodcuts
Wood and paper products; printing and reproduction of recorded media
Chemicals and chemical products
Rubber and plastics products, and other non-metallic mineral products
Basic metals and fabricated metal products, except machinery and equipment
Electrical and optical equipment
Machinery and equipment n.e.c.
Transport equipment
Other manufacturing; repair and installation of machinery and equipment

Notes: The sector agriculture, forestry and fishing is the only sector in the aggregate agriculture, forestry, and fishing. The sector mining and quarrying is the only sector in the aggregate mining and quarrying. The remaining ten sectors are part of the aggregate manufacturing. The sector coke and refined petroleum products which is part of the manufacturing aggregate in the EU KLEMS database is not considered in this empirical study. I drop the sector coke and refined petroleum products because the gross the value-added price index in this sector is extremely volatile. According to Klaas de Vries, economist from The Conference Board, the sector *coke and refined petroleum products* is heavily influenced by the volatility of oil prices particularly in small countries. He concluded the data in this specific sector is not very informative.

2.8.2 Insights from the empirical literature

This part of the appendix revisits of the empirical methods in Bond and Xing (2015) and Fatica (2018). Its objective is to ensure that the approach and the results that are presented in this paper are comparable to the literature.

2.8.2.1 Bond and Xing (2015)

Bond and Xing (2015) used a sector-level panel dataset that combines capital and output data on 11 manufacturing sectors in 14 OECD countries, and over the period 1982-2007 to investigate the relationship between the ratio of capital to output and the tax component of the user cost of capital. They contribute to the literature on investment behaviour by proposing one of the first empirical tests of the neoclassical model of investment behaviour that exploits a sector-level panel dataset, in comparison to previous studies that have used quarterly or aggregate macro data. Their econometric approach consists of a distributed lag model, an autoregressive distributed lag model, and an error correction model.

In order to reproduce some of the results of Bond and Xing (2015), I combined a sector-level panel dataset of 11 manufacturing sectors in 13 countries over the period 1982-2007 from the EU KLEMS database (2009 release). In contrast to Bond and Xing (2015), this dataset does not contain the data for France. It proved a challenge to find available data for the net present value of capital allowances series. In this work, this series is determined by multiplying the statutory corporate income tax rate by the replacement cost recovery of capital provided by the Tax Foundation. The Tax Foundation produces a series for machinery and equipment and one for building structures. Indeed, the series for total capital (physical capital) is the weighted average of machinery and building structures. This approach may produce a series with less variability, which is little problematic, in comparison to the case where there exist specific series for each component of total capital such as computing equipment (IT), communications equipment (CT), transport equipment (TraEq), other machinery and equipment (OMach), and building structures (OCon).

As seen in Table 2.11, the results for the static models are qualitatively and quantitatively consistent with Bond and Xing (2015). There is a noticeable difference in the estimate for the log of the tax component for the user cost of capital for equipment, $lnTAX_t$, columns (2a) and (2b). This difference can be explained by the construction of the net present value of capital allowances (NPV). Indeed, in this reproduction, the NPV for equipment is the same as for machinery and equipment. It is possible that the authors used a weighted average of the NPVs of IT, CT, TraEq, and OMach in their own calculations. The results for the distributed lag models, shown in Table 2.12, are consistent in sign and in range of magnitude with their results shown in columns (1a), (2a), and (3a). Finally, the results for the error correction models shown in Table 2.13 indicate that globally the estimates keep their qualitative interpretation. I found higher long-run elasticities of capital with respect to the relative price. The long-run elasticities of capital with respect to the tax component of the user cost of capital are very close, but the new estimate is not significant for total capital. These elasticities are higher for equipment. The long-run elasticities of structures with respect to the user cost of capital are not significant in both Bond and Xing (2015) and this reproduction.

2.8.2.2 Fatica (2018)

Fatica (2018) used a sector-level panel dataset composed of 23 sectors in 10 OECD countries over the period 1984-2007 to investigate the responsiveness of aggregate and disaggregate investment

Table 2.11: Static models for total capital, equipment, and structures: Table 1 in Bond and Xing (2015).

Dependent variable:	(1a)	(1b)	(2a)	(2b)	(3a)	(3b)
$ln(K_t/Q_t)$	Total capital		Equipment		Structures	
$ln(P_t^K/P_t)$	-0.512***	-0.548***	-0.693***	-0.633***	-0.453***	-0.284***
	(0.055)	(0.058)	(0.046)	(0.052)	(0.093)	(0.059)
$lnTAX_t$	-0.317***	-0.393***	-0.305**	-0.169	-0.255***	-0.300***
	(0.080)	(0.079)	(0.123)	(0.130)	(0.067)	(0.068)
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes
Country-sector trends	Yes	Yes	Yes	Yes	Yes	Yes
No. of groups	154	143	154	143	154	143
Observations	3443	3002	3442	3003	3440	3024
R^2	0.842	0.842	0.844	0.851	0.837	0.847

Notes: Columns (1a), (2a), and (3a) show the results presented in Table 1 in (Bond and Xing, 2015, p. 23). Columns (1b), (2b), and (3b) show the estimated coefficients of their model under new dataset.

Table 2.12: Distributed lag models for total capital, equipment, and structures: Table 2 in Bond and Xing (2015).

Dependent variable:	(1a)	(1b)	(2a)	(2b)	(3a)	(3b)
$ln(K_t/Q_t)$	Total capital		Equipment		Structures	
$ln(P^K/P)_t$	-0.368***	-.435***	-0.488***	-0.474***	-0.348***	-0.269***
	(0.044)	(0.064)	(0.050)	(0.059)	(0.063)	(0.056)
$ln(P^K/P)_{t-1}$	-0.070***	-0.119***	-0.096***	-0.125***	-0.068***	-0.037
	(0.024)	(0.034)	(0.030)	(0.034)	(0.033)	(0.030)
$ln(P^K/P)_{t-2}$	-0.096***	-0.035	-0.110***	-0.094***	0.002	0.027
	(0.022)	(0.027)	(0.026)	(0.028)	(0.025)	(0.021)
$ln(P^K/P)_{t-3}$	-0.058	-0.064	-0.055	-0.047	-0.075	0.021
	(0.046)	(0.050)	(0.044)	(0.056)	(0.062)	(0.039)
$lnTAX_t$	-0.279***	-0.045	-0.108	0.290	-0.085	-0.020
	(0.075)	(0.063)	(0.125)	(0.160)	(0.054)	(0.061)
$lnTAX_{t-1}$	0.067*	-0.042	0.028	0.041	0.051*	-0.021
	(0.038)	(0.063)	(0.061)	(0.071)	(0.026)	(0.050)
$lnTAX_{t-2}$	-0.094**	-0.156***	-0.179***	-0.148***	-0.073**	-0.108***
	(0.041)	(0.044)	(0.062)	(0.053)	(0.032)	(0.033)
$lnTAX_{t-3}$	-0.072	-0.260***	-0.167***	-0.137	-0.142***	-0.251***
	(0.050)	(0.077)	(0.067)	(0.130)	(0.044)	(0.055)
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes
Country-sector trends	Yes	Yes	Yes	Yes	Yes	Yes
No. of groups	154	143	154	143	154	143
Observations	2992	2570	2988	2574	2986	2592
R^2	0.854	0.848	0.859	0.858	0.839	0.851

Notes: Columns (1a), (2a), and (3a) show the results presented in Table 2 in (Bond and Xing, 2015, p. 23). Columns (1b), (2b), and (3b) show the estimated coefficients of their model under new dataset.

Table 2.13: Error correction models for total capital, equipment, and structures: Table 3 in Bond and Xing (2015).

Dependent variable:	(1a)	(1b)	(2a)	(2b)	(3a)	(3b)
ΔlnK_t	Total capital		Equipment		Structures	
$ln(K/Q)_{t-2}$	-0.092***	-0.028***	-0.151***	-0.054***	-0.048***	-0.017***
	(0.010)	(0.004)	(0.017)	(0.009)	(0.006)	(0.002)
$ln(P^K/P)_{t-2}$	-0.070***	-0.033***	-0.129***	-0.062***	-0.035***	-0.018***
	(0.010)	(0.006)	(0.021)	(0.012)	(0.007)	(0.003)
$lnTAX_{t-2}$	-0.035***	-0.009	-0.110***	-0.050*	-0.005	0.000
	(0.012)	(0.012)	(0.026)	(0.029)	(0.008)	(0.006)
ΔlnK_{t-1}	0.329***	0.480***	0.218***	0.361***	0.404***	0.519***
	(0.041)	(0.042)	(0.073)	(0.070)	(0.037)	(0.033)
ΔlnQ_t	0.094***	0.068***	0.151***	0.120***	0.037***	0.025***
	(0.011)	(0.011)	(0.019)	(0.018)	(0.007)	(0.006)
ΔlnQ_{t-1}	0.091***	0.061***	0.144***	0.089***	0.046***	0.029***
	(0.009)	(0.009)	(0.015)	(0.012)	(0.007)	(0.007)
$\Delta ln(P^K/P)_t$	-0.088***	-0.070***	-0.146***	-0.153***	-0.019***	-0.014***
	(0.010)	(0.014)	(0.020)	(0.022)	(0.006)	(0.005)
$\Delta ln(P^K/P)_{t-1}$	-0.074***	-0.075***	-0.126***	-101***	-0.030***	-0.020***
	(0.010)	(0.009)	(0.018)	(0.015)	(0.006)	(0.005)
$\Delta lnTAX_t$	-0.030**	-0.052***	-0.031	-0.018	0.004	-0.002
	(0.013)	(0.016)	(0.025)	(0.027)	(0.007)	(0.008)
$\Delta lnTAX_{t-1}$	-0.032**	-0.030*	-0.041	-0.038	0.001	-0.013
	(0.014)	(0.018)	(0.033)	(0.036)	(0.007)	(0.008)
Long-run elasticities						
$ln(P^K/P)$	-0.760***	-1.191***	-0.852***	-1.160***	-0.728***	-1.049***
	(0.082)	(0.200)	(0.080)	(0.129)	(0.153)	(0.175)
$lnTAX$	-0.375***	-0.325	-0.727***	-0.94*	-0.108	0.049
	(0.115)	(0.447)	(0.170)	(0.542)	(0.173)	(0.369)
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes
Country-sector trends	Yes	Yes	Yes	Yes	Yes	Yes
No. of groups	154	143	154	143	154	143
Observations	3146	2714	3143	2717	3141	2736
R^2	0.571	0.502	0.507	0.374	0.546	0.500

Notes: Columns (1a), (2a), and (3a) show the results presented in Table 3 in (Bond and Xing, 2015, p. 23). Columns (1b), (2b), and (3b) show the estimated coefficients of their model under new dataset.

to the tax-adjusted user cost of capital. Her work contributes to the literature by proposing an empirical testing of the neoclassical model of investment behaviour on disaggregate capital asset data such as computing equipment, communications equipment, transport equipment, and other machinery and equipment. Her model is also tested on aggregate equipment that groups the four types of capital assets mentioned above and on total capital that combines aggregate equipment and building structures. She estimates an error correction model and concludes that, both for aggregate and disaggregate data, the tax-adjusted user cost of capital significantly influences capital accumulation.

In an effort to reproduce some results from this paper, I combine a sector-level panel dataset from the EU KLEMS database (2009 release) of 10 sectors of the manufacturing industry in 13 OECD countries over the period 1982-2007. This dataset differs from Fatica's (2018) in several aspects. First, in contrast to hers that combined 23 sectors that form the market economy, this one groups only 10 sectors in manufacturing. Second, the country list contains seven countries that are part of her dataset plus six others. Note that the data on France and Ireland that were used in Fatica (2018) are not available. Third, the sample period begins in 1982 in contrast to hers, which began in 1984. Again, the data on the net present value of capital allowances is calculated by multiplying the statutory corporate income tax rate by the replacement cost recovery of capital provided by the Tax Foundation.

Despite the differences in the datasets, as seen in Table 2.14, the results are qualitatively and quantitatively consistent with Fatica (2018). The estimates have correct sign, are in the same magnitude range, and are qualitatively similar. The long-run elasticities of capital with respect to the user cost of capital are similarly significant with same expected signs but larger in magnitude. The speed of adjustment estimates are almost identical.

2.8.2.3 Takeaway

Despite facing some challenges to find the exact net present value of depreciation allowances data used in Bond and Xing (2015) and Fatica (2018), my calculations with the help the data obtained from the Tax Foundation allow me to consistently reproduce results in these papers. I can confirm that my calculations are correct. Also, I constitute a dataset on the net present value of depreciation allowances of capital specifically for intangible capital, which had been ignored by the literature.

2.8.3 Error-correction specification

Assuming an autoregressive distributed lag model, ARDL(2,2), following Alogoskoufis and Smith (1991) and Hassler and Wolters (2006), the estimating equation for the log of the stock of capital can be written as follows

$$k_t^n = \alpha_0^n + \sum_{s=1}^{2} \alpha_s^n k_{t-s}^n + \sum_{s=0}^{2} \beta_s^n y_{t-s} + \sum_{s=0}^{2} \gamma_s^n \vartheta_{t-s}^n + u_t^n. \qquad [2.15]$$

We want the dynamic equation [2.15] to be consistent with the long-term equilibrium relationship expressed in [2.13] (Section 5.2, p27). That is, we set $k_t^n = k_{t-1}^n = k_{t-2}^n = k^n$, $y_t = y_{t-1} = y_{t-2} = y$, and $\vartheta_t^n = \vartheta_{t-1}^n = \vartheta_{t-2}^n = \vartheta^n$. As a result, we have

$$k^n = \frac{\alpha_0^n}{1-\alpha_1^n-\alpha_2^n} + \frac{\beta_0^n+\beta_1^n+\beta_2^n}{1-\alpha_1^n-\alpha_2^n} y + \frac{\gamma_0^n+\gamma_1^n+\gamma_2^n}{1-\alpha_1^n-\alpha_2^n} \vartheta^n. \qquad [2.16]$$

Equation [2.16] is compared to [2.13] to derive :

Table 2.14: Error correction model for total capital and aggregate equipment: Table 1 in Fatica(2018).

Dependent variable:	(1a)	(1b)	(2a)	(2b)
Δk_t	Total capital		Aggregate equipment	
Δy_t	0.045***	0.057***	0.070***	0.106***
	(0.008)	(0.010)	(0.013)	(0.016)
Δy_{t-1}	0.043***	0.055***	0.057***	0.085***
	(0.009)	(0.009)	(0.018)	(0.012)
Δuc	-0.036***	-0.023**	-0.050***	-0.098***
	(0.006)	(0.010)	(0.009)	(0.017)
Δuc_{t-1}	-0.027***	-0.060***	-0.052***	-0.093***
	(0.007)	(0.007)	(0.009)	(0.013)
Δk_{t-1}	0.501***	0.522***	0.438***	0.398***
	(0.035)	(0.044)	(0.035)	(0.071)
Speed of adjustment	-0.029***	-0.021***	-0.042***	-0.043***
	(0.005)	(0.005)	(0.006)	(0.008)
Long-run elasticity	-0.729***	-0.971***	-0.863***	-1.099***
	(0.101)	(0.244)	(0.083)	(0.165)
Observations	5060	2,714	5060	2,717
Country-sector pairs	230	143	230	143

Notes: Columns (1a) and (2a) show the results presented in Table 1 in (Fatica, 2018, p. 23). Columns (1b) and (2b) show the estimated coefficients of their model under new dataset.

$$\frac{\alpha_0^n}{1-\alpha_1^n-\alpha_2^n} = z^n,$$

$$\frac{\beta_0^n+\beta_1^n+\beta_2^n}{1-\alpha_1^n-\alpha_2^n} = 1,$$

$$\frac{\gamma_0^n+\gamma_1^n+\gamma_2^n}{1-\alpha_1^n-\alpha_2^n} = -1.$$

Let $\beta_0^n+\beta_1^n+\beta_2^n = 1-\alpha_1^n-\alpha_2^n = \lambda_a^n$ and $\gamma_0^n+\gamma_1^n+\gamma_2^n = -(1-\alpha_1^n-\alpha_2^n) = \lambda_b^n$, equation [2.15] can be rewritten as

$$\begin{aligned} k_t^n = \alpha_0^n + \alpha_1^n k_{t-1}^n + (1-\alpha_1^n-\lambda_a^n)k_{t-2}^n + \beta_0^n y_t + \beta_1^n y_{t-1} + (\lambda_a^n - \beta_0^n - \beta_1^n) y_{t-2} \\ + \gamma_0^n \vartheta_t^n + \gamma_1^n \vartheta_{t-1}^n + (\lambda_b^n - \gamma_0^n - \gamma_1^n)\vartheta_{t-2}^n + u_t^n. \end{aligned} \quad [2.17]$$

After few rearrangements, we have

$$\begin{aligned} \Delta k_t^n = \alpha_0^n + \beta_0^n \Delta y_t + (\beta_0^n+\beta_1^n)\Delta y_{t-1} + \gamma_0^n \Delta\vartheta_t^n + (\gamma_0^n+\gamma_1^n)\Delta\vartheta_{t-1}^n \\ + (\alpha_1^n - 1)\Delta k_{t-1}^n - \lambda_a^n \left[(k_{t-2}^n - y_{t-2}) - \frac{\lambda_b^n}{\lambda_a^n}\vartheta_{t-2}^n\right] + u_t^n. \end{aligned} \quad [2.18]$$

Equation [2.18] corresponds to equation [2.14] in Section 5.2 by setting:

$$\begin{aligned} \alpha^n &= \alpha_0^n \\ \pi_0^n &= \alpha_1^n - 1 \\ \pi_1^n &= \beta_0^n \\ \pi_2^n &= \beta_0^n + \beta_1^n \\ \pi_3^n &= \gamma_0^n \\ \pi_4^n &= \gamma_0^n + \gamma_1^n \\ \varphi^n &= -\lambda_a^n \\ \theta^n &= -\frac{\lambda_b^n}{\lambda_a^n}. \end{aligned}$$

Chapter 3

Heterogeneity within the Relationship between Capital and the User Cost of Capital

Abstract

This paper investigates heterogeneity by type of capital within the relationship between capital and its user cost, for five physical and two intangible capital assets. The primary data source for an annual sector-level panel dataset of 12 sectors in 12 OECD countries over the period 1995-2015 is the EU KLEMS database. In the short-run dynamics, both dynamic fixed-effects and GMM results seem to agree on the role of changes in the user cost of capital on the evolution of the capital stock. Overall, dynamic fixed-effects estimation seems to be more in line with the theoretical conclusions on investment behaviour and empirical results for physical capital already established in the literature.

3.1 Introduction

Empirical studies of the relationship between business investment and the tax-adjusted user cost of capital agree on a negative relationship between them.[1] Using a balanced panel dataset of thousands of plants in the U.S. manufacturing sector covering the period 1972-1988, Caballero et al. (1995) found that the elasticity of capital with respect to the user cost of capital may vary from -0.01 for transportation to -2.0 for textiles. With a firm-level unbalanced panel dataset for the period 1953-1998 taken from the Compustat database, Cummins et al. (1994) and Cummins et al. (1995) found that the elasticity of capital with respect to its user cost varies from -0.60 for aggregate capital to -0.75 for equipment. Using quarterly aggregate Canadian data covering the period 1962-1999 and estimating a dynamic OLS regression model, Schaller (2006) found that the user cost elasticity of equipment capital varies between -1.42 and -1.64.

In empirical studies of the relationship between capital and the user cost of capital, econometric specifications in autoregressive distributed lag or error-correction models are based on the existence of a long-term cointegrating relationship between capital, output and the user cost of capital (Bond and Xing, 2015; Fatica, 2018). Several studies have avoided the need to account for dynamic small-sample bias by using a dataset with a sufficiently large time dimension (e.g., more than 20 observations per cross-sectional unit). Roodman (2009a) argued that if the time dimension of a panel dataset is large, then the dynamic panel bias becomes insignificant and the fixed-effects estimator has good properties. Indeed, with the help of data from the EU KLEMS database on 11 sectors in 14 OECD countries for the period 1982-2007, Bond and Xing (2015) applied an autoregressive distributed lag model and a model in error correction form to argue that tax incentives matter for the evolution of sector-level capital stocks. They found that the long-run elasticities of capital with respect to the tax component of the user cost of capital are around -0.4 for total capital and around -0.7 for equipment.

Later, using EU KLEMS investment data on 23 sectors in 10 OECD countries covering the period 1984-2007, Fatica (2018) proposed a detailed analysis of the relationship between capital accumulation and its user cost. This relationship is investigated by applying the dynamic fixed effects (DFE), mean group (MG), and pooled mean group (PMG) estimation methods to a neoclassical model of investment in error correction form for computing equipment, transport equipment, other machinery and equipment, communications equipment, and structures. She found that capital accumulation is strongly affected by changes in the user cost. Her DFE estimates of the long-run elasticities of capital with respect to the user cost of capital vary from -0.43 for structures to -1.48 for transport equipment.

This study investigates the responses of different types of physical and intangible capital to changes in the user cost of capital. It fills a gap in two respects. First, it tests an investment model on a dataset that straddles a long and short panel. Second, it applies a neoclassical investment model to two intangible capital assets that have so far been ignored in the literature on business investment behaviour. It follows the lead of Fatica (2018), but also examines whether her results hold using the new edition of the EU KLEMS database (July 2018 version). This edition is in congruence with the new European System of National Accounts (ESA 2010), which replaces the 1995 system on which the dataset used by Fatica (2018) was built. This new version includes data for the period 1995-2015. Under ESA 2010, the definition of gross fixed capital formation has undergone significant changes, of which those concerning intangible capital assets are worth mentioning. Research and development expenditure is now capitalised. Computer software is

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[1] In this respect it is worth citing Caballero et al. (1995), Cummins et al. (1994), Cummins et al. (1995), Hassett and Hubbard (2002), Schaller (2006), Bond and Xing (2015), and Fatica (2018).

combined with databases to create the asset type computer software and databases. Finally, mineral exploration and artistic originals form the subgroup other intellectual property products (Jäger, 2017; van Ark and Jäger, 2017).

The model in error-correction form that must be estimated is a dynamic panel data model. However, least squares estimation methods applied to panel data may suffer from small sample bias when the time dimension of the dataset is less than 20. Using a panel dataset with a time length of 17 years, Caballero et al. (1995) recognised this phenomenon and took steps to reduce these biases by adding lagged differenced variables to the right-hand side of his estimating equation. Faced with a 12-year estimation period (1981-1992) and using investment data from the Compustat database, Cummins and Dey (1998) implemented the generalized method of moments (GMM) estimator to study the heterogeneity of investment responses to changes in the user cost of capital.

The dataset used in our study comprises between 11 and 19 observations per cross-sectional unit. This characterisation of our dataset allows us to deepen our understanding of the relationship between capital and the user cost of capital by estimating an investment equation in error correction form applying both the DFE and GMM estimation methods. It is clear that GMM estimation can be an appropriate solution. However, since the average number of observations per country-sector pair is 17.62, the dataset straddles a long and a short panel, hence DFE estimation cannot be ruled out. Therefore, both methods are applied to estimate an equation of investment for five types of physical capital assets: computing equipment (IT), communications equipment (CT), transport equipment (TraEq), other machinery and equipment (OMach), and non-residential investment (OCon); and two types of intangible capital assets: software and databases (SoftD) and research and development (R&D).

The results show that using a panel dataset with a large or nearly large time dimension, the DFE estimation of the relationship between capital and the user cost of capital provides estimates that most closely match the theoretical and empirical findings of the literature on business investment for all types of capital except for R&D, although in terms of the short-run dynamics the DFE and GMM estimation methods give rise to qualitatively almost equivalent results. When the user cost of capital is decomposed into its price and non-price components, DFE estimation shows that the price component of the user cost of capital (relative prices of capital goods) influences the accumulation of capital, except for R&D. Changes in the capital stock are responsive to changes in the non-price component of the user cost of capital only for OMach. If the model is estimated using the GMM estimator, then changes in the capital stock are impacted by changes in relative prices for IT and CT. However, changes in the non-price component of the user cost of capital influence changes in the stock of capital for IT and TraEq. It appears that the relationship between capital and the user cost of capital is consistent for IT capital type regardless of the estimation method applied.

The rest of the paper is organised as follows. In section 2 the empirical strategy is outlined. The data are discussed in section 3. Diagnostic tests and empirical estimates are presented in section 4. Section 5 deals with a sensitivity analysis. In section 6, I conclude.

3.2 Empirical strategy

This empirical study is based on the neoclassical theory of firm investment behaviour. According to this theory, if the production function is of the Cobb-Douglas type, combines two factors of production (labour and capital) and exhibits constant returns to scale, then the economy's desired capital stock is the level at which the marginal product of capital services equals their rental price (Jorgenson, 1963, 1967, 1971; Bernanke et al., 1988; Bond and Xing, 2015). Thus, if we let K_t^*

denote the desired stock of capital, Y_t the level of output, c_t the user cost of capital, and ξ the elasticity of output with respect to capital, under this theory, at any time t we have $K_t^* = \xi \cdot (Y_t/c_t)$.[2]

Assuming that new investment is financed by retained earnings,[3] following Devereux and Griffith (1999) and Devereux and Griffith (2003), the user cost of capital is

$$c_t = \frac{P_t}{p_t}\left[\frac{(1-A_t)(r_t+\delta)}{(1-\tau_t)} - \delta\right], \tag{3.1}$$

where P_t/p_t is the price of capital investment goods relative to the price of output, A_t is the net present value of the current and future tax depreciation allowances associated with one dollar of investment in capital in year t, r_t is the real discount rate, δ is the depreciation rate, and τ_t is the corporate income tax rate. The expressions P_t/p_t and $[(1-A_t)(r_t+\delta)/(1-\tau_t)-\delta]$ are called the price component (relative prices) and non-price component of the user cost of capital, following Fatica (2018).

For every country-sector pair (i,j) at time t, the condition for the desired level of capital stock, after a logarithmic transformation, can be written as

$$k_{ij,t}^* = z_{ij} + y_{ij,t} - \vartheta_{ij,t}, \tag{3.2}$$

where $k_{ij,t}^*$, z_{ij}, $y_{ij,t}$, and $\vartheta_{ij,t}$ represent the logs of the desired level of the capital stock, the elasticity of output with respect to capital, the level of output, and the user cost of capital. Caballero et al. (1995) demonstrate that, in any period, the observed level of the stock of capital deviates from its desired level such that $k_{ij,t} = k_{ij,t}^* + e_{ij,t}$, where $e_{ij,t}$ represents the deviations between the desired and actual capital at the sector level.

If we want to transform equation [3.2] into an autoregressive econometric model, the choice of the optimal number of lags is of great importance. Indeed, in Fatica (2018), an equation similar to [3.2] is converted into an error correction model with the lag length fixed at 2. In an effort to optimally determine the number of lags, the implementation of Westerlund's (2007) four error-correction based cointegration tests selects a lag length of 1.67. Consequently, the number of lags is fixed at 2.

Assuming an autoregressive distributed lag model of length 2, ARDL(2,2), as in Fatica (2018) the equation to be estimated can be written as follows

$$k_{ij,t} = \sum_{s=1}^{2}\alpha_s k_{ij,t-s} + \sum_{s=0}^{2}\beta_s y_{ij,t-s} + \sum_{s=0}^{2}\gamma_s \vartheta_{ij,t-s} + \lambda_{ij} + \omega_t + \epsilon_{ij,t}, \tag{3.3}$$

where λ_{ij} are country-sector pair-specific fixed effects, ω_t year-specific fixed effects, and $\epsilon_{ij,t}$ the disturbances.[4] Equation [3.3] allows the elasticity of output with respect to capital, the z_{ij} term in [3.2], to be absorbed by the country-sector pair-specific fixed effects λ_{ij}. The parameters to be estimated are α_s for $s = 1, 2$, and β_s and γ_s for $s = 0, 1, 2$. Jeanniton (2022) shows in an appendix that equation [3.3] can be written in error-correction form as follows:

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[2] If a more general production function such as the constant elasticity of substitution (CES) production function had been adopted, the desired capital stock condition would also incorporate the capital-labour substitution elasticity. In this empirical exercise the Cobb-Douglas production function is sufficient and corresponds well to the original model of the determinants of investment behaviour put forward by Jorgenson (1963).

[3] This assumption is a reasonable approximation since, according to Fazzari et al. (1988), retained earnings represent 71.1% of total financing sources.

[4] The year-specific fixed effects will catch shocks such as the financial crisis in 2008.

$$
\begin{aligned}
\Delta k_{ij,t} = {} & \pi_0 \Delta k_{ij,t-1} + \pi_1 \Delta y_{ij,t} + \pi_2 \Delta y_{ij,t-1} \\
& + \pi_3 \Delta \vartheta_{ij,t} + \pi_4 \Delta \vartheta_{ij,t-1} \\
& + \varphi[(k_{ij,t-2} - y_{ij,t-2}) + \theta \vartheta_{ij,t-2}] + \lambda_{ij} + \omega_t + \epsilon_{ij,t},
\end{aligned} \qquad [3.4]
$$

where $\pi_0 = \alpha_1 - 1$, $\pi_1 = \beta_0$, $\pi_2 = \beta_0 + \beta_1$, $\pi_3 = \gamma_0$, and $\pi_4 = \gamma_0 + \gamma_1$. The speed of adjustment is $\varphi = -1 + \alpha_1 + \alpha_2$. The long-run elasticity of capital with respect to the user cost of capital is $\theta = (\gamma_0 + \gamma_1 + \gamma_2)/(\beta_0 + \beta_1 + \beta_2)$. Since the estimated coefficients of the error correction model are derived from the estimated coefficients of the ARDL(2,2) model, the restriction to 1 of the coefficient of $k_{ij,t-2} - y_{ij,t-2}$ in the long-run equilibrium relationship (equation [3.4]) will be taken into account in the estimation of the autoregressive distributed lag model.

An important challenge arises when equation [3.3] has to be estimated: the potential problem of dynamic panel bias due to too few time periods in the dataset. In the dataset used in this study, the time dimension per cross-sectional unit varies between 11 and 19. Indeed, according to Nerlove (1967), Nickell (1981), and Baltagi (2013), the least squares, the random effects, and the fixed effects estimators are biased and/or inconsistent in this case. The problem of finding good estimators in the case of a dynamic panel-data model when there are few time periods (small T) and a large number of cross-sections (large N) is resolved by using the generalized method of moments (GMM) approach designed by Arellano and Bond (1991). According to Roodman (2009a), the GMM estimator is consistent and can be made feasibly efficient by using the two-step GMM estimator.[5] In the empirical literature the GMM estimator is used for dynamic panel data model estimation when the number of cross-sectional units is larger than 20 and the number of time periods varies between 8 and 19 (Wen et al., 2020).

To examine potential heterogeneity due to asset specificities within the relationship between capital and the user cost of capital, equation [3.3] will be estimated separately for five physical capital assets: computing equipment (IT), communications equipment (CT), transport equipment (TraEq), other machinery and equipment (OMach), and non-residential investment or structures (OCon); and two intangible capital assets: software and databases (SoftD) and research and development (R&D). The estimated coefficients of the error-correction model (equation [3.4]) will be computed as linear or non-linear combinations of the coefficients of the autoregressive distributed lag model.

If the time dimension of the dataset was greater than 20, the dynamic fixed effects (DFE) regression would be the method of choice, since there would be no or insignificant potential dynamic panel bias (Roodman, 2009a). The DFE method would provide unbiased and consistent estimators. The GMM estimation method would not even be considered. Since the dataset straddles a long and short panel, it is important that we let the estimators speak for themselves. Therefore, we will present the results from both methods. Also, the results of the DFE model for physical capital assets, i.e., IT, CT, TraEq, OMach, and OCon can be compared to the results obtained by Fatica (2018). The results for intangible capital assets (SoftD and R&D) will be brand new, since these assets have not yet been studied in an investment model in the literature.

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[5] Researchers tend to prefer the two-step system GMM (Heid et al., 2012; Hou and Chen, 2013; Ulaşan, 2015; Habimana, 2017). Depending on the setting, the full set of instruments can be used or the instrument set can be collapsed. The term "collapsed instruments set" refers to transforming the matrix of instrument variables into a column vector of instruments. The option of collapsing the instruments set can be considered a robustness check according to Roodman (2009a), who wrote the code to implement the GMM estimator in Stata.

3.3 Data description

The data for this empirical investigation are drawn from the EU KLEMS database.[6] The dataset covers twelve sectors in twelve countries, and covers the time period 1995-2015.[7] It also incorporates information on corporate taxation compiled by the Oxford University Centre for Business Taxation,[8] and replacement cost values of capital calculated by the Tax Foundation.[9] The dataset used contains 2,414 observations.

3.3.1 Capital-output ratio

The capital-output ratio for each type of asset is obtained by dividing the value of the real stock of capital by the amount of real value-added, both in millions of US dollars measured in purchasing power parity.[10] As shown in Table 3.1, the average capital-output ratios, over all sectors during the sample period 1995-2015, are 0.017 for computing equipment (IT), 0.020 for communications equipment (CT), 0.057 for transport equipment (TraEq), 0.791 for other machinery and equipment (OMach), and 1.035 for non-residential investment or structures (OCon). For intangible capital assets, these averages are 0.043 for software and databases (SoftD) and 0.284 for research and development (R&D).

Figure 3.1 shows the evolution of the capital-output ratios for physical and intangible capital assets respectively in the left and right panels. The highest ratios of capital to output in the form of computing equipment and communications equipment (respectively 2.094 and 0.751) are observed in the Czech Republic in the agriculture, forestry, and fishing sector in the year 2014. However, the average capital-output ratio in this country-sector pair over all years is 0.254 for IT and 0.088 for CT. Furthermore, the highest ratio of capital to output in the form of transport equipment (0.744) is observed in Austria in the agriculture, forestry, and fishing sector for the year 1997. However, the average capital-output ratio in this country-sector pair in TraEq over all years is 0.589. The largest ratio of capital to output in the form of other machinery and equipment (6.332) is observed in the Netherlands in the rubber and plastics products, and other non-metallic mineral products sector in the year 2003. This sector has in general high capital to output ratios in OMach, as the average over all years in this country-sector pair for this type of capital is 5.842. Lastly, the highest capital-output ratio in the form of non-residential investment or structures (9.302) is observed in Denmark in the agriculture, forestry, and fishing sector in the year 2009. Over all years, the average capital-output ratio in this country-sector pair for OCon is 7.631.

Turning to intangible capital assets, the average ratio of capital to output across all sectors and over all years in research and development is more than six times higher than for software and

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[6] EU KLEMS is a research project originally financed by the European Commission. It aims to produce industry level data on output, capital, employment, and other intermediate inputs. EU KLEMS stands for EU level analysis of capital (K), labour (L), energy (E), materials (M) and service (S) inputs.

[7] The countries are Austria, the Czech Republic, Denmark, Finland, France, Germany, Italy, the Netherlands, Spain, Sweden, the United Kingdom, and the United States.

[8] The Oxford University Centre for Business Taxation is an independent research centre which aims to promote effective policies for the taxation of corporations.

[9] The Tax Foundation is a leading independent tax policy non-profit located in the DC area in the United States. Established in 1937, it aims to promote smarter tax policy at the federal, state, and global levels.

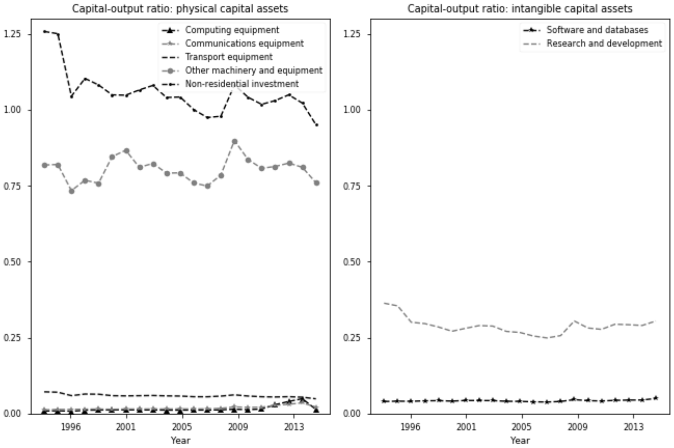
[10] Purchasing power parities (PPP) are the rates of currency conversion that try to equalise the purchasing power of different currencies, by eliminating the differences in price levels between countries. The PPP for the base year 2010 are used to convert the variables expressed in national currency to US dollars. The PPP data are taken from OECD (2020c).

Table 3.1: Descriptive Statistics

Variables	Mean	Std.	Min	Max
Capital-output ratio for IT	0.017	0.066	0.000	2.094
Capital-output ratio for CT	0.020	0.035	0.000	0.751
Capital-output ratio for TraEq	0.057	0.081	0.002	0.744
Capital-output ratio for OMach	0.791	0.570	0.130	6.332
Capital-output ratio for OCon	1.035	1.312	0.101	9.302
Capital-output ratio for SoftD	0.043	0.080	0.001	1.244
Capital-output ratio for R&D	0.284	0.437	0.000	5.104
User cost of capital for IT	0.126	0.133	0.000	1.629
User cost of capital for CT	0.072	0.040	0.000	0.520
User cost of capital for TraEq	0.067	0.028	0.014	0.546
User cost of capital for OMach	0.062	0.023	0.011	0.418
User cost of capital for OCon	0.065	0.021	0.011	0.366
User cost of capital for SoftD	0.086	0.043	0.018	0.622
User cost of capital for R&D	0.070	0.028	0.014	0.382
Relative price of IT	1.633	1.552	0.003	18.875
Relative price of CT	1.157	0.561	0.003	7.425
Relative price of TraEq	1.027	0.349	0.220	6.722
Relative price of OMach	1.004	0.280	0.222	5.301
Relative price of OCon	0.945	0.234	0.158	4.212
Relative price of SD	1.024	0.333	0.235	5.719
Relative price of R&D	0.966	0.263	0.209	4.608
Non-price component of IT	0.075	0.013	0.021	0.115
Non-price component of CT	0.061	0.011	0.015	0.089
Non-price component of TraEq	0.065	0.011	0.016	0.099
Non-price component of OMach	0.061	0.011	0.014	0.090
Non-price component of OCon	0.069	0.014	0.015	0.119
Non-price component of SoftD	0.083	0.024	0.024	0.182
Non-price component of R&D	0.073	0.019	0.019	0.147

Notes: Physical capital assets are computing equipment (IT), communications equipment (CT), transport equipment (TraEq), other machinery and equipment (OMach), and non-residential investment or structures (OCon). Intangible capital assets are software and databases (SoftD) and research and development (R&D).

Figure 3.1: Capital-output ratios, annual average across all sectors, 1995-2015



Notes: This figure provides, on the left, the evolution of the ratios of the stock of capital to output for five types of physical capital assets such as computing equipment, communications equipment, transport equipment, other machinery and equipment, and non-residential investment or structures. On the right are shown the ratios of capital to output for software and databases and research and development. For each sector j in country i, the capital-output ratio is obtained by dividing the real stock of capital by the amount of real value-added, both measured in millions of US dollars in purchasing power parity.

databases. The highest ratio of capital to output for software and databases (1.244) is observed in France in the electrical and optical equipment sector in the year 1998. Over all years, the average SoftD capital-output ratio in this country-sector pair is 0.823. For research and development capital assets, the highest ratio of capital to output (5.104) is observed in Sweden in the electrical and optical equipment sector in the year 1997. This ratio decreased to 1.930 in 2014. Although the stock of capital in R&D has almost doubled over the period, the value-added in this country-sector pair has almost quintupled, resulting in declining capital to output ratios.

3.3.2 User cost of capital

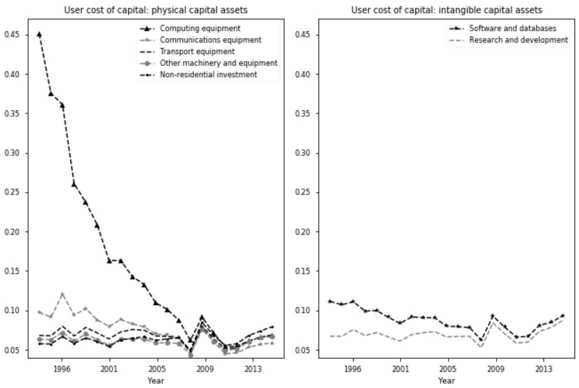
The user cost of capital expression (equation [3.1]) is calculated following Devereux and Griffith (1999) and Devereux and Griffith (2003). In this formula, the discount rate r_t is calculated as a weighted combination of the cost of debt and the cost of equity. The nominal cost of debt is approximated by the interest rate on government bonds maturing in ten years taken from the OECD database (OECD, 2020b). The interest rate on government bonds varies by country and by year. The nominal cost of equity and the weight of debt and equity are produced by Professor Aswath Damodaran of the Stern School of Business at New York University (Damodaran, 2020). Using the CPI inflation rate for each country taken from the OECD database (OECD, 2020a), the resulting real discount rate varies across countries and years but remains fixed for country-sector pairs within each country for a specific year. The average real discount rate, across all sectors and over the entire sample period 1995-2015, is 5.05 percent.

The rates of depreciation (δ) are fixed for each asset type. The data on depreciation rates are taken from the EU KLEMS database, and amount to 0.315 for computing equipment (IT) and software and databases (SoftD), 0.115 for communications equipment (CT), 0.200 for research and development (R&D). They vary between 0.166 and 0.193 for transport equipment (TraEq), between 0.104 and 0.129 for other machinery and equipment (OMach), and 0.024 and 0.033 for non-residential investment or structures (OCon). The net present value of depreciation allowances (A_t^n) is approximated by multiplying the corporate income tax rate (τ_t) by the replacement cost recovery of capital. The corporate income tax data are taken from the CBT tax database (Devereux and Bilicka, 2017). The Tax Foundation produces replacement cost recovery values of capital for machines, buildings, and intangibles (Tax Foundation, 2019). The value for machines is used to calculate the net present value of depreciation allowances for computing equipment, communications equipment, transport equipment, and other machinery and equipment. The value for buildings is used to calculate the net present value of depreciation allowances for non-residential investment or structures. Finally, the value for intangibles is used to determine the net present value of depreciation allowances for software and databases and research and development.

As shown in Table 3.1, the average values of the user cost of physical capital assets, across all sectors over the sample period 1995-2015, are 0.126 for computing equipment (IT), 0.072 for communications equipment (CT), 0.067 for transport equipment (TraEq), 0.062 for other machinery and equipment (OMach), and 0.065 for non-residential investment (OCon). For intangible capital assets, the values of the user cost of capital are 0.086 for software and databases (SoftD) and 0.070 for research and development (R&D).

Figure 3.2 shows a convergent pattern of the values of the user cost of capital at both the physical and the intangible asset levels. This tendency towards convergence of the values of the user cost of capital is mainly explained by the convergence of relative prices (Figure 3.3). Indeed, the standard deviations of the relative prices of physical capital assets are 1.258 in 1997 and 0.130 in 2015. For intangible capital assets, these values are 0.553 in 1997 and 0.122 in 2015. The standard deviations of the non-price component of the user cost of the physical capital assets are 0.006 in 1997 and 0.012 in 2015. For intangible capital assets these values are 0.015 in 1997 and 0.032 in 2015. This tendency towards convergence of the user cost of capital at the level of physical capital assets as well as at the level of intangible capital assets is thus explained by the convergence of relative prices rather than of the non-price component of the user cost of capital.

Figure 3.2: User cost of capital: annual average across all sectors, 1995-2015



Notes: This figure provides, on the left, the evolution of the user cost values of capital for five types of physical capital assets such as computing equipment, communications equipment, transport equipment, other machinery and equipment, and non-residential investment or structures. On the right is shown the graph of the user cost values of capital for two types of intangible capital or intellectual property assets such as software and databases and research and development. The values of the user cost of capital are calculated following Devereux and Griffith (1999) and Devereux and Griffith (2003).

The relative prices of all capital goods are obtained by dividing the price index of each type of capital asset by the price index of gross real value-added. All price indices are 100.0 for the base year of 2010. Thus all relative prices are 1.0 for the year 2010. As shown in Table 3.1, the average relative prices, over all cross-sections and time periods, are 1.633 for computing equipment, 1.157 for communications equipment, 1.027 for transport equipment, 1.004 for other machinery and equipment, and 0.945 for non-residential investment or structures. The average relative prices of intangible capital assets, over all cross-sections and time periods, are 1.024 for software and databases and 0.966 for research and development. There is a clear pattern of declining relative prices for computing equipment, communications equipment, and software and databases (Figure 3.3). Strongly declining relative prices for computing and communication equipment (IT and CT) are also observed in Fatica (2018) over the period 1984-2007 for the whole market economy. The evolution of relative prices allows us to understand the pattern of the evolution of the user costs of capital and thus explains to a large extent the tendency of convergence of the user costs of capital.[11]

The non-price component (NPC) of the user cost of capital is the part of the formula for the user cost of capital proposed by Devereux and Griffith (1999) and Devereux and Griffith (2003) that does not involve the relative prices of capital goods:

$$NPC_t = \frac{(1 - A_t)(r_t + \delta)}{(1 - \tau_t)} - \delta \qquad [3.5]$$

The non-price component of the user cost of capital captures, among other things, the impact of the corporate income tax rate on the evolution of the user cost of capital. As shown in Table 3.1, the average values of the non-price component of the user cost of physical capital assets, over all cross-sections and time periods, are 0.075 for computing equipment, 0.061 for communications equipment, 0.065 for transport equipment, 0.061 for other machinery and equipment, and 0.069 for non-residential investment or structures. For intangible capital assets, the average values of the non-price component of the user cost of capital, over all cross-sections and time periods, are 0.083 for software and databases and 0.073 for research and development. The evolution of the average values of the non-price component of the user cost of capital is shown in Figure 3.4, in the left panel for physical capital and the right panel for intangible capital assets. The NPC are generally lower for physical than for intangible capital assets.

3.4 Testing and empirical results

This empirical analysis rests on the acceptance of the existence of a long-run equilibrium relationship between the levels of the stock of capital, output, and the user cost of capital, all in logarithmic transformation. Thus these three variables must be cointegrated. Unit root and cointegration tests are done to verify that this long-run equilibrium relationship exists. In addition, according to Hoyos and Sarafidis (2006), testing for cross-sectional dependence is an important step in fitting panel-data models. The presence of cross-sectional dependence is then tested. Following the diagnostic tests, this section continues with the estimation of the parameters.

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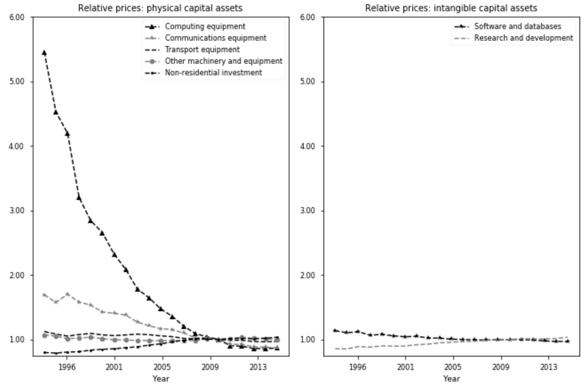
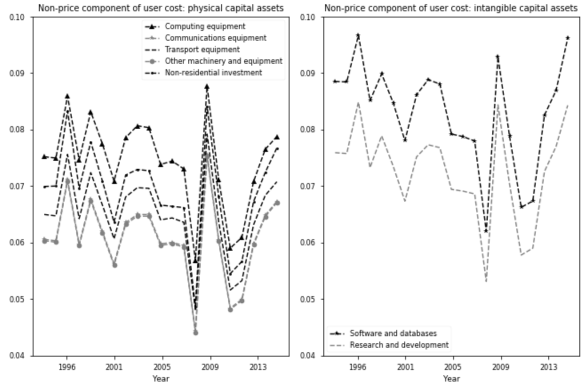
[11] The declining relative prices of capital goods observed in the dataset do not mean that these assets have been affected by negative inflation. This phenomenon is rather a consequence of the fact that all price indices for both value added and capital goods are equal to 100 in the same year, which is the base year of 2010. This is a drawback that cannot be circumvented since the prices of value added and capital goods are not available. These data are the best options that currently exist.

Figure 3.3: Relative prices: annual average across all sectors, 1995-2015



Notes: This figure provides a graphical illustration of the evolution of the price index of capital relative to the price index of real value-added. On the left are the relative prices of computing equipment, communications equipment, transport equipment, other machinery and equipment, and non-residential investment or structures. On the right are the relative price of software and databases and the relative price of research and development. All price indices are 100.0 for the base year of 2010.

Figure 3.4: Non-price component of user cost of capital: annual average across all sectors, 1995-2015



Notes: This figure shows, on the left, the evolution of the non-price component of the user cost of capital for computing equipment, communications equipment, transport equipment, other machinery and equipment, and non-residential investment or structures. On the right, it provides the evolution of the non-price component of the user cost of capital for software and databases and for research and development. The non-price component of the user cost of capital is the part that does not involve relative prices in the user cost of capital formula proposed by Devereux and Griffith (1999) and Devereux and Griffith (2003).

3.4.1 Diagnostic tests

The diagnostic tests start with a cross-sectional dependence test. If the number of cross-sectional units (N) is small relative to the time series dimension (T), the Lagrange multiplier (LM) test or the bias-adjusted LM test can be used to detect cross section dependence of the errors in a panel dataset (Breusch and Pagan, 1980; Pesaran et al., 2008). If both N and T are large, Pesaran's cross-sectional dependence (CD) test is a reliable alternative (Pesaran, 2004). For the case of small

T, Sarafidis et al. (2009) propose Sargan's difference tests for heterogeneous error cross section dependence to detect cross sectional dependence of the errors after estimating a linear dynamic panel data model with covariates using the GMM estimator.

The latter procedure tests the null hypothesis of homogeneous error cross-sectional dependence against the alternative of heterogeneous error cross-sectional dependence. Homogeneous cross-sectional dependence is cross-sectional dependence that can be eliminated by including time dummies or by cross-sectionally demeaning the data. Heterogeneous cross-sectional dependence is that which remains even after including time dummies or cross-sectionally demeaning the data. This procedure uses two sets of moment conditions: moment conditions (I) consider only the lags of the dependent variable as instruments, and moment conditions (II) consider as instruments the lags of covariates (Sarafidis and Robertson, 2009; Sarafidis et al., 2009). Under the null of homogeneous cross-sectional dependence, both moment conditions hold. However, under the alternative only moment conditions (II) hold. In Table 3.2, under the null (i.e., when the full set of moment conditions is used), S_{SYS2} is the test statistic of over-identifying restrictions proposed by Sargan (1958). Similarly, under the alternative (i.e., when only moment conditions II are used), S_{SYSX2} is Sargan's (1958) test statistic of over-identifying restrictions.

Table 3.2: Error cross section dependence test following Sarafidis et al. (2009)

	S_{SYS2}	S_{SYSX2}	D_{SYS2}
Computing equipment (IT)	1618.0	1373.5	244.5
Communication equipment (CT)	1489.2	1045.2	444.0
Transport equipment (TraEq)	1175.7	760.9	414.8
Other machinery and equipment (OMach)	1064.7	713.0	351.7
Non-residential investment (OCon)	1471.2	326.4	1144.8
Software and databases (SoftD)	1258.6	960.4	298.2
Research and development (R&D)	1165.0	534.6	630.5

According to Sarafidis et al. (2009), $D_{SYS2} = S_{SYS2} - S_{SYSX2}$ follows a chi-squared distribution with $df = T(T-1)/2 + (T-1)$ degrees of freedom. For $df = 189$, the 5% critical value is $\chi^2 = 222$.[12] Thus at the 5% level of significance, the null hypothesis of homogeneous error cross-sectional dependence is rejected for all the investment equations. Furthermore, according to Sarafidis et al. (2009), the system GMM estimator can be a reliable alternative under heterogeneous error cross-sectional dependence. As a result, the investment equations (equation 3.3 for each type of assets) will be estimated using the two-step GMM estimator.

The existence of a long-run equilibrium relationship between capital, output, and the user cost of capital presupposes that these three variables are cointegrated. Thus, they must have unit roots. Therefore, unit root and cointegration tests are carried out before carrying out an in-depth analysis of this long-run relationship. The standard unit root test for non-stationary time series (the augmented Dickey-Fuller test) is inappropriate when panels (here country-sector pairs) are cross-sectionally dependent. Pesaran (2007) proposes a cross-sectionally augmented Dickey-Fuller test (CADF) which is suitable for detecting unit roots when the cross-sectional units are dependent. The test evaluates the null hypothesis that all series are non-stationary against the alternative of stationary time series. Here, the CADF test is carried out for the logs of the stocks of capital in form of

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[12] The critical value of the chi-squared distribution for 189 degrees of freedom was retrieved from the online chi-squared calculator https://www.socscistatistics.com /tests/criticalvalues/.

computing equipment (IT), communications equipment (CT), transport equipment (TraEq), other machinery and equipment (OMach), non-residential investment or structures (OCon), software and databases (SoftD), and research and development (R&D); for the logs of output; and the logs of the user cost of capital. After several modelling attempts, the Akaike and Schwarz's Bayesian information criteria suggest that the lag lengths can be fixed between 1 and 3, depending on the length of each panel. The test is performed with both a constant and a constant and trend included. The variables are found to have unit roots (see Tables 3.12 to 3.14 in the appendix).

Next, Pedroni (1999) and Pedroni (2004) propose seven test statistics to test the null hypothesis of no cointegration in non-stationary panel-data series.[13] The seven test statistics follow a standard normal distribution when both the time and the cross sectional dimensions are large, and account for heterogeneity between country-sector pairs. The test accounts for error cross section dependence by time-demeaning the data for each individual variable. This test is based on residuals, imposes common factor restrictions, and offers two categories of statistics: the within-dimension statistics (panel cointegration statistics) and between-dimension statistics (group cointegration statistics). Pedroni (2004) considers that, when the time dimension of the time series is less than one hundred, one of the seven tested statistics (the ADF test) has the best power.

Westerlund (2007) also developed four error-correction-based tests to test the null hypothesis of no cointegration against the alternatives of cointegration as a whole (panel test) or cointegration for at least one cross-sectional unit (group-mean test). The tests can account for unit-specific short-run dynamics, unit-specific trend and slope parameters, and cross-sectional dependence (Westerlund, 2007; Westerlund and Edgerton, 2007). Contrary to Pedroni's (2004) test, Westerlund's (2007) does not impose common factor restrictions. In that sense Westerlund's (2007) test is more general, since the risk of imposing invalid common factor restrictions is non-existent.

Table 3.3: Cointegration tests

	Pedroni's ADF test		Westerlund's tests			
Equation for	Panel	Group	G_τ	G_α	P_τ	P_α
IT	7.889	7.677	0.005	0.000	0.000	0.000
CT	10.100	8.762	0.000	0.020	0.330	0.455
TraEq	10.850	10.330	0.040	0.280	0.025	0.085
Omach	8.733	10.100	0.005	0.075	0.020	0.030
Ocon	9.406	9.406	0.805	0.975	0.385	0.610
SoftD	8.331	8.128	0.000	0.000	0.000	0.000
R&D	11.760	14.410	0.060	0.420	0.260	0.400

Table 3.3 (columns 1 and 2) presents Pedroni's (1999, 2004) ADF test statistics for the existence of a long-run relationship between the logarithms of capital, output, and the user cost of capital. With a standard normal critical value of 2.58 at the 1% level, since all values in columns 1 and 2 are strictly greater than that number, Pedroni's (1999, 2004) tests strongly reject the null hypothesis of no cointegrating relationship between the logarithms of capital, output, and the user

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[13] Neal (2014) creates the code in Stata to implement Pedroni's seven test statistics to detect the existence of a cointegrating relationship between non-stationary variables.

[13] Persyn and Westerlund (2008) implement the Stata commands to carry out the four error-correction based tests by Westerlund (2007).

cost of capital in computing equipment (IT), communication equipment (CT), transport equipment (TraEp), other machinery and equipment (OMach), non-residential investment or structures (OCon), software and databases (SoftD), and research and development (R&D). Columns 3 to 6 of Table 3.3 show Westerlund's (2007) four error-correction-based test statistics for cointegration. Since the values shown in columns 3 to 6 are p-values, we fail to reject the null hypothesis of no cointegration at the 5% or 10% levels whenever a p-value is greater than 5% or 10%. Thus, at the 5% level of significance, Westerlund's (2007) cointegration panel test (P_τ) confirms the existence of a cointegrating relationship between the logarithms of capital, output, and the user cost of capital in IT, CT, OMach, and SoftD. Westerlund's (2007) group-mean test (G_τ) confirms the existence of a cointegrating relationship between the logarithms of capital, output, and the user cost of capital for at least one cross-sectional unit, except for structures (OCon), at the 10% level of significance.

Pedroni's tests provide more unambiguous results with respect to cointegration than Westerlund's tests do. Although Pedroni's tests are more restrictive and therefore less general, the common factor restrictions imposed by these tests do not conflict with the purpose of this study. It is clear that Westerlund's tests reject the null hypothesis of no cointegration for at least one cross-sectional unit for all capital assets except non-residential investment or structures (OCon). But also Pedroni's tests reject the null hypothesis of no cointegration with more confidence for OCon compared to IT and SoftD, for which the null hypothesis is strongly rejected under Westerlund's tests. The results of Pedroni's tests are sufficient to presume that cointegration exists.

3.4.2 Parameter estimates

The relationship between capital and the user cost of capital is studied here for five types of physical capital assets and two types of intangible capital assets. If we ignore the potential dynamic bias due to too few time periods in our dataset, the estimation of a dynamic fixed effects model in error correction form provides estimates for physical capital assets that can be compared to Fatica (2018). As shown in Table 3.4, in the short-run dynamics the estimated coefficients associated with the current change in the log of the user cost of capital have the negative sign predicted by the literature and are statistically significant, except for transport equipment. Furthermore, the estimated coefficients of the change in the log of the user cost of capital in $t-1$ have the expected negative sign, but are insignificant for both intangible capital assets. For physical capital assets, those coefficients have the expected sign and are significant at the 1% level of significance for computing equipment (IT), communications equipment (CT), other machinery and equipment (OMach), and non-residential investment or structures (OCon), and at 10% for transport equipment (TraEq). In summary, these estimates suggest that short-term changes in the user cost of capital have a significant impact on changes in the capital stock for computing equipment (IT), communications equipment (CT), other machinery and equipment (OMach), and non-residential investment (OCon), but to a lesser extent for transport equipment (TraEq), software and databases (SoftD), and research and development (R&D).

As for the long-run equilibrium relationship, the speed of adjustment parameters are negative and significant at the 1% level of significance for all types of capital. Similar to Fatica (2018) (in Table 2), computing equipment has the fastest speed adjustment parameter among the five physical capital assets. This value is -0.145, here compared to -0.102 in Fatica (2018). Turning to intellectual property assets, the speed of adjustment parameters are -0.127 for software and databases and -0.030 for research and development. It appears that capital stock in form of software and databases (SoftD) adjusts to its desired level four times faster than capital in the form of research and development (R&D).

The long-run elasticities of capital with respect to the user cost of capital have the negative sign predicted by the literature (Bond and Xing (2015), and Fatica (2018)) and are strongly significant for the five physical capital assets. Under this framework of homogenous parameters in an error correction model, the coefficient estimates imply that a 1% decrease in the user cost of capital would increase the stock of capital by 1.01% for computing equipment (IT), 1.68% for communications equipment (CT), 0.61% for transport equipment (TraEq), 1.17% for other machinery and equipment (OMach), and 0.73% for non-residential investment or structures (OCon). As regards intangible capital assets, the long-run elasticity of capital with respect to the user cost of capital is -0.41 for software and databases (SoftD) and 0.08 for research and development (R&D). This elasticity is negative and significant at the 1% level of significance for SoftD, but positive and insignificant for R&D.[14]

Taking into account the potential problem of dynamic panel bias, the GMM estimator is one of the most appropriate solutions. Table 3.16 (in the appendix) shows the estimated coefficients for the log of the stock of capital equations in an ARDL(2,2) model (equation 3.3). These estimates are obtained using the two-step system GMM estimator. The estimated coefficients for the equations in error-correction form are presented in Table 3.5. Note that the statistical summaries of the variables included in the error-correction model can be found in Table 3.15 (in the appendix). The two-step GMM estimation method put to use takes into account cross-sectional dependence (Sarafidis et al., 2009; Sarafidis and Robertson, 2009). The standard errors used are made robust to heteroscedasticity and arbitrary patterns of autocorrelation within cross-sectional units by applying the Windmeijer (2005) correction.

The estimates presented in Table 3.16 were selected after comparing many choices of instruments, by paying special attention to the AR(1) and AR(2) tests and the Hansen test of overidentifying restrictions. Roodman (2009b) suggests that for a good specification, the null hypothesis of the AR(1) test should be rejected because of the dynamics of the model, the null hypothesis of the AR(2) test should not be rejected, and the p-value of the Hansen test of overidentifying restrictions should be between 0.1 and 0.25.

As shown in Table 3.5, in the short-run dynamics the estimated coefficients associated with the current change in the log of the user cost of capital are negative and significant at the 1% level of significance for computing equipment (IT), communications equipment (CT), and other machinery and equipment (OMach). The estimates are negative and significant at the 10% level for non-residential investment or structures (OCon) and for software and databases (SoftD). The estimate for research and development (R&D) has the expected negative sign, but is insignificant. The estimate for transport equipment (TraEq) has an incorrect sign and is insignificant.

Furthermore, the estimates corresponding to the change in the log of the user cost of capital at $t-1$ have the expected negative sign for both physical and intangible capital assets. These estimates are strongly significant for IT and CT. They are significant at the 5% and 10% levels for R&D and OCon, but insignificant for TraEq and SoftD. The GMM short-run estimates thus show a consistent pattern with the dynamic fixed effects (DFE) model estimates for IT and CT and to a lesser extent for OCon and SoftD.

As for the long-run equilibrium relationship in Table 3.5, the speed of adjustment parameters have the negative sign predicted by literature for two types of physical capital, namely computing

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[14] Lokshin and Mohnen (2007) found a negative and significant value of the user cost elasticity of R&D capital of -0.72 for the Netherlands. However, using a meta-analysis, Gaillard-Ladinska et al. (2019) found that R&D capital user cost elasticities ranged from 1.34 to -1.52. It is possible that the result obtained from this study is due to the aggregation of different user cost impacts on R&D capital accumulation across country-sector pairs in a panel data setting, since this elasticity seems to be very heterogeneous according to Gaillard-Ladinska et al. (2019).

equipment (IT) and transport equipment (TraEq). The IT speed of adjustment parameter is also significant at the 1% level of significance. The speed of adjustment parameters are strongly significant but with incorrect signs for other machinery and equipment (OMach) and non-residential investment (OCon). The CT speed of adjustment parameter is both insignificant and has an incorrect sign. However, the speed of adjustment parameters for both types of intangible capital are negative and significant at the 5% level of significance.

Furthermore, the long-run elasticities of capital with respect to the user cost of capital have the expected negative sign for computing equipment (IT) and transport equipment (TraEq). Among all five physical capital assets, only IT has a user cost elasticity that is both negative and significant (at the 1% level). This result is consistent with the dynamic fixed effects (DFE) results in Table 3.4 ($\hat{\theta}^{IT} = -1.011$), and is close to the IT user cost elasticity of -1.018 obtained by Fatica (2018). As for intangible capital assets (SoftD and R&D), the user cost elasticities have the negative sign expected by the literature, but are insignificant.

At the level of short-term dynamics, both the DFE and GMM estimation methods agree on almost similar qualitative results for all types of physical and intangible capital. The estimated coefficients differ in magnitude, but agree for the most part in sign and significance. As an example, in the case of IT and CT, the coefficients of the current and lagged values of the change in log of the user cost of capital are negative and strongly significant under both estimation methods. For TraEq, the estimated coefficient associated with the current change in log of the user cost of capital is insignificant under both estimation methods. Finally, the current change in log of the user cost of capital for SoftD is significant at the 5% level under the DFE, but at the 10% level under the GMM. As for the SoftD change in log of the user cost of capital in $t-1$ estimate, it is insignificant under both methods.

In terms of speed of adjustment parameters, similarities can be noted under both estimation methods for IT and R&D. For the long-term parameters (speed of adjustment and long-run elasticities of capital with respect to the user cost of capital), the results of the two estimation methods clearly agree well for IT. A large time dimension of a panel dataset increases the unbiasedness of the DFE estimator. In the GMM estimator, the number of instruments increases quadratically with the time dimension of the panel dataset. Roodman (2009a) explained that the bias of the GMM estimator becomes more pronounced when the number of instruments explodes. With a number of observations per cross-section of 17.62 in our dataset, it is possible that the bias is sufficiently large to affect the reliability of long-term estimated parameters of the GMM results.

Table 3.4: Estimates for the equations of the change in log of the stock of capital in error-correction form (equation 3.4), using the dynamic fixed effects (DFE) regression

Dependent variable: Δk_t^n	IT	CT	TraEq	OMach	OCon	SoftD	R&D
change in log of capital lag t-1, Δk_{t-1}^n	0.137***	0.080***	0.265***	0.239***	-0.244***	0.119**	0.279***
	(0.050)	(0.026)	(0.083)	(0.063)	(0.092)	(0.057)	(0.081)
Change in log of output, Δy_t	0.113*	0.089	0.061**	0.080***	0.099***	0.108**	0.059*
	(0.065)	(0.092)	(0.025)	(0.018)	(0.026)	(0.042)	(0.034)
Change in log of output lag t-1, Δy_{t-1}	-0.023	0.060	0.091***	0.071***	0.112***	0.141***	0.074***
	(0.051)	(0.053)	(0.026)	(0.020)	(0.029)	(0.032)	(0.027)
Change in log of user cost of capital, $\Delta \vartheta_t^n$	-0.419***	-0.438***	-0.010	-0.050***	-0.023**	-0.050**	-0.021**
	(0.064)	(0.058)	(0.018)	(0.009)	(0.009)	(0.020)	(0.011)
Change in log of user cost of capital lag t-1, $\Delta \vartheta_{t-1}^n$	-0.182***	-0.130***	-0.022*	-0.059***	-0.042***	-0.026	-0.009
	(0.027)	(0.027)	(0.013)	(0.010)	(0.010)	(0.019)	(0.014)
Speed of adjustment, φ^n	-0.145***	-0.076***	-0.068***	-0.056***	-0.072***	-0.127***	-0.030***
	(0.016)	(0.010)	(0.010)	(0.011)	(0.016)	(0.016)	(0.009)
Long-run elasticity of capital w.r.t user cost, θ^n	-1.011***	-1.679***	-0.605***	-1.167***	-0.732***	-0.408***	0.083
	(0.108)	(0.258)	(0.210)	(0.249)	(0.174)	(0.098)	(0.467)
Country-sector fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year dummy	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of groups	137	137	137	137	137	137	137
Observations	2414	2414	2414	2414	2414	2414	2414

Notes: Each column presents the estimation results of the investment equation for each capital asset such that n equals computing equipment (IT), communications equipment (CT) and transport equipment (TraEq), other machinery and equipment (OMach), non-residential investment or structures (OCon), software and databases (SoftD), and research and development (R&D). The estimation method is dynamic fixed effects (DFE). The standard errors are in parenthesis. We consider: * $p < 0.10$, ** $p < 0.05$, and *** $p < 0.01$.

Table 3.5: Estimates for the equations of the change in log of the stock of capital in error-correction form (equation 3.4), using the GMM estimator

Dependent variable: Δk_t^n	IT	CT	TraEq	OMach	OCon	SoftD	R&D
Change in log of the stock of capital lag t-1, Δk_{t-1}^n	-0.059	0.067	0.481^{***}	0.352^{***}	-0.308^{***}	0.044	0.374^{***}
	(0.078)	(0.058)	(0.094)	(0.092)	(0.117)	(0.123)	(0.091)
Change in log of output, Δy_t	0.202	0.031	0.057	0.038	0.031	0.211	0.107
	(0.227)	(0.241)	(0.105)	(0.055)	(0.047)	(0.161)	(0.073)
Change in log of output lag t-1, Δy_{t-1}	-0.257^{*}	-0.161	-0.001	0.005	0.128^{**}	0.275^{*}	0.175^{*}
	(0.143)	(0.183)	(0.068)	(0.071)	(0.052)	(0.150)	(0.092)
Change in log of user cost of capital, $\Delta \vartheta_t^n$	-0.344^{***}	-0.295^{***}	0.029	-0.029^{***}	-0.015^{*}	-0.064^{*}	-0.028
	(0.072)	(0.087)	(0.019)	(0.010)	(0.008)	(0.033)	(0.028)
Change in log of user cost of capital lag t-1, $\Delta \vartheta_{t-1}^n$	-0.221^{***}	-0.137^{***}	-0.033	-0.009	-0.028^{*}	-0.019	-0.072^{**}
	(0.045)	(0.041)	(0.029)	(0.027)	(0.016)	(0.028)	(0.033)
Speed of adjustment, φ^n	-0.131^{***}	0.006	-0.005	0.017^{**}	0.025^{***}	-0.040^{**}	-0.037^{**}
	(0.034)	(0.012)	(0.011)	(0.008)	(0.008)	(0.016)	(0.015)
Long-run elasticity of capital w.r.t user cost, θ^n	-1.052^{***}	10.850	-6.370	1.451	0.688	-0.171	-0.553
	(0.135)	(21.823)	(12.723)	(1.429)	(0.734)	(0.761)	(0.807)
Country-sector fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year dummy	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of instruments	131	136	131	136	136	118	131
Number of groups	137	137	137	137	137	137	137
Observations	2414	2414	2414	2414	2414	2414	2414
Arellano-Bond test for AR(1) (p-value)	0.000	0.000	0.000	0.005	0.075	0.006	0.008
Arellano-Bond test for AR(2) (p-value)	0.763	0.207	0.886	0.101	0.040	0.832	0.089
Sargan test of overid. restrictions (p-value)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Hansen test of overid. restrictions (p-value)	0.130	0.155	0.195	0.425	0.324	0.197	0.187

Notes: Each column presents the estimation results of the investment equation for each capital asset such that n equals computing equipment (IT), communications equipment (CT) and transport equipment (TraEq), other machinery and equipment (OMach), non-residential investment or structures (OCon), software and databases (SoftD), and research and development (R&D). The estimation method is two-step system GMM. The standard errors are in parentheses. We consider: * $p < 0.10$, ** $p < 0.05$, and *** $p < 0.01$. For this GMM specification the predetermined variables are the lagged values of capital, the current and lagged values of output, and the current and lagged values of the user cost of capital. The exogenous variables are the year dummies. The set of instrument variables is collapsed. The leftmost columns of the instrument matrix are dropped. For example, the first 3 columns for IT, the first 2 for CT, the first 3 for TraEq, the first 2 for OMach, the first 2 for OCon, the first 5 for SoftD, and the first 3 for R&D were dropped.

3.5 Sensitivity analysis

This analysis of sensitivity allows us to see how the results of the model hold up when estimated on restricted balanced panel datasets. Moreover, this analysis allows the results to be deepened by admitting the possibility that relative prices (the price component of the user cost of capital) and the non-price component of the user cost of capital affect the capital accumulation process differently, by decomposing the user cost of capital into its price and non-price components.

3.5.1 Long restricted balanced panel dataset

The first element of the sensitivity analysis is to apply the dynamic fixed effects and GMM estimation methods to the longest balanced panel that can be extracted from the dataset. This dataset consists of six countries.[15] It contains 68 groups from 1997 to 2015, i.e., 19 observations per cross-sectional unit (country-sector pair). This strategy raises an important question: Is it a long or short panel dataset? The answer is not immediately clear, as 20 observations are generally considered necessary for a long panel dataset. A possible tentative answer can be found in a comparison of the estimation results of the dynamic fixed effects (DFE) model and the GMM estimator.

Table 3.6 shows the estimation results for the model in error correction form when the dynamic fixed effects method is used. Table 3.7 presents the results for the error-correction model obtained using the GMM estimation method. The estimated coefficients for the associated autoregressive distributed lag model obtained using GMM estimation are shown in Table 3.17 (in the appendix). If we compare the dynamic fixed effects models in Tables 3.4 and 3.6, we can see that although the estimated coefficients are different, they display a consistent pattern and maintain their qualitative interpretations. For both the entire and restricted datasets, the speed of adjustment parameters are negative and significant at the 1% level of significance for all types of capital. The long-run elasticities of capital with respect to the user cost of capital are negative and strongly significant, except for research and development (R&D) (in both datasets) and for communications equipment (CT) (in the restricted dataset) .

As for the GMM estimates (Table 3.7 and Table 3.17 in the appendix) based on the restricted dataset, the results seem unreliable. The number of instruments still exceeds the number of groups (68), even after collapsing the set of instruments and dropping the leftmost instrument vectors as suggested by Roodman (2009a). Furthermore, the p-value of the Hansen test of overidentifying restrictions cannot be placed within the range (0.1, 0.25) as recommended in the literature (Roodman, 2009a,b). Thus for the restricted dataset, the dynamic fixed-effects model seems better able to describe the process of capital accumulation. This model seems more in line with the general conclusions of neoclassical theory of business investment behaviour (Jorgenson, 1963, 1967, 1971). These DFE results are also more similar to those obtained by Fatica (2018), who implemented the DFE, mean group, and pooled mean group estimators using data from 23 sectors in 10 OECD countries covering the period 1984-2007 taken from EU KLEMS database (March 2008 Release).

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[15] The countries are Austria, Denmark, Finland, France, Germany, and the United States.

Table 3.6: Estimates for the equations of the change in log of the stock of capital in error-correction form (equation 3.4): using the dynamic fixed effects (DFE) regression with the longest possible balanced panel dataset

Dependent variable: Δk_t^n	IT	CT	TraEq	OMach	OCon	SoftD	R&D
Change in log of the stock of capital lag t-1, Δk_{t-1}^n	0.102	0.061^{**}	0.171^{**}	0.178^{***}	-0.313^{***}	0.071	0.265^{***}
	(0.074)	(0.027)	(0.076)	(0.059)	(0.086)	(0.089)	(0.056)
Change in log of output, Δy_t	0.154^{***}	0.158	0.149^{***}	0.109^{***}	0.148^{***}	0.101^{***}	0.142^{***}
	(0.059)	(0.144)	(0.031)	(0.022)	(0.043)	(0.029)	(0.034)
Change in log of output lag t-1, Δy_{t-1}	0.025	0.179^{***}	0.075^{**}	0.086^{***}	0.178^{***}	0.107^{***}	0.061
	(0.043)	(0.064)	(0.032)	(0.021)	(0.048)	(0.029)	(0.039)
Change in log of user cost of capital, $\Delta \vartheta_t^n$	-0.228^{**}	-0.470^{***}	-0.106^{**}	-0.046^{***}	-0.044^{*}	-0.047^{*}	-0.061^{*}
	(0.105)	(0.074)	(0.049)	(0.013)	(0.023)	(0.024)	(0.034)
Change in log of user cost of capital lag t-1, $\Delta \vartheta_{t-1}^n$	-0.091^{***}	0.090^{**}	0.001	-0.073^{***}	-0.088^{***}	-0.063^{**}	0.034
	(0.059)	(0.038)	(0.030)	(0.014)	(0.023)	(0.027)	(0.036)
Speed of adjustment, φ^n	-0.110^{***}	-0.050^{***}	-0.050^{***}	-0.058^{***}	-0.097^{***}	-0.113^{***}	-0.060^{***}
	(0.034)	(0.009)	(0.016)	(0.018)	(0.026)	(0.015)	(0.020)
Long-run elasticity of capital w.r.t user cost, θ^n	-0.856^{***}	-0.705	-0.760^{***}	-1.228^{***}	-0.578^{***}	-0.468^{***}	-0.183
	(0.168)	(0.921)	(0.431)	(0.346)	(0.186)	(0.128)	(0.369)
Country-sector fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year dummy	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of groups	68	68	68	68	68	68	68
Observations	2414	2414	2414	2414	2414	2414	2414

Notes: Each column presents the estimated coefficients of the investment equations for each type of capital such that n equals computing equipment (IT), communications equipment (CT) and transport equipment (TraEq), other machinery and equipment (OMach), non-residential investment or structures (OCon), software and databases (SoftD), and research and development (R&D). The estimation method is dynamic fixed effects (DFE). The standard errors are in parenthesis. We consider: * $p < 0.10$, ** $p < 0.05$, and *** $p < 0.01$.

Table 3.7: Estimates for the equations of the change in log of the stock of capital in error-correction form (equation 3.4): using the GMM estimator with the longest possible balanced panel dataset

Dependent variable: Δk_t^n	IT	CT	TraEq	OMach	OCon	SoftD	R&D
Change in log of the stock of capital lag t-1, Δk_{t-1}^n	0.387***	0.163*	0.493***	0.497***	-0.339***	0.248	0.200***
	(0.137)	(0.082)	(0.096)	(0.137)	(0.094)	(0.175)	(0.072)
Change in log of output, Δy_t	0.384**	0.070	0.180*	0.088	-0.021	0.080	0.093
	(0.152)	(0.235)	(0.105)	(0.073)	(0.107)	(0.085)	(0.090)
Change in log of output lag t-1, Δy_{t-1}	0.124	0.198	-0.048	0.008	0.205**	-0.006	0.217*
	(0.243)	(0.374)	(0.092)	(0.049)	(0.087)	(0.076)	(0.110)
Change in log of user cost of capital, $\Delta \vartheta_t^n$	-0.356***	-0.114	-0.008	0.029	0.078*	0.072	-0.041
	(0.116)	(0.091)	(0.048)	(0.034)	(0.044)	(0.054)	(0.049)
Change in log of user cost of capital lag t-1, $\Delta \vartheta_{t-1}^n$	-0.162***	0.353*	0.093	-0.059**	-0.059	0.052	0.103
	(0.088)	(0.190)	(0.092)	(0.028)	(0.039)	(0.070)	(0.048)
Speed of adjustment, φ^n	-0.042**	-0.052***	0.005	0.008	0.009	-0.006	-0.013
	(0.016)	(0.018)	(0.009)	(0.011)	(0.010)	(0.006)	(0.008)
Long-run elasticity of capital w.r.t user cost, θ^n	-1.156***	1.479	-2.925	0.633	2.788	-1.804	1.458
	(0.405)	(1.206)	(5.928)	(2.233)	(3.775)	(4.609)	(2.421)
Country-sector fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year dummy	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of instruments	88	93	98	108	98	108	103
Number of groups	68	68	68	68	68	68	68
Observations	1292	1292	1292	1292	1292	1292	1292
Arellano-Bond test for AR(1) (p-value)	0.000	0.000	0.001	0.002	0.041	0.035	0.001
Arellano-Bond test for AR(2) (p-value)	0.937	0.572	0.387	0.431	0.045	0.297	0.553
Sargan test of overid. restrictions (p-value)	0.000	0.000	0.000	0.019	0.000	0.000	0.000
Hansen test of overid. restrictions (p-value)	0.465	0.891	0.968	0.995	0.979	0.973	0.998

Notes: Each column presents the estimated coefficients of the investment equations for each type of capital such that n equals computing equipment (IT), communications equipment (CT) and transport equipment (TraEq), other machinery and equipment (OMach), non-residential investment or structures (OCon), software and databases (SoftD), and research and development (R&D). The estimation method is two-step system GMM. The standard errors are in parenthesis. We consider: * $p < 0.10$, ** $p < 0.05$, and *** $p < 0.01$. For this GMM specification the predetermined variables are the lagged values of capital, the current and lagged values of output, and the current and lagged values of the user cost of capital. The exogenous variables are the year dummies. The set of instrument variables is collapsed. The leftmost columns of the instrument matrix are dropped. For example, the first 6 columns for IT, the first 5 for CT, the first 4 for TraEq, the first 2 for OMach, the first 4 for OCon, the first 2 for SoftD, and the first 3 for R&D were dropped.

3.5.2 Short restricted balanced panel dataset

This second element of the sensitivity analysis uses a simple balanced panel dataset spanning from 1998 to 2003. This dataset contains 571 observations for 126 groups (country-sector pairs) and includes all countries in the original dataset except for the Netherlands. Tables 3.8 and 3.9 present the dynamic fixed effects (DFE) and GMM estimates in error correction form. Table 3.18 shows the GMM estimates of the associated autoregressive distributed lag model.

In comparison to the DFE results using the original dataset (Table 3.4), the DFE estimates obtained with this short restricted dataset, shown in Table 3.8, provide speed of adjustment parameters that are two to four times higher than those obtained using the original dataset. The long-run elasticities of capital with respect to the user cost of capital that were significant for IT, TraEq and OCon are no longer significant. The same observation about the speed of adjustment parameters can be made when comparing the GMM results using the original dataset (Table 3.5) and ones using the short restricted dataset (Table 3.9). The user cost elasticities obtained from these datasets are very different in terms of magnitude and significance.

If we compare the DFE and GMM results obtained using the short restricted dataset (Tables 3.8 and 3.9), we can see that the speed of adjustment parameters are negative, significant, and larger in magnitude in comparison to the estimates obtained using the original dataset for all types of capital. Under both estimation methods, the long-run elasticities of capital with respect to the user cost of capital are negative for all types of capital except transport equipment. Both methods provide significant long-run user cost elasticities of capital for communications equipment (CT), other machinery and equipment (OMach), and research and development (R&D). Although the DFE and GMM results obtained using this short restricted dataset have points of similarity, one can question the reliability of the DFE estimates for such a short panel dataset. Furthermore, the results of Hansen's test for the GMM estimates for IT, OMach and SoftD are not convincing or only somewhat convincing for TraEq and OCon. Since the AR(1), AR(2), and Hansen tests associated with the GMM results for CT and R&D are consistent with a good choice of instruments, these results confirm that changes in the user cost of capital affect capital accumulation in the short run for CT and R&D.

Table 3.8: Estimates for the equations of the change in log of the stock of capital in error-correction form (equation 3.4): using the dynamic fixed effects (DFE) regression with a short restricted balanced panel dataset

Dependent variable: Δk_t^n	IT	CT	TraEq	OMach	OCon	SoftD	R&D
Change in log of the stock of capital lag t-1, Δk_{t-1}^n	-0.067	-0.278***	0.024	-0.095*	-0.276***	-0.146	-0.219***
	(0.069)	(0.087)	(0.118)	(0.048)	(0.075)	(0.116)	(0.082)
Change in log of output, Δy_t	0.182	0.193	0.161***	0.170***	0.136**	0.137*	0.074
	(0.137)	(0.135)	(0.059)	(0.045)	(0.055)	(0.075)	(0.096)
Change in log of output lag t-1, Δy_{t-1}	0.077	0.208	0.156**	0.227***	0.206**	0.181**	0.228***
	(0.107)	(0.137)	(0.073)	(0.050)	(0.102)	(0.080)	(0.076)
Change in log of user cost of capital, $\Delta \vartheta_t^n$	-0.068	-0.376***	-0.090*	-0.036***	-0.018	-0.096**	-0.094***
	(0.049)	(0.093)	(0.047)	(0.013)	(0.020)	(0.042)	(0.026)
Change in log of user cost of capital lag t-1, $\Delta \vartheta_{t-1}^n$	-0.061	-0.156***	-0.004	-0.128***	-0.048*	-0.070	-0.106***
	(0.047)	(0.055)	(0.047)	(0.022)	(0.027)	(0.059)	(0.034)
Speed of adjustment, φ^n	-0.308***	-0.253***	-0.104**	-0.206***	-0.181**	-0.311***	-0.241***
	(0.101)	(0.069)	(0.043)	(0.043)	(0.076)	(0.062)	(0.057)
Long-run elasticity of capital w.r.t user cost, θ^n	-0.134	-1.029***	0.928	-0.495***	-0.195	-0.257*	-0.402**
	(0.177)	(0.333)	(0.679)	(0.136)	(0.209)	(0.151)	(0.163)
Country-sector fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year dummy	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of groups	126	126	126	126	126	126	126
Observations	571	571	571	571	571	571	571

Notes: Each column presents the estimated coefficients of the investment equation for each capital asset such that n equals computing equipment (IT), communications equipment (CT) and transport equipment (TraEq), other machinery and equipment (OMach), non-residential investment or structures (OCon), software and databases (SoftD), and research and development (R&D). The estimation method is dynamic fixed effects (DFE). We consider: * $p < 0.10$, ** $p < 0.05$, and *** $p < 0.01$.

Table 3.9: Estimates for the equations of the change in log of the stock of capital in error-correction form (equation 3.4): using the GMM estimator with a short restricted balanced panel dataset

Dependent variable: Δk_t^n	IT	CT	TraEq	OMach	OCon	SoftD	R&D
Change in log of the stock of capital lag t-1, Δk_{t-1}^n	-0.215***	-0.382***	0.083	-0.045	-0.324***	-0.008	-0.166**
	(0.077)	(0.104)	(0.152)	(0.122)	(0.093)	(0.164)	(0.063)
Change in log of output, Δy_t	0.097	0.160	0.131**	0.167***	0.053	0.135*	0.057
	(0.160)	(0.099)	(0.061)	(0.050)	(0.043)	(0.080)	(0.070)
Change in log of output lag t-1, Δy_{t-1}	0.085	0.177	0.120*	0.185***	0.078	0.171	0.154***
	(0.133)	(0.109)	(0.067)	(0.048)	(0.052)	(0.106)	(0.055)
Change in log of user cost of capital, $\Delta \vartheta_t^n$	0.026	-0.287***	-0.049	-0.026*	-0.004	-0.081**	-0.068***
	(0.052)	(0.064)	(0.035)	(0.014)	(0.017)	(0.037)	(0.020)
Change in log of user cost of capital lag t-1, $\Delta \vartheta_{t-1}^n$	-0.022	-0.203***	0.047	-0.090***	-0.027	-0.012	-0.098***
	(0.052)	(0.065)	(0.044)	(0.024)	(0.024)	(0.062)	(0.025)
Speed of adjustment, φ^n	-0.297***	-0.272***	-0.083*	-0.191***	-0.110*	-0.278***	-0.190***
	(0.056)	(0.078)	(0.048)	(0.050)	(0.062)	(0.096)	(0.043)
Long-run elasticity of capital w.r.t user cost, θ^n	-0.003	-0.919***	1.646*	-0.327**	-0.243	-0.222	-0.458***
	(0.154)	(0.302)	(0.944)	(0.161)	(0.383)	(0.216)	(0.210)
Country-sector fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year dummy	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of instruments	26	26	26	26	26	26	26
Number of groups	126	126	126	126	126	126	126
Observations	571	571	571	571	571	571	571
Arellano-Bond test for AR(1) (p-value)	0.006	0.010	0.024	0.009	0.013	0.006	0.033
Arellano-Bond test for AR(2) (p-value)	0.399	0.625	0.921	0.169	0.308	0.175	0.263
Sargan test of overid. restrictions (p-value)	0.001	0.000	0.014	0.000	0.000	0.000	0.000
Hansen test of overid. restrictions (p-value)	0.001	0.263	0.079	0.001	0.096	0.012	0.292

Notes: Each column presents the estimated coefficients of the investment equation for each capital asset such that n equals computing equipment (IT), communications equipment (CT) and transport equipment (TraEq), other machinery and equipment (OMach), non-residential investment or structures (OCon), software and databases (SoftD), and research and development (R&D). The estimation method is two-step system GMM. We consider: * $p < 0.10$, ** $p < 0.05$, and *** $p < 0.01$. For this GMM specification the predetermined variables are the lagged values of capital, the current and lagged values of output, and the current and lagged values of the user cost of capital. The exogenous variables are the year dummies. The set of instrument variables is collapsed.

3.5.3 Alternative model

As in Fatica (2018), this third element of the sensitivity analysis allows for the assessment of capital elasticities with respect to the price component of the user cost of capital (the relative prices of capital) and with respect to the non-price component of the user cost of capital. This alternative specification uses the entire dataset and implements the DFE and GMM estimation methods. Let the price component of the user cost of capital be denoted $\widetilde{p}_t^n = log(P_t^n/p_t)$. Let the non-price component of the user cost of capital be defined as $\widetilde{np}_t^n = log[(1 - A_t^n)(r_t^n + \delta^n)/(1 - \tau_t) - \delta^n]$. Then, the logarithm of the user cost of capital can be decomposed as $\vartheta_t^n = \widetilde{p}_t^n + \widetilde{np}_t^n$. Therefore the autoregressive distributed lag model can be expressed as follows:

$$k_{ij,t} = \sum_{s=1}^{2} \alpha_s k_{ij,t-s} + \sum_{s=0}^{2} \beta_s y_{ij,t-s} + \sum_{s=0}^{2} \zeta_s \widetilde{p}_{ij,t-s} + \sum_{s=0}^{2} \psi_s \widetilde{np}_{ij,t-s} + \lambda_{ij} + \omega_t + \epsilon_{ij,t}. \tag{3.6}$$

The model in error-correction form is

$$\begin{aligned}\Delta k_{ij,t} = {} & \pi_0 \Delta k_{ij,t-1} + \pi_1 \Delta y_{ij,t} + \pi_2 \Delta y_{ij,t-1} + \pi_3 \Delta \widetilde{p}_{ij,t} + \pi_4 \Delta \widetilde{p}_{ij,t-1} \\ & + \pi_5 \Delta \widetilde{np}_{ij,t} + \pi_6 \Delta \widetilde{np}_{ij,t-1} + \varphi[(k_{ij,t-2} - y_{ij,t-2}) + \theta_{\widetilde{p}} \widetilde{p}_{ij,t-2} + \theta_{\widetilde{np}} \widetilde{np}_{ij,t-2}] \\ & + \lambda_{ij} + \omega_t + \epsilon_{ij,t},\end{aligned} \tag{3.7}$$

where $\theta_{\widetilde{p}}$ and $\theta_{\widetilde{np}}$ are the capital long-run elasticities with respect to the price and non-price components of the user cost of capital, respectively. The estimated coefficients for this alternative specification are presented in Tables 3.10 and 3.11 for the DFE and GMM models in error correction form and Table 3.19 for the autoregressive distributed lag model (in the appendix).

This alternative model uses the same dataset as the original specification whose estimated coefficients can be seen in Tables 3.4 and 3.5. Although these are two different specifications, it is possible to compare the speed of adjustment parameters. The dynamic fixed-effects (DFE) method provides very similar speed of adjustment parameters in both Tables 3.4 and 3.10. They are negative and significant for all types of capital. The GMM method provides consistent speed of adjustment parameters in Tables 3.5 and 3.11 for IT and R&D.

As shown in Table 3.10, in the short-run dynamics of the DFE regression, the estimated coefficients corresponding to the current change in the log of the price component of the user cost of capital (the relative prices) are negative for all types of capital. They are significant except for TraEq. It should be noted that the magnitudes of the coefficients for IT and CT differ greatly from the estimated coefficients for the other types of capital. The estimated coefficients for the change in the log of the price component of the user cost of capital for lag $t - 1$ are negative, except for R&D. They are significant for CT, OMach, and OCon. Furthermore, the estimated coefficients associated with the current change in the log of the non-price component of the user cost of capital for OMach, SoftD, and R&D are negative and strongly significant only for OMach. The estimated coefficients corresponding to the change in the log of the non-price component of the user cost of capital for lag $t - 1$ are negative for IT, CT, OMach, SoftD, and R&D, but are significant for only OMach.

As for the long-run equilibrium relationship in the DFE regression (Table 3.10), the speed of adjustment parameters are negative and strongly significant for all types of capital. The long-run elasticities of capital with respect to the price component of the user cost of capital (the relative prices) are negative and significant except for R&D. Fatica (2018), applying the cross-sectionally dependent mean group (CDMG) estimation method using a panel dataset from 1987-2004 covering

23 sectors of the market economy, found negative and significant long-run elasticities of capital with respect to the price component of the user of capital for IT, CT, TraEq, OMach, and OCon. It should be noted that intangible capital assets (SoftD and R&D) are not part of her study. The long-run elasticities of capital with respect to the non-price component of the user cost of capital are negative for IT, CT, OMach, and SoftD, but significant at the 5% level of significance for only OMach. Using the CDMG estimation method, Fatica (2018) found negative and significant non-price component of user cost elasticities for CT, TraEq, OMach, and OCon, but insignificant for IT.

In the short-run dynamics of the GMM estimation results shown in Table 3.11, among physical capital assets the estimated coefficients corresponding to the current change in the log of the price component of the user cost of capital (the relative prices of capital) are negative for IT, CT, OMach, and OCon. They are strongly significant for IT and CT. Turning to intangible capital assets, this coefficient is negative and significant at the 5% level for R&D. In addition, the estimated coefficients of the change in the log of the price component of the user cost in lag $t - 1$ are negative for all physical and intangible capital assets, but are insignificant. In summary, using the GMM estimation method it can be said that changes in relative prices significantly affect capital accumulation in the short term for IT, CT, and R&D in this dataset.

As for the estimated coefficients associated with the current change in the log of the non-price component of the user cost of capital, they are negative for all types of capital except for TraEq (Table 3.11). The OCon estimate is significant at the 10% level. Furthermore, the estimates corresponding to the change in the log of the non-price component of the user cost of capital at lag $t - 1$ are negative for IT, TraEq, OMach, OCon, and R&D, but significant at the 1% level of significance for TraEq. Although the negative signs seem to suggest that short-term changes in the non-price component of the user cost of capital appear to influence the capital accumulation process in the expected direction, this result appears to be significant for only TraEq.

With respect to the long-run equilibrium relationship, as seen in Table 3.11 the speed of adjustment parameters for physical capital assets are negative for IT, CT, and TraEq. However, these parameters are significant at the 5% significance level only for IT and TraEq. As for intangible capital assets (SoftD and R&D), the speed of adjustment parameters are both negative, but significant only for R&D. Moreover, the long-run elasticities of capital with respect to the relative price of capital (the price component of the user cost of capital) have the negative sign observed in the literature (Bond and Xing, 2015; Fatica, 2018) for all physical and intangible capital assets, except for transport equipment. They are significant at the 1% and 10% levels for IT and CT respectively. Indeed, a one-percent decrease in the relative price of capital goods induces the stock of capital to increase by 1.9% for IT and by 5.1% for CT. In addition, the long-run elasticities of capital with respect to the non-price component of the user cost of capital have a negative sign as in Fatica (2018) for IT, TraEq, and R&D. These elasticities are significant at the 5% level of significance for computing equipment (IT) and transport equipment (TraEq). In short, a one-percent decrease in the non-price component of the user cost of capital causes the stock of capital to increase by 2.0% for IT and 5.5% for TraEq.

It can be noted that the types of capital for which the GMM estimates of the long-run elasticities of capital with respect to the relative price of capital goods are significant (IT and CT) have seen the largest declines in relative prices over the period (Figure 3.2). Also, the types of capital for which the long-run elasticities of capital with respect to the non-price component of the user cost of capital are significant (IT and TraEq) have higher depreciation rates than other physical capital assets. The non-price component of the user cost of capital incorporates the transmission mechanism of the effects of the corporate income tax rate on the capital accumulation process. Indeed, in this dataset, it can be said that the impacts of a decreasing corporate income tax rate tend to create positive incentives for capital accumulation in form of IT, TraEq and R&D.

Table 3.10: Estimates for the equations of the change in log of the stock of capital in error-correction form (equation 3.4): using the dynamic fixed effects (DFE) regression with decomposed user cost of capital

Dependent variable: Δk_t^n	IT	CT	TraEq	OMach	OCon	SoftD	R&D
Change in log of the stock of capital lag t-1,Δk_{t-1}^n	0.169***	0.117***	0.267***	0.228***	-0.259***	0.117**	0.281***
	(0.055)	(0.024)	(0.082)	(0.062)	(0.091)	(0.056)	(0.081)
Change in log of output, Δy_t	0.249***	0.218**	0.083**	0.107***	0.106***	0.101**	0.071**
	(0.070)	(0.088)	(0.034)	(0.024)	(0.026)	(0.045)	(0.035)
Change in log of output lag t-1, Δy_{t-1}	-0.029	0.100**	0.084***	0.080***	0.126***	0.133***	0.067**
	(0.047)	(0.047)	(0.029)	(0.020)	(0.031)	(0.033)	(0.029)
Change in log of relative price, $\Delta \widetilde{p}_t^n$	-0.724***	-0.717***	-0.094	-0.149***	-0.050**	-0.063*	-0.071*
	(0.071)	(0.068)	(0.067)	(0.039)	(0.022)	(0.034)	(0.037)
Change in log of relative price lag t-1, $\Delta \widetilde{p}_{t-1}^n$	-0.074	-0.094**	-0.013	-0.094***	-0.073***	-0.024	0.013
	(0.054)	(0.041)	(0.032)	(0.022)	(0.022)	(0.038)	(0.042)
Change in log of n.p.c. of user cost, $\Delta \widetilde{np}_t^n$	0.038	0.013	0.028*	-0.018***	0.004	-0.038	-0.006
	(0.025)	(0.029)	(0.015)	(0.007)	(0.008)	(0.027)	(0.009)
Change in log of n.p.c. of user cost lag t-1, $\Delta \widetilde{np}_{t-1}^n$	-0.016	-0.015	0.004	-0.027**	0.001	-0.007	-0.004
	(0.036)	(0.036)	(0.020)	(0.013)	(0.011)	(0.020)	(0.012)
Speed of adjustment, φ^n	-0.131***	-0.070***	-0.068***	-0.063***	-0.093***	-0.128***	-0.034***
	(0.015)	(0.009)	(0.010)	(0.011)	(0.018)	(0.016)	(0.010)
Long-run elasticity of capital w.r.t relative price, $\theta_{\widetilde{p}}^n$	-1.143***	-1.579***	-0.923***	-1.424***	-0.993***	-0.612***	-0.380
	(0.115)	(0.267)	(0.272)	(0.223)	(0.150)	(0.136)	(0.567)
Long-run elasticity of capital w.r.t n.p.c of user cost, $\theta_{\widetilde{np}}^n$	-0.092	-0.931	0.074	-0.541**	0.122	-0.017	0.716
	(0.298)	(0.612)	(0.387)	(0.252)	(0.138)	(0.203)	(0.473)
Country-sector fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year dummy	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of groups	137	137	137	137	137	137	137
Observations	2414	2414	2414	2414	2414	2414	2414

Notes: Each column presents the estimated coefficients of the investment equation for each capital asset such that n equals computing equipment (IT), communications equipment (CT) and transport equipment (TraEq), other machinery and equipment (OMach), non-residential investment or structures (OCon), software and databases (SoftD), and research and development (R&D). The estimation method is dynamic fixed effects (DFE). We consider: * $p < 0.10$, ** $p < 0.05$, and *** $p < 0.01$.

Table 3.11: Estimates for the equations of the change in log of the stock of capital in error-correction form (equation 3.4): using the GMM estimator with decomposed user cost of capital

Dependent variable: Δk_t^n	IT	CT	TraEq	OMach	OCon	SoftD	R&D
Change in log of the stock of capital lag t-1,Δk_{t-1}^n	1.057	0.013	0.120	0.300***	-0.243	0.047	0.404***
	(0.129)	(0.079)	(0.112)	(0.166)	(0.117)	(0.115)	(0.107)
Change in log of output, Δy_t	0.318**	-0.021	0.081	-0.026	0.140	0.114	0.173**
	(0.159)	(0.252)	(0.111)	(0.059)	(0.084)	(0.290)	(0.074)
Change in log of output lag t-1, Δy_{t-1}	-0.262*	0.254	0.018	0.094*	0.132**	0.317	0.141
	(0.136)	(0.192)	(0.096)	(0.048)	(0.062)	(0.243)	(0.097)
Change in log of relative price, $\Delta \widetilde{p}_t^n$	-1.035***	-0.911***	0.131	-0.093	-0.075	0.007	-0.206**
	(0.066)	(0.067)	(0.123)	(0.061)	(0.047)	(0.158)	(0.090)
Change in log of relative price lag t-1, $\Delta \widetilde{p}_{t-1}^n$	-0.069	-0.076	-0.032	-0.046	-0.047	-0.197	-0.013
	(0.129)	(0.105)	(0.099)	(0.084)	(0.063)	(0.153)	(0.065)
Change in log of n.p.c. of user cost, $\Delta \widetilde{np}_t^n$	-0.040	-0.108	0.013	-0.014	-0.024*	-0.017	-0.015
	(0.041)	(0.125)	(0.016)	(0.019)	(0.015)	(0.039)	(0.021)
Change in log of n.p.c. of user cost lag t-1, $\Delta \widetilde{np}_{t-1}^n$	-0.114	0.035	-0.082***	-0.002	-0.034	0.022	-0.033
	(0.070)	(0.115)	(0.030)	(0.036)	(0.022)	(0.039)	(0.023)
Speed of adjustment, φ^n	-0.081**	-0.021	-0.026**	0.012	0.019**	-0.035	-0.023***
	(0.034)	(0.015)	(0.024)	(0.014)	(0.007)	(0.024)	(0.009)
Long-run elasticity of capital w.r.t relative price, $\theta_{\widetilde{p}}^n$	-1.934***	-5.091*	0.756	-5.166	-0.210	-4.770	-1.686
	(0.329)	(2.878)	(2.487)	(9.672)	(1.719)	(3.531)	(1.528)
Long-run elasticity of capital w.r.t n.p.c of user cost, $\theta_{\widetilde{np}}^n$	-1.995**	3.524	-5.541**	0.902	0.495	0.219	-0.190
	(0.992)	(3.393)	(2.671)	(3.981)	(1.285)	(1.306)	(1.082)
Country-sector fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year dummy	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of instruments	120	90	130	90	130	110	130
Number of groups	137	137	137	137	137	137	137
Observations	2414	2414	2414	2414	2414	2414	2414
Arellano-Bond test for AR(1) (p-value)	0.002	0.001	0.002	0.004	0.116	0.003	0.010
Arellano-Bond test for AR(2) (p-value)	0.602	0.711	0.541	0.226	0.094	0.670	0.135
Sargan test of overid. restrictions (p-value)	0.000	0.001	0.000	0.000	0.000	0.000	0.009
Hansen test of overid. restrictions (p-value)	0.109	0.154	0.114	0.134	0.403	0.170	0.213

Notes: Each column presents the estimated coefficients of the investment equation for each capital asset such that n equals computing equipment (IT), communications equipment (CT) and transport equipment (TraEq), other machinery and equipment (OMach), non-residential investment or structures (OCon), software and databases (SoftD), and research and development (R&D). The estimation method is two-step system GMM. The symbol n.p.c. stands for non-price component. We consider: * $p < 0.10$, ** $p < 0.05$, and ***. $p < 0.01$. For this GMM specification the predetermined variables are the lagged values of capital, the current and lagged values of output, and the current and lagged values of the user cost of capital. The exogenous variables are the year dummies. The set of instrument variables is collapsed. The leftmost columns of the instrument matrix are dropped. For example, the first 9 columns for IT, the first 12 for CT, the first 8 for TraEq, the first 12 for OMach, the first 8 for OCon, the first 10 for SoftD, and the first 8 for R&D were dropped.

3.5.4 Lessons from the sensitivity analysis

Taken together, the results presented in this paper show that if one has a panel dataset with a time dimension of close 20 (e.g., 19), the dynamic fixed-effects (DFE) estimator of the relationship between capital and the user cost of capital seems to be more in line with the general conclusions of the neoclassical theory of business investment behaviour. This is evidenced by the similarity in signs and significance of the results presented in Table 3.6 to those obtained by Fatica (2018) for disaggregated capital (using a panel dataset covering the time period 1984-2007) and by Bond and Xing (2015) for aggregated capital (using a panel dataset covering the time period 1982-2007). Since Fatica (2018) obtained estimates that were smaller in terms of magnitude when applying the group mean or pooled mean group estimators, there is reason to believe that the DFE estimates presented in Table 3.6 may be overestimates, but they give the right direction of the relationship under study and are significant.

If one has a panel dataset with a short time dimension (as is the case in Tables 3.8 and 3.9), the results of DFE estimation would raise quite a few doubts which the GMM estimates would dispel. Therefore, in this case, there is reason to believe that the results obtained using the GMM method are more reliable (Table 3.9). Thus one can conclude that changes in the user cost of capital affect capital accumulation for communications equipment (CT) among physical capital assets and for research and development (R&D) among intangible capital assets, although the diagnostic tests (particularly the Hansen test of overidentifying restrictions) suggest that the GMM estimates aren't necessarily perfect.

As for the results involving the entire dataset (Tables 3.4, 3.5, 3.10, and 3.11), the number of observations per cross-sectional unit varies between 11 and 19. Although the estimated coefficients for the short-term dynamics of the DFE and GMM estimation methods seem to agree, the DFE estimates associated with the long-term equilibrium variables are more in line with the general conclusions of the neoclassical theory of business investment behaviour and better coincide with the empirical results already established in the literature (Bond and Xing, 2015; Fatica, 2018). Since the average number of observations per cross-sectional is 17.62, it is possible that the bias in the instrumental variable estimation method (the GMM estimator) due to too many instruments is quite pronounced. Roodman (2009a) explains that the instrument count is quadratic in the time dimension of the panel dataset, and the bias becomes very noticeable when the number of instruments explodes.

3.6 Conclusion

Empirical studies of the relationship between capital and the user cost of capital agree on an inverse relationship between them. This relationship is underpinned by the existence of a long-term cointegrating relationship between capital, output and the user cost of capital. This cointegrating relationship is studied for five types of physical capital assets: computing equipment (IT), communications equipment (CT), transport equipment (TraEq), other machinery and equipment (OMach), non-residential investment or structures (OCon); and two types of intangible capital assets: software and databases (SoftD) and research and development (R&D).

The first conclusion we draw summarises the results using first an unbalanced panel dataset containing 137 country-sector pairs and an average number of observations per country-sector pair of 17.62, and then a balanced panel dataset containing 68 country-sector pairs with 19 observations per country-sector pair. These data cover the period 1995-2015. The DFE estimates of the relationship between capital and the user cost of capital in an error-correction model of the change in the capital stock provide the empirical results that are the most consistent with the general conclusions of the neoclassical theory of business investment behaviour. These results are also consistent with empirical results for physical capital assets already established in the literature. Thus changes in the user cost of capital significantly affect capital accumulation for all physical capital assets in IT, CT, TraEq, OMach, and OCon; and for SoftD, but not for R&D, among intangible capital assets. If we take into account the potential problem of dynamic panel bias by applying GMM estimation, we see that these conclusions hold adequately well for IT capital, although at the level of the short-run dynamics both DFE and GMM provide estimates that are qualitatively equivalent for all types of capital.

In a second effort, the model is estimated using a short balanced panel dataset containing 126 country-sector pairs over the period 1998-2003. The bias in the DFE estimation seems very noticeable. This is evidenced by the speed of adjustment parameters, which are two or three times higher compared to the cases presented in the previous paragraph. The GMM estimation confirms the long-run relationship between capital and the user cost of capital for CT and R&D.

Finally, a modified model that assumes that the user cost of capital can be decomposed into its price and non-price components is estimated using the unbalanced panel dataset containing 137 country-sector pairs and an average number of 17.62 observations per country-sector pairs. The DFE estimates confirm that changes in the relative prices of capital goods (i.e., the price component of the user cost of capital) significantly influence changes in the capital stock for all types of capital, except for R&D. However, the non-price component of the user cost of capital impacts capital change for only OMach. The GMM estimation confirms that changes in the relative prices of capital goods have a long-term impact on the evolution of the capital stock for IT and CT. In contrast, changes in the non-price component of the user cost of capital affect changes in the stock of capital for IT and TraEq, in the long-run. Altogether, it seems that for capital stock in the form of IT, the relationship between capital and the user cost of capital is verified and the choice of estimation method does not matter.

Roodman (2009a) argued that if one has a panel dataset with a sufficiently large time dimension, e.g., 20 or more observations per cross-sectional unit, fixed-effects estimation will work well since small sample biases will be insignificant. In this respect, future releases of the EU KLEMS database that extend the time dimension of the dataset will be very useful, as they will allow us to measure the robustness of the DFE estimation results. They will also allow us to apply other fixed-effects estimation methods that are able to take into account the heterogeneity between country-sector pairs.

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3.8 Appendix

3.8.1 Time series properties

Table 3.12: Cross-sectionally augmented Dickey-Fuller test (CADF) for the log of output

		Constant		Constant and trend	
Variables	Lags	Z[t-bar]	p-value	Z[t-bar]	p-value
Log of output	0	0.988	0.838	-1.379	0.084
	1	1.134	0.872	-2.412	0.008
	2	4.081	1.000	2.553	0.995
	3	6.178	1.000	6.369	1.000

Table 3.13: Cross-sectionally augmented Dickey-Fuller test (CADF) for the log of the stocks of capital

		Constant		Constant and trend	
Variables	Lags	Z[t-bar]	p-value	Z[t-bar]	p-value
Log of stock of capital in computing equipment	0	2.366	0.991	7.329	1.000
	1	-0.574	0.283	4.077	1.000
	2	3.449	1.000	8.963	1.000
	3	3.088	0.999	6.245	1.000
Log of stock of capital in communication equipment	0	4.122	1.000	4.104	1.000
	1	1.086	0.861	-2.878	0.002
	2	3.310	1.000	1.109	0.866
	3				
Log of stock of capital in transport equipment	0	10.680	1.000	11.580	1.000
	1	7.098	1.000	8.331	1.000
	2	8.537	1.000	9.755	1.000
	3	8.732	1.000	10.334	1.000
Log of stock of capital in other machinery and equipment	0	10.849	1.000	6.591	1.000
	1	6.610	1.000	1.285	0.901
	2	11.864	1.000	7.548	1.000
	3	13.984	1.000	12.489	1.000
Log of stock of capital in non-residential investment	0	4.232	1.000	7.979	1.000
	1	4.325	1.000	3.237	0.999
	2	6.212	1.000	6.205	1.000
	3	8.952	1.000	8.677	1.000
Log of stock of capital in software and databases	0	-3.662	0.000	0.369	0.644
	1	-4.870	0.000	-3.565	0.000
	2	1.398	0.919	2.784	0.997
	3	3.484	1.000	0.754	0.775
Log of stock of capital in research and development	0	2.496	0.994	8.408	1.000
	1	-2.126	0.017	3.196	0.999
	2	-0.505	0.307	6.657	1.000
	3	-2.571	0.005	4.138	1.000

Table 3.14: Cross-sectionally augmented Dickey-Fuller test (CADF) for the log of the user cost of capital

		Constant		Constant and trend	
Variables	Lags	Z[t-bar]	p-value	Z[t-bar]	p-value
Log of user cost of capital in computing equipment	0	-4.740	0.000	3.585	1.000
	1	-4.470	0.000	5.460	1.000
	2	0.059	0.523	11.459	1.000
	3	1.197	0.884	11.991	1.000
Log of user cost of capital in communication equipment	0	-9.152	0.000	-3.492	0.000
	1	-5.133	0.000	1.199	0.885
	2	-0.888	0.187	8.761	1.000
	3	3.468	1.000	10.325	1.000
Log of user cost of capital in transport equipment	0	-3.458	0.000	-2.529	0.006
	1	0.753	0.774	1.577	0.943
	2	3.315	1.000	6.753	1.000
	3	1.761	0.961	8.470	1.000
Log of user cost of capital in other machinery and equipment	0	-0.827	0.204	-1.786	0.037
	1	3.367	1.000	2.302	0.989
	2	3.432	1.000	5.925	1.000
	3	3.579	1.000	5.056	1.000
Log of user cost of capital in non-residential investment	0	-1.257	0.104	-2.704	0.003
	1	1.458	0.928	1.795	0.964
	2	5.420	1.000	5.077	1.000
	3	4.905	1.000	5.213	1.000
Log of user cost of capital in software and databases	0	-5.935	0.000	-5.936	0.000
	1	-5.604	0.000	-1.521	0.064
	2	-5.789	0.000	0.692	0.756
	3	5.788	1.000	6.530	1.000
Log of user cost of capital in research and development	0	-0.435	0.332	-1.136	0.128
	1	3.192	0.999	3.487	1.000
	2	5.010	1.000	5.774	1.000
	3	7.455	1.000	7.011	1.000

Table 3.15: Statistical summaries of the variables involved in the model in error correction form

Variables	Mean	Std.	Min	Max
Change in log of the stock of capital lag t-1 in IT	0.054	0.220	-1.040	2.982
Change in log of the stock of capital lag t-1 in CT	0.060	0.260	-1.036	4.330
Change in log of the stock of capital lag t-1 in TraEq	-0.011	0.099	-0.724	0.628
Change in log of the stock of capital lag t-1 in OMach	0.008	0.058	-0.256	0.788
Change in log of the stock of capital lag t-1 in OCon	0.001	0.066	-0.612	0.753
Change in log of the stock of capital lag t-1 in SoftD	0.037	0.106	-0.573	0.844
Change in log of the stock of capital lag t-1 in R&D	0.028	0.091	-1.032	1.256
Change in log of output	0.009	0.085	-0.572	0.417
Change in log of output lag t-1	0.008	0.086	-0.572	0.417
Change in log of user cost of capital in IT	-0.081	0.283	-3.386	1.658
Change in log of user cost of capital lag t-1 in IT	-0.093	0.282	-3.386	1.658
Change in log of user cost of capital in CT	-0.036	0.321	-3.401	1.937
Change in log of user cost of capital lag t-1 in CT	-0.045	0.322	-3.401	1.937
Change in log of user cost of capital in TraEq	-0.001	0.243	-1.445	1.833
Change in log of user cost of capital lag t-1 in TraEq	-0.007	0.243	-1.445	1.833
Change in log of user cost of capital in OMach	0.005	0.252	-1.468	1.969
Change in log of user cost of capital lag t-1 in OMach	-0.001	0.253	-1.468	1.969
Change in log of user cost of capital in OCon	0.016	0.252	-1.750	2.002
Change in log of user cost of capital lag t-1 in OCon	0.011	0.253	-1.750	2.002
Change in log of user cost of capital in SoftD	-0.005	0.203	-1.136	1.606
Change in log of user cost of capital lag t-1 in SoftD	-0.009	0.204	-1.136	1.606
Change in log of user cost of capital in R&D	0.012	0.223	-1.295	1.764
Change in log of user cost of capital lag t-1 in R&D	0.008	0.223	-1.295	1.764
Change in log of relative price of IT	-0.079	0.176	-3.305	1.059
Change in log of relative price lag t-1 of IT	-0.087	0.175	-3.305	1.059
Change in log of relative price of CT	-0.037	0.193	-3.311	1.060
Change in log of relative price lag t-1 of CT	-0.040	0.194	-3.311	1.060
Change in log of relative price of TraEq	-0.001	0.084	-1.055	0.970
Change in log of relative price lag t-1 of TraEq	-0.002	0.083	-1.055	0.970
Change in log of relative price of OMach	0.004	0.073	-0.662	0.506
Change in log of relative price lag t-1 of OMach	0.003	0.072	-0.662	0.506
Change in log of relative price of OCon	0.017	0.083	-1.607	1.278
Change in log of relative price lag t-1 of OCon	0.017	0.082	-1.607	1.278
Change in log of relative price of SoftD	-0.001	0.072	-0.635	0.451
Change in log of relative price lag t-1 of SoftD	-0.001	0.072	-0.635	0.451
Change in log of relative price of R&D	0.014	0.070	-0.628	0.480
Change in log of relative price lag t-1 of R&D	0.014	0.069	-0.628	0.480
Change in log of n-p.c. of user cost of capital in IT	-0.002	0.205	-0.987	1.282
Change in log of n-p.c. of user cost of capital lag t-1 in IT	-0.007	0.205	-0.987	1.282
Change in log of n-p.c. of user cost of capital in CT	0.001	0.240	-1.214	1.573
Change in log of n-p.c. of user cost of capital lag t-1 in CT	-0.004	0.241	-1.214	1.573
Change in log of n-p.c. of user cost of capital in TraEq	0.000	0.227	-1.144	1.485
Change in log of n-p.c. of user cost of capital lag t-1 in TraEq	-0.005	0.228	-1.144	1.485
Change in log of n-p.c. of user cost of capital in OMach	0.001	0.241	-1.230	1.593
Change in log of n-p.c. of user cost of capital lag t-1 in OMach	-0.004	0.242	-1.230	1.593
Change in log of n-p.c. of user cost of capital in OCon	-0.001	0.244	-1.282	1.636
Change in log of n-p.c. of user cost of capital lag t-1 in OCon	-0.007	0.245	-1.282	1.636
Change in log of n-p.c. of user cost of capital in SoftD	-0.004	0.191	-0.926	1.198
Change in log of n-p.c. of user cost of capital lag t-1 in SoftD	-0.008	0.191	-0.926	1.198
Change in log of n-p.c. of user cost of capital in R&D	-0.002	0.211	-1.050	1.363
Change in log of n-p.c. of user cost of capital in lag t-1 in R&D	-0.006	0.211	-1.050	1.363

3.8.2 Choice of instruments in GMM regressions

The autoregressive distributed lag ARDL(2,2) model expressed in equation [3.3] is estimated by applying the GMM estimation method (two-step system GMM). In this respect, some considerations have been made. First of all, we note that the long-term coefficient of the log of the capital-output ratio ($k_{ij,t-2} - y_{ij,t-2}$) of the model in equation [3.4] is equal to 1. This restriction is taken into account in the estimation of the ARDL(2,2) model. Second, this GMM implementation uses as predetermined variables the lagged values of capital, the current and lagged values of output, and the current and lagged values of the user cost of capital. The exogenous variables are year dummies. The final consideration concerns how to limit the proliferation of instruments. In order to restrain the proliferation of instruments Roodman (2009a) and Roodman (2009b) proposed "collapsing" the instrument set and/or limiting the number of lags to be included by dropping the leftmost columns of the instrument matrix. All this is done while paying special attention to the results of the AR(1) and AR(2) tests and the Hansen test of overidentifying restrictions. In practice the AR(1) hypothesis should be rejected because of the dynamics of the model, the AR(2) hypothesis should not be rejected, and finally we should find the p-value of the Hansen test of overidentifying restrictions between 0.1 and 0.25 (Roodman, 2009b).[16]

3.8.2.1 GMM regression results in Table 3.5

This paragraph describes the choice of instruments used in the regression results presented in Table 3.5. The instrumental variables are the first lag of the change in the logarithm of the capital stock ($L1.dlnK$), the second lag of the logarithm of the capital stock minus the second lag of the logarithm of real value added ($L2.lnK - L2.lnY$), the change in the logarithm of real value added ($dlnY$), the first lag of the change in the logarithm of real value added ($L1.dlnY$), the change in the logarithm of the user cost of capital ($dlnc$), the first lag of the change in the logarithm of the user cost of capital ($L1.dlnc$), the second lag of the logarithm of the user cost of capital ($L2.lnc$). The set of instrumental variables is collapsed. Some of the leftmost columns of the instrument matrix are dropped. For example, the first three for computing equipment (IT), the first two for communications equipment (CT), the first three for transport equipment (TraEq), the first two for other machinery and equipment (OMach), the first two for non-residential investment or structures (OCon), the first five for software and databases (SoftD), and the first three for research and development (R&D). When the three leftmost columns of the instrument matrix are dropped as is the case for IT capital for example, variable lags from 4 to 20 are available instruments.

3.8.2.2 GMM regression results in Table 3.7

The instrument variables are virtually the same as described above for the GMM results presented in Table 3.5. The set of instruments is collapsed as before. The only difference comes from the strategy to limit the proliferation of instruments by dropping the leftmost columns of the instrument matrix. The first six columns of the instrument matrix are dropped for IT. The first five for CT, the first four for TraEq, the first two for OMach, the first four for OCon, the first two for SoftD,

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[16] The procedure xtabond2 in Stata is used to obtain the estimated coefficients. Several options are used: *twosep* to request feasibly efficient GMM estimator (FEGMM); *robust*, which is equivalent to *cluster(id)*, to request standard errors that are robust to heteroscedasticity; *small* to request small-sample corrections; and finally *orthogonal* to request the forward orthogonal-deviations transform instead of first differencing. The option *laglimits(a .)* drops the $a-1$ first vectors of instruments; i.e., the $a-1$ leftmost columns of the instrument matrix.

and the first three for R&D. Thus, lagged variables from 7 to 20, 6 to 20, 5 to 20, 3 to 20, 5 to 20, 3 to 20, and 4 to 20 lags are available instruments for respectively IT, CT, TraEq, OMach, OCon, SoftD, and R&D.

3.8.2.3 GMM regression results in Table 3.9

Again, the instrument variables used previously are considered. The set of instrument variables is collapsed. Since the time dimension of this sub-sample dataset used in the regression is short, the strategy of dropping the leftmost columns of the instrument matrix is not applied.

3.8.2.4 GMM regression results in Table 3.11

The instrument variables are the same as before. Also in this case, the set of instruments is collapsed. The only difference comes from the effort to limit the proliferation of instruments by dropping the leftmost columns of the instrument matrix. The first nine columns of the instrument matrix are dropped for IT capital. The first twelve are dropped for CT, the first eight for TraEq, the first twelve for OMach, the first eight for OCon, the first ten for SoftD, and the first eight for R&D. Thus, lagged variables from 10 to 20, 13 to 20, 9 to 20, 13 to 20, 9 to 20, 11 to 20, and 9 to 20 lags are available instruments for respectively IT, CT, TraEq, OMach, OCon, SoftD, and R&D.

3.8.3 Regression results for the ARDL(2,2) models

Table 3.16 shows the estimated coefficients of the autoregressive distributed lag model, ARDL(2,2), estimated in section 3.4.2. Tables 3.17, 3.18, and 3.19 show the estimated coefficients of the autoregressive distributed lag model, ARDL(2,2), estimated respectively using the longest possible panel dataset, a simple short panel dataset, and applying an alternative specification that allows the user cost of capital to be decomposed into its price and non-price components. This autoregressive model is restricted because it imposes the long-term coefficient of the log of capital-output ratio in the model in error correction, $(k_{ij,t-2} - y_{ij,y-2})$, to be equal to 1. The estimated coefficients are obtained applying the GMM estimation method. Collapsing the set of instruments and dropping the leftmost columns of the matrix of instruments are two techniques suggested by Roodman (2009b) used to help limit the proliferation of instruments.

Table 3.16: Estimates for the log of stock of capital equations in an autoregressive distributed lag model (equation 3.3), using GMM estimator

Dependent variable: k_t^n	IT	CT	TraEq	OMach	OCon	SoftD	R&D
Log of the stock of capital lag t-1, k_{t-1}^n	0.941^{***}	1.067^{***}	1.481^{***}	1.352^{***}	0.692^{***}	1.044^{***}	1.374^{***}
	(0.078)	(0.058)	(0.094)	(0.092)	(0.117)	(0.123)	(0.091)
Log of the stock of capital lag t-1, k_{t-2}^n	-0.072	-0.061	-0.486^{***}	-0.335^{***}	0.333^{***}	-0.083	-0.411^{***}
	(0.066)	(0.054)	(0.101)	(0.093)	(0.116)	(0.119)	(0.083)
Log of output, y_t	0.202	0.031	0.057	0.038	0.031	0.211	0.107
	(0.227)	(0.241)	(0.105)	(0.055)	(0.047)	(0.161)	(0.073)
Log of output lag t-1, y_{t-1}	-0.459	-0.193	-0.058	-0.033	0.097	0.064	0.068
	(0.294)	(0.352)	(0.137)	(0.095)	(0.071)	(0.211)	(0.096)
Log of output lag t-2, y_{t-2}	0.388^{**}	0.155	0.006	-0.022	-0.153^{***}	-0.235	-0.138
	(0.156)	(0.188)	(0.065)	(0.070)	(0.054)	(0.145)	(0.091)
Log of user cost of capital, ϑ_t^n	-0.344^{***}	-0.295^{***}	0.029	-0.029^{***}	-0.015^{*}	-0.064^{*}	-0.028
	(0.072)	(0.087)	(0.019)	(0.010)	(0.008)	(0.033)	(0.028)
Log of user cost of capital lag t-1, ϑ_{t-1}^n	0.123^{**}	0.158^{**}	-0.063^{**}	0.021	-0.013	0.045	-0.044^{**}
	(0.049)	(0.069)	(0.027)	(0.021)	(0.012)	(0.038)	(0.021)
Log of user cost of capital lag t-2, ϑ_{t-2}^n	0.083^{***}	0.070^{*}	-0.001	-0.016^{*}	0.011	0.012	0.052^{***}
	(0.028)	(0.038)	(0.024)	(0.008)	(0.012)	(0.027)	(0.018)
Country-sector fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year dummy	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of instruments	131	136	131	136	136	118	131
Number of groups	137	137	137	137	137	137	137
Observations	2414	2414	2414	2414	2414	2414	2414
Arellano-Bond test for AR(1) (p-value)	0.000	0.000	0.000	0.005	0.075	0.006	0.008
Arellano-Bond test for AR(2) (p-value)	0.763	0.207	0.886	0.101	0.040	0.832	0.089
Sargan test of overid. restrictions (p-value)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Hansen test of overid. restrictions (p-value)	0.130	0.155	0.195	0.425	0.324	0.197	0.187

Notes: Each column presents the estimated coefficients of the investment equation for each capital asset such that n equals computing equipment (IT), communications equipment (CT) and transport equipment (TraEq), other machinery and equipment (OMach), non-residential investment or structures (OCon), software and databases (SoftD), and research and development (R&D). The estimation method is two-step system GMM. The standard errors are in parenthesis. We consider: * $p < 0.10$, ** $p < 0.05$, and *** $p < 0.01$. For this GMM specification the predetermined variables are the lagged values of capital, the current and lagged values of output, and the current and lagged values of the user cost of capital. The exogenous variables are the year dummies. The set of instrument variables is collapsed. The leftmost columns of the instrument matrix are dropped. For example, the first 3 columns for IT, the first 2 for CT, the first 3 for TraEq, the first 2 for OMach, the first 2 for OCon, the first 5 for SoftD, and the first 3 for R&D were dropped.

Table 3.17: Estimates for the log of stock of capital equations in an autoregressive distributed lag model (equation 3.3): using the GMM estimator with the longest balanced panel dataset

Dependent variable: k_t^n	IT	CT	TraEq	OMach	OCon	SoftD	R&D
Log of the stock of capital lag t-1, k_{t-1}^n	1.387***	1.163***	1.493***	1.497***	0.661***	1.248***	1.200***
	(0.075)	(0.082)	(0.096)	(0.137)	(0.094)	(0.175)	(0.072)
Log of the stock of capital lag t-1, k_{t-2}^n	-0.429***	-0.215***	-0.488***	-0.489***	0.348***	-0.255	-0.212***
	(0.073)	(0.075)	(0.100)	(0.139)	(0.089)	(0.173)	(0.074)
Log of output, y_t	0.384**	0.070	0.180*	0.088	-0.021	0.080	0.093
	(0.152)	(0.235)	(0.105)	(0.073)	(0.107)	(0.085)	(0.090)
Log of output lag t-1, y_{t-1}	-0.260	0.128	-0.228*	-0.080	0.226	-0.086	0.124
	(0.314)	(0.518)	(0.121)	(0.084)	(0.165)	(0.123)	(0.143)
Log of output lag t-2, y_{t-2}	-0.082	-0.146	0.044	-0.016	-0.214**	0.012	-0.204*
	(0.238)	(0.375)	(0.092)	(0.048)	(0.090)	(0.077)	(0.111)
Log of user cost of capital, ϑ_t^n	-0.356***	-0.114	-0.008	0.029	0.078*	0.072	-0.041
	(0.116)	(0.091)	(0.048)	(0.034)	(0.044)	(0.054)	(0.049)
Log of user cost of capital lag t-1, ϑ_{t-1}^n	0.194	0.467**	0.101	-0.088**	-0.137***	-0.020	0.144**
	(0.177)	(0.186)	(0.090)	(0.039)	(0.043)	(0.069)	(0.065)
Log of user cost of capital lag t-2, ϑ_{t-2}^n	0.113	-0.276	-0.079	0.054*	0.034	-0.063	-0.085*
	(0.093)	(0.167)	(0.077)	(0.028)	(0.036)	(0.063)	(0.044)
Country-sector fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year dummy	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of instruments	88	93	98	108	98	108	103
Number of groups	68	68	68	68	68	68	68
Observations	1292	1292	1292	1292	1292	1292	1292
Arellano-Bond test for AR(1) (p-value)	0.000	0.000	0.001	0.002	0.041	0.035	0.001
Arellano-Bond test for AR(2) (p-value)	0.937	0.572	0.387	0.431	0.045	0.297	0.553
Sargan test of overid. restrictions (p-value)	0.000	0.000	0.000	0.019	0.000	0.000	0.000
Hansen test of overid. restrictions (p-value)	0.465	0.891	0.968	0.995	0.979	0.973	0.998

Notes: Each column presents the estimated coefficients of the investment equations for each type of capital such that n equals computing equipment (IT), communications equipment (CT) and transport equipment (TraEq), other machinery and equipment (OMach), non-residential investment or structures (OCon), software and databases (SoftD), and research and development (R&D). The estimation method is two-step system GMM. The standard errors are in parenthesis. We consider: * $p < 0.10$, ** $p < 0.05$, and *** $p < 0.01$. For this GMM specification the predetermined variables are the lagged values of capital, the current and lagged values of output, and the current and lagged values of the user cost of capital. The exogenous variables are the year dummies. The set of instrument variables is collapsed. The leftmost columns of the instrument matrix are dropped. For example, the first 6 columns for IT, the first 5 for CT, the first 4 for TraEq, the first 2 for OMach, the first 4 for OCon, the first 2 for SoftD, and the first 3 for R&D were dropped.

Table 3.18: Estimates for the log of stock of capital equations in an autoregressive distributed lag model (equation 3.3): using the GMM estimator with a short restricted balanced panel dataset

Dependent variable: k_t^n	IT	CT	TraEq	OMach	OCon	SoftD	R&D
Log of the stock of capital lag t-1, k_{t-1}^n	0.785***	0.618***	1.083***	0.955***	0.676***	0.992***	0.834***
	(0.077)	(0.104)	(0.152)	(0.122)	(0.093)	(0.164)	(0.063)
Log of the stock of capital lag t-1, k_{t-2}^n	-0.082	0.110	-0.167	-0.147*	0.215***	-0.270***	-0.024
	(0.056)	(0.077)	(0.147)	(0.087)	(0.066)	(0.093)	(0.028)
Log of output, y_t	0.097	0.160	0.131**	0.167***	0.053	0.135*	0.057
	(0.160)	(0.099)	(0.061)	(0.050)	(0.043)	(0.080)	(0.070)
Log of output lag t-1, y_{t-1}	-0.012	0.017	-0.012	0.018	0.025	0.036	0.097
	(0.125)	(0.097)	(0.065)	(0.057)	(0.036)	(0.098)	(0.067)
Log of output lag t-2, y_{t-2}	0.212	0.095	-0.036	0.007	0.032	0.107	0.035
	(0.149)	(0.105)	(0.066)	(0.050)	(0.046)	(0.088)	(0.060)
Log of user cost of capital, ϑ_t^n	0.026	-0.287***	-0.049	-0.026*	-0.004	-0.081**	-0.068***
	(0.052)	(0.064)	(0.035)	(0.014)	(0.017)	(0.037)	(0.020)
Log of user cost of capital lag t-1, ϑ_{t-1}^n	-0.049	0.083	0.096**	-0.064***	-0.023	0.069	-0.029
	(0.043)	(0.064)	(0.042)	(0.022)	(0.018)	(0.056)	(0.021)
Log of user cost of capital lag t-2, ϑ_{t-2}^n	0.021	-0.047	0.090*	0.027	-0.000	-0.050	0.011
	(0.039)	(0.041)	(0.049)	(0.019)	(0.022)	(0.048)	(0.029)
Country-sector fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year dummy	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of instruments	26	26	26	26	26	26	26
Number of groups	126	126	126	126	126	126	126
Observations	571	571	571	571	571	571	571
Arellano-Bond test for AR(1) (p-value)	0.006	0.010	0.024	0.009	0.013	0.006	0.033
Arellano-Bond test for AR(2) (p-value)	0.399	0.625	0.921	0.169	0.308	0.175	0.263
Sargan test of overid. restrictions (p-value)	0.001	0.000	0.014	0.000	0.000	0.000	0.000
Hansen test of overid. restrictions (p-value)	0.001	0.263	0.079	0.001	0.096	0.012	0.292

Notes: Each column presents the estimated coefficients of the investment equation for each capital asset such that n equals computing equipment (IT), communications equipment (CT) and transport equipment (TraEq), other machinery and equipment (OMach), non-residential investment or structures (OCon), software and databases (SoftD), and research and development (R&D). The estimation method is two-step system GMM. The standard errors are in parenthesis. We consider: * $p < 0.10$, ** $p < 0.05$, and *** $p < 0.01$. For this GMM specification the predetermined variables are the lagged values of capital, the current and lagged values of output, and the current and lagged values of the user cost of capital. The exogenous variables are the year dummies. The set of instrument variables is collapsed.

Table 3.19: Estimates for the log of stock of capital equations in an autoregressive distributed lag model (equation 3.3): using the GMM estimator with decomposed user cost of capital

Dependent variable: k_t^n	IT	CT	TraEq	OMach	OCon	SoftD	R&D
Log of the stock of capital lag t-1, k_{t-1}^n	1.057***	1.013***	1.120***	1.300***	0.757***	1.047***	1.404***
	(0.129)	(0.079)	(0.112)	(0.092)	(0.166)	(0.115)	(0.107)
Log of the stock of capital lag t-2, k_{t-2}^n	-0.138	-0.035	-0.146	-0.288***	0.263	-0.082	-0.427***
	(0.115)	(0.074)	(0.109)	(0.097)	(0.166)	(0.109)	(0.106)
Log of output, y_t	0.319**	-0.021	0.081	-0.026	0.140	0.114	0.173**
	(0.159)	(0.252)	(0.111)	(0.059)	(0.084)	(0.290)	(0.074)
Log of output lag t-1, y_{t-1}	-0.581***	0.275	-0.063	0.120*	-0.007	0.203	-0.032
	(0.202)	(0.236)	(0.119)	(0.063)	(0.061)	(0.253)	(0.102)
Log of output lag t-2, y_{t-2}	0.343**	-0.232	0.008	-0.105**	-0.152**	-0.282	-0.117
	(0.145)	(0.198)	(0.096)	(0.048)	(0.059)	(0.235)	(0.094)
Log of relative price, $\widetilde{p}_t^n$	-1.035***	-0.911***	0.131	-0.093	-0.075	0.007	-0.206**
	(0.066)	(0.067)	(0.123)	(0.061)	(0.047)	(0.158)	(0.090)
Log of relative price lag t-1, $\widetilde{p}_{t-1}^n$	0.966***	0.835***	-0.163	0.048	0.028	-0.204	0.194
	(0.127)	(0.118)	(0.134)	(0.085)	(0.054)	(0.155)	(0.128)
Log of relative price lag t-2, $\widetilde{p}_{t-2}^n$	-0.089	-0.033	0.052	0.106	0.051	0.030	-0.026
	(0.096)	(0.094)	(0.080)	(0.076)	(0.052)	(0.177)	(0.062)
Log of n.p.c. of user cost, $\widetilde{np}_t^n$	-0.040	-0.108	0.013	-0.014	-0.024*	-0.017	-0.015
	(0.041)	(0.125)	(0.016)	(0.019)	(0.015)	(0.039)	(0.021)
Log of n.p.c. of user cost lag t-1, $\widetilde{np}_{t-1}^n$	-0.074	0.143**	-0.094***	0.011	-0.009	0.039	-0.018
	(0.064)	(0.059)	(0.026)	(0.024)	(0.012)	(0.039)	(0.019)
Log of n.p.c. of user cost lag t-2, $\widetilde{np}_{t-2}^n$	-0.048	0.041	-0.061***	-0.008	0.024**	-0.014	0.028
	(0.051)	(0.060)	(0.022)	(0.010)	(0.012)	(0.038)	(0.018)
Country-sector fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year dummy	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of instruments	120	90	130	90	130	110	130
Number of groups	137	137	137	137	137	137	137
Observations	2414	2414	2414	2414	2414	2414	2414
Arellano-Bond test for AR(1) (p-value)	0.002	0.001	0.002	0.004	0.116	0.003	0.010
Arellano-Bond test for AR(2) (p-value)	0.602	0.711	0.541	0.226	0.094	0.670	0.135
Sargan test of overid. restrictions (p-value)	0.000	0.001	0.000	0.000	0.000	0.000	0.009
Hansen test of overid. restrictions (p-value)	0.109	0.154	0.114	0.134	0.403	0.170	0.213

Notes: Each column presents the estimated coefficients of the investment equation for each capital asset such that n equals computing equipment (IT), communications equipment (CT) and transport equipment (TraEq), other machinery and equipment (OMach), non-residential investment or structures (OCon), software and databases (SoftD), and research and development (R&D). The estimation method is two-step system GMM. The symbol n.p.c. stands for non-price component. We consider: * $p < 0.10$, ** $p < 0.05$, and *** $p < 0.01$. For this GMM specification the predetermined variables are the lagged values of capital, the current and lagged values of output, and the current and lagged values of the user cost of capital. The exogenous variables are the year dummies. The set of instrument variables is collapsed. The leftmost columns of the instrument matrix are dropped. For example, the first 9 columns for IT, the first 12 for CT, the first 8 for TraEq, the first 12 for OMach, the first 8 for OCon, the first 10 for SoftD, and the first 8 for R&D were dropped.