Cross your border and look around

Henry van der Wiel, Harold Creusen, George van Leeuwen and Eugène van der Pijll

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Explanation of symbols

.	= data not available
*	= provisional figure
x	= publication prohibited (confidential figure)
–	= nil or less than half of unit concerned
–	= (between two figures) inclusive
0 (0,0)	= less than half of unit concerned
blank	= not applicable
2005-2006	= 2005 to 2006 inclusive
2005/2006	= average of 2005 up to and including 2006
2005/'06	= crop year, financial year, school year etc. beginning in 2005 and ending in 2006
2003/'04–2005/'06	= crop year, financial year, etc. 2003/'04 to 2005/'06 inclusive

Due to rounding, some totals may not correspond with the sum of the separate figures.

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Cross your border and look around

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Abstract

This document focuses on innovation, human capital, technology transfers and competition as potential sources of productivity growth for firms. It integrates the views of existing literature such as the two faces of R&D, the convergence debate and the existence of firm-level heterogeneity in productivity. Using firm-level data of 127 industries in the Netherlands, the document analyses which determinants are most relevant for a catch up to the global frontier and in that respect are important for the productivity performance of firms. Moreover, the document takes into account the potential importance of a national frontier. The frontier is defined as the highest productivity level at the national or global level respectively. The document provides econometric evidence that technology transfers matter, predominantly from the national frontier. Particularly, R&D encourages growth through technology transfers from the national frontier. This suggests that firms mainly conduct R&D in order to adopt existing technologies from other (domestic) firms. Competition on Dutch markets plays a role in productivity growth as well. Finally, human capital also seems to affect productivity growth.

Keywords: Competition, human capital, technological frontier, R&D, productivity

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Preface

This paper is the result of a common research project of the Central Planning Bureau (CPB) and Statistics Netherlands. The project fits into a wider program of the CPB which has investigated the productivity gap and convergence to the frontier in two related research projects: a macro and micro project. The current paper documents the results of the micro-project. Using firm-level data, it analyses the convergence to the technological frontier (i.e. the highest level of productivity) of firms located in the Netherlands. Two issues are particularly addressed in the micro research project. First, it distinguishes convergence to the national frontier from convergence to the global frontier. Second, it also explicitly investigates the impact of competition on productivity growth.

This study was conducted by a project team consisting of Harold Creusen, George van Leeuwen (Statistics Netherlands), Eugene van der Pijll (Statistics Netherlands) and Henry van der Wiel (project leader). We express our thanks to George Gelauff, Free Huizinga, Debby Lanser, Bert Balk (Statistics Netherlands), Michael Polder (Statistics Netherlands) and other colleagues for their comments on earlier versions of this document. We also thank participants of the EUKLEMS final conference (Groningen, 19-20 June 2008), the conference on 'Knowledge for Growth' (Toulouse, 7-9 July 2008) and a sounding board meeting at the CPB.

Finally, part of the data analysis reported in this document was carried out at the Centre for Policy Related Statistics of Statistics Netherlands. The paper is also available as a CPB Document (no. 170) The views expressed in this paper are those of the authors and do not necessarily reflect any policy by CPB or CBS.

Summary

Research question

This document focuses on innovation, human capital, technology transfers and competition as potential sources of productivity growth for firms. It integrates the views of existing literature such as the two faces of R&D, the importance of R&D-spillovers, the convergence debate and the existence of firm-level heterogeneity in productivity. It adds two related but important issues to the literature. First, it explicitly distinguishes convergence to the national frontier from convergence to the global frontier. The frontier is defined as the highest Total Factor Productivity (TFP) level at the national or global level respectively. Second, it also investigates the impact of competition on productivity growth. The main research questions in this study are:

- Which determinants are relevant for catch up, either to the global frontier or to the national frontier?
- Does competition stimulate convergence to the frontiers?

Main conclusions

The document provides econometric evidence that technology transfers matter. We find that the national frontier exercises a stronger pull on domestic firms than the global frontier. Apparently, firms benefit more from national spillovers rather than from international spillovers. R&D encourages growth through technology transfers from the national frontier. This suggests that firms mainly conduct investments in own R&D in order to adopt existing technologies from other (domestic) firms. We hardly find evidence that R&D contributes to productivity via innovation if controlled for other explanatory variables. Competition on (Dutch) markets seems to affect productivity growth in several ways. Competition enhances TFP-growth directly, as it drives firms to operate efficiently and reduce X-inefficiencies. More competition also stimulates firms to imitate and catch up to the national frontier. Finally, we find preliminary evidence for human capital stimulating productivity.

Model and data

There exists a vast literature on explaining productivity levels and convergence between countries emphasising the role of knowledge spillovers and imitation. For example, several studies at the industry level have analysed potential means that may help lagging countries to catch up to the global frontier. In this respect, Griffith et al. (2004) also point to the ‘second face’ of R&D: countries may also use investment in own R&D to absorb knowledge and adopt technologies from leading firms. Bartelsman et al. (2006) stress the importance of heterogeneity across firms within each country. They suggest that lagging firms likely focus on the convergence to the national frontier rather than to the global frontier. The relevance of a

national frontier finds its arguments, amongst others, in social, geographical and institutional barriers. Finally, theoretical and empirical research of Aghion et al. (2004, 2006) emphasises the effect of competition on productivity growth, as competition may affect firm's incentives to innovate or imitate in diverging directions.

In our econometric framework, we combine all those views including the distinction between two types of convergence, i.e. to the national frontier versus to the global frontier. Using firm-level data of 127 manufacturing, services and construction industries in the Netherlands, we analyse which determinants are most relevant for catch up and in that respect are important for the productivity performance of firms.

Robustness checks

We have examined the robustness of our main findings as a number of econometric concerns can be put forward. All in all, the results of these robustness tests do not radically change the overall conclusions. More precisely, we review concerns related to measurement errors in TFP and the sensitivity to the definition of the frontier including the available data. Another concern is the endogeneity of R&D. Finally, we have checked the robustness of the estimates with respect to human capital. At the firm level we cannot measure human skills directly, because no specific data of the (average) education level and experience of the employees within each firm are available. We approximate human capital by the average wage level per firm.

Concluding remarks

This document underlines the importance of R&D, competition and to some extent human capital for productivity. The importance of those determinants hardly differs at the industry level or between firms. For both manufacturing and services, the convergence to the national frontier is more relevant than to the global frontier. Additionally, a distinction between advanced and lagging firms does not alter the results either. This is particularly relevant for the impact of competition as theory argues that fiercer competition may stimulate productivity of leading firms, while it may induce lagging firms to abstain from improvements of productivity.

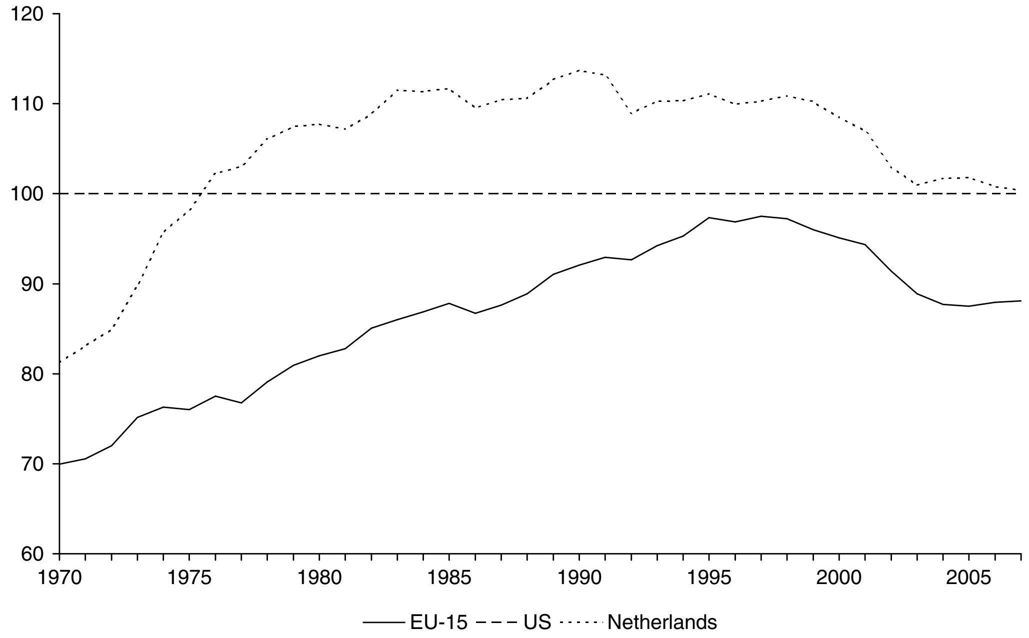
The implications of our findings for additional or new policy measures are not clear-cut. The importance of knowledge (spillovers) via technology transfers, innovation and sufficient competition are already embedded in existing policy. We did not investigate whether market failures are at stake and could legitimize government intervention. Instead, we address options for future work in terms of policy implications, and improvements in model and data.

1 Introduction

Background

Over the last decades the labour productivity lead of the Dutch economy seems to have easy come and easy gone. After World War II, the Netherlands caught up with the US, and took over the lead in the early 1970s (see figure 1.1). This is remarkable, as the US is mostly considered as the country with the most advanced technology and the highest productivity level. Since the second half of the 1990s, however, the lead of the Dutch economy as a whole on the US has diminished. Similarly, the Dutch favourable position to the average of the old EU-15 countries as a whole has deteriorated to some extent as well.

Figure 1.1 Labour productivity level total economy of the Netherlands and EU compared to the US, 1907-2007



Source: The Conference Board and Groningen Growth and Development Centre, Total Economy Database, January 2008 with GDP converted to US$ at 2007 EKS PPPs (updated from 2005 benchmark)

Comparisons at the industry level put the Dutch favourable macro position in another light. Being the best at the aggregated level does not automatically imply being the best at lower levels of aggregation all across the board. In fact, the leading position of the Dutch market sector as a whole can only be traced back to a few industries. Data from the EUKLEMS-database reveal, for instance, that the Dutch transport industry is one of the world leaders in productivity levels.[2] In contrast, many other Dutch industries, such as the telecom industry, feature productivity levels that are far below the productivity level of the global frontier: the

[2] See www.euklems.net.

highest attainable productivity level given the existing technologies.[3] So in these industries opportunities exist to catch up to the global frontier.

Analysing the distance to the global frontier (or shortly the productivity gap) is relevant as it may signal potentials for productivity growth. Recent studies of Griffith et al. (2004) and Conway et al. (2006) emphasize the importance of technology transfers and the effect of product market regulations on the international diffusion of productivity shocks. Griffith et al. (2004) show that R&D is important for the catch up process as well as for stimulating innovation. A lagging industry may learn from the leading industry elsewhere in the world, particularly by knowledge spillovers and imitation of existing technologies. Then, this industry can realize a productivity growth that is higher than the productivity growth of the leading (foreign) industry, and thus can reduce its productivity gap with the frontier. Conway et al. (2006) find that restrictive product market regulations slow the process of adjustment through which best practice production techniques diffuse across borders and new technologies are incorporated into the production process.

Most of these ‘convergence’ studies use industry data across countries. However, these studies include two shortcomings as they do not explicitly take into account the heterogeneity across firms in one particular industry.

First, industry-level studies implicitly assume that all firms have the same productivity level, or at least they assume that the distribution in productivity levels across firms remain constant over time. Mostly those kinds of studies use industry averages of productivity levels and compare these averages across countries. Studies based on firm-level data, however, point to a large, non-constant, dispersion of productivity levels across firms in different countries. Bartelsman et al. (2006) point out that the average productivity level might provide a “poor proxy” of the global frontier. In some countries individual firms may have higher TFP-levels than the global frontier based on industry averages, and thus will less likely learn from the technology of the global frontier. Hence, the parameters of the explanatory variables might be biased in industry-level studies.

Second, these types of studies do not investigate the convergence within countries to some kind of national frontier: the firm representing the highest productivity level of an industry at the national level. Bartelsman et al. (2006) suggest that it is likely that within a country lagging firms converge to the leading firm of that country, while the latter may converge to the global frontier. A number of arguments support the idea of a national frontier. Indeed, some firms may not catch up directly with the global frontier as they have insufficient R&D and human skills, have little international trade or international contact with firms at the global frontier, or

[3] Note that this document focuses on total factor productivity (TFP-) levels and growth as measures of productivity performance. The frontier is defined for each industry as the country with the highest level of TFP. TFP-growth reflects the growth in gross value added that cannot be attributed to the growth in inputs.

institutional restrictions hinder them too much. Those arguments bring forth the introduction of the national frontier.

Note that in services industries compared to manufacturing industries, convergence to the national frontier might be more relevant than convergence to the global frontier. The reason is that firms in services industries more likely operate on national or even regional markets, and cope with specific preferences of (Dutch) customers and/or institutional settings. A priori, firms in manufacturing industries, however, operate more often on international markets, and may thus focus on convergence to the global frontier.

Aim of document

CPB investigates the productivity gap and convergence to the frontier in two related research projects: macro and micro project. The macro-project analyses the position of the Dutch industries on the international productivity level ladder, and investigates the determinants of convergence of industries to the global frontier.[4] Following current studies on the convergence to the frontier, it also considers the industry averages of productivity levels of several countries.

The current document documents the results of the micro project. Using firm-level data, this document analyses the convergence of firms located in the Netherlands to the frontier. It adds two related issues to the existing literature. First, it distinguishes convergence to the national frontier from convergence to the global frontier. Second, it also investigates the impact of competition on productivity growth.

The main research questions in this document are:

- Which determinants are relevant for catch up, either to the global frontier or to the national frontier?
- Does competition stimulate convergence to the frontiers?

The structure of the document is as follows. Chapter 2 discusses the main theoretical determinants of productivity growth to the technological frontier. Chapter 3 presents our basic model and elaborates on the econometric specification. It also highlights issues that may bias the results. In Chapter 4 we introduce the available data and show some stylized facts. Chapter 5 presents the results of our basic model and discusses the contribution of the determinants to productivity growth. Chapter 6 examines the robustness of the results along a number of channels. Finally, Chapter 7 sums up the main conclusions and sketches some implications for policy makers.

[4] Batrakova et al., 2008.

2 Theoretical framework

2.1 Introduction

This chapter provides a brief theoretical overview of the main determinants and their impact on productivity growth and convergence to the technological frontier. More precisely, we will focus on the total factor productivity (TFP) growth of firms, and the distance in TFP level to the national or global frontier.

For a better understanding this chapter classifies the determinants of productivity into three groups. The first group contains the *means* to attain productivity growth, particularly R&D and human skills. Conducting R&D or using relative more human skills may (initially) require some costs, but eventually result in additional benefits from higher productivity levels. The second group of determinants represents the determinants that affect the *incentives* for productivity growth, particularly competition. The intensity of competition including (the threat of) entry emerge from the market structure together with institutional settings on product markets, and are mostly beyond the reach of individual firms. The third group of determinants facilitates codified or embodied knowledge transfers that enhance productivity growth. These determinants mainly concern the level of international trade with the frontier country, and the cultural and physical proximity of the frontier country.

The theoretical discussion ends with a brief view on the theory of convergence clubs. This theory provides a helpful starting tool to introduce and to analyse the convergence of firms to the national or global frontier, as it combines several determinants into one framework.

2.2 Determinants of productivity growth

Group 1: R&D and human capital as means to attain productivity growth

Many studies have investigated the impact of R&D on productivity growth (see e.g. Cameron, 1998, for an overview). Griffith et al. (2004) provide some empirical evidence that R&D may have “two faces”. First, firms conduct R&D in order to generate own innovations for their products or production process, and thus create new technologies. This face, the innovation part, reflects the direct effect of R&D on productivity growth of firms. Second, firms may use their own R&D in order to absorb knowledge and adopt innovations from either domestic or foreign firms. To some extent, followers may reap benefits from cheap or costless imitation, e.g. by adopting codified knowledge of frontier firms that is free available (no licences) and that can be applied without any adjustments. But in order to reap *all* benefits from imitation they may also apply some own R&D to enhance their absorptive capacity, particularly to regenerate and/or adapt tacit knowledge in order to implement innovations in firm’s own products and process. So the second face of R&D, the imitation effect, refers to the benefits of knowledge spillovers. Hereafter, we will call this effect the indirect effect of R&D on productivity growth.

Note that with the potential for imitation, the social rate of return on *innovative* R&D is larger than the private rate of return. More precisely, an innovating firm cannot appropriate all the benefits of other imitating firms that may accrue from its innovation.[5] Firms may even abstain from innovation if their costs of innovation exceed their private (expected) benefits, notwithstanding the possibility that the social benefits may be higher than the costs of innovation.

Similarly as with R&D, human capital may have a direct effect and an indirect effect on productivity growth. Both effects are more or less related to heterogeneity in skills among employees, as high skilled employees have had more education or have more experience than low skilled employees have.

The direct effect of human capital is quite straightforward and refers to the skills and ability of employees. In fact, it is likely that high skilled employees are more productive than low skilled employees are. Then employing relatively more high skilled people will result in a higher (average) productivity (growth) as those people can come up more easily with new ideas increasing the rate of innovation.

Human capital may also affect the absorption capacity of knowledge and imitation, thus resulting in an indirect effect. Traditionally, it is argued that higher human skills facilitate the imitation of frontier technology, as high skilled employees are more able to absorb external knowledge than low skilled employees (see e.g. Nelson and Phelps, 1966). As a result, countries with higher skill levels more rapidly close the gap and catch up with the frontier than countries with lower skills.

In contrast, Vandenbussche et al. (2006) argue that higher skilled employees are more important for countries or firms close to the frontier, but less for countries that are more distant from the frontier and (more likely) should rely on imitation.[6] The basic assumption is that innovation is relatively more skilled-intensive than imitation. Then given the total size of the workforce, using *relatively* more high skilled labour has a growth-enhancing effect that goes through innovations. In this theoretical framework, the level of human skills is less important for countries (or firms) that are further behind the frontier, because those countries (or firms) can imitate either with high skilled or with low-skilled employees.

Group 2: Impact competition and entry on productivity growth

Recent papers have studied the impact of competition on innovation, imitation and productivity growth in different settings (see e.g. Aghion et al. (2002), Aghion et al. (2006)). They conclude

[5] I.e. if imitation of existing technologies are less expensive than reinventing similar technologies by innovations.

[6] See also Acemoglu et al., 2006.

that competition (including entry) may affect firms' incentives to innovate and/or imitate. However, the direction of these effects depends on firms' advantage vis-à-vis their competitors, or technically speaking on the relative productivity levels of the firms.

Aghion et al. (2002) investigated the impact of competition on innovation by analysing the different strategies of leaders and laggards on innovation or imitation. Their theory comes up with two basic effects that are useful for our research. On the one hand, more competition serves as a driving force for leading firms to innovate. In fact, the threat of (tougher) competition induces leading firms to enhance their productivity level and thus their competitive advantage vis-à-vis all other leading and lagging firms. This effect is also known as the escape competition effect. On the other hand, more competition may be detrimental for lagging firms to imitate the technology at the frontier. The reason is that fierce competition prevents lagging firms to recover all the costs of imitation, even if they *would* catch up with the leader. This effect is known as the Schumpeter effect.

A priori, it is ambiguous whether the escape competition or the Schumpeter effect dominates in an industry. In fact, Aghion et al. (2002) suggest that combining these two effects in a dynamic model results in an inverted U-relationship between competition and innovation.[7]

If there exist considerable productivity differences between firms within an industry, one could conclude that more competition eventually raises the distance between leading and lagging firms. In fact, if competition increases leading firms jump ahead (i.e. escape competition effect), while lagging firms stay behind. The increase in distance emerges only *after* innovations and TFP-growth (of leading firms) are realised, but it removes further (future) incentives of lagging firms to innovate or catch up.[8]

Aghion et al. (2006) investigated the impact of entry on incumbents' strategy to innovate. This model also makes a distinction between leading and lagging firms. The main conclusion is that … "*Increasing the threat of entry has a positive effect on incumbent innovation in sectors that are close to the* [global] *technological frontier, and a possibly negative effect on innovation in sectors that are further behind the* [global] *frontier…*" (see Aghion et al. (2006)). The effect of entry on the industry or sector productivity is in both cases positive.

Note that entry may be related to the intensity of competition between incumbents. If competition is low, then new firms may enter the market if they can easily recover their (sunk) cost of entry. However, if competition is high, then new firms cannot recover those costs and will not enter the market as long as they are going to sell the same product as incumbents do.

[7] More precisely, as competition intensifies the aggregate industry innovation expenditures will first increase as the escape competition effects dominates, but in case of a further increase of competition beyond some level the total innovation expenditures will decline as the Schumpeter effect dominates.

[8] Eventually, this effect is one of the crucial elements of the convergence trap of lagging firms, which will be discussed in section 2.2.

Group 3: International trade and physical proximity facilitating knowledge transfers
Finally, international trade of goods may contribute to productivity growth for three reasons. First, the discipline of (international) competition may induce firms to innovate and apply the most advanced technologies. For example, fierce price competition forces firms to produce in the most efficient way, and thus to adopt the most efficient production technology. Similarly, if foreign buyers prefer high quality standards this may serve as a driving force to improve the quality of products. Second, imports of high tech products, particularly from frontier countries, may entail embodied knowledge transfers. Third, international trade may also facilitate contact with foreign professionals, and thus enhance the exchange of (disembodied or tacit) knowledge.

Finally, larger physical distances with the frontier country may reduce the potential of imitation, because knowledge spillovers from the global frontier become more difficult due to increasing travelling costs and cultural differences. Empirical research by Kneller (2005), however, points to a limited effect of physical distance, particularly when compared to absorptive capacity measured by R&D or human capital, or to the effect of international trade. In this document we therefore ignore the physical distance as determinant in the empirical part.

2.3 Convergence to frontier

Various studies have pointed to the emergence of convergence clubs, i.e. groups of firms or countries with persistent differences in productivity level and development (see e.g. Howitt and Mayer-Foulkes (2005) and Acemoglu et al. (2006)). These clubs emerge from the differences in firms (initial) productivity levels and their strategies to innovate or imitate.

Howitt and Mayer-Foulkes (2005) investigated the convergence clubs that emerge from the introduction of scientific R&D as a source of technology change[9] and from imitation and technology transfers that become more costly as countries/firms get further behind the technology frontier. The model of Howitt and Mayer-Foulkes then arrive at three convergence clubs.

The first club concerns the group of leaders, or countries or firms near the global frontier. In the model of Howitt and Mayer-Foulkes they take the initiative to conduct R&D. Then particularly in the initial phase when other firms have not (yet) responded to the increase in R&D, the leading firms can extend the productivity gap with other firms.

The second convergence club contains the group of following countries or firms. Note that the initial productivity gap reduces the absorptive capacity of all countries behind the frontier by the increasing cost of imitation. However, lagging firms with an initial productivity level

[9] Howitt and Mayer-Foulkes point out that technology progress culminated in the late 19th century by the introduction of the R&D lab which "… exploited the growing interconnections between science and technology, and the rise of various institutions such as government research labs and […] universities with close ties to industry and commerce …"

slightly below the frontier still have sufficient absorptive capacity to attain a *similar productivity growth* as the leaders. Their productivity gap in terms of levels then remains constant at the long term.

Finally, the third club contains the group of notorious laggards, i.e. countries or firms that face an increasing productivity gap with the leaders. Their initial gap with the frontier is too large to overcome the initial erosion of absorptive capacity, and thus they cannot attain a similar productivity growth as the leading firms. Then as the gap widens over time, their absorptive capacity erodes further which makes it even more difficult to imitate, etc.

The framework of Howitt and Mayer-Foulkes, however, is somewhat ambiguous in the sense that no follower can catch up or even leapfrog the technology frontier.[10] In that sense, this framework is to some extent at odds with empirics. Acemoglu et al. (2006), however, do allow convergence to the frontier. They show that countries may catch up with the technology frontier, but can only maintain productivity growth after changes in institutional settings. Firms in countries behind the frontier will imitate from the frontier only if competition between firms is restricted, because only then the cost of imitation can be recovered. But within some distance to the frontier countries/firms have to switch their strategy from imitation to innovation triggered by fierce competition. Followers may end up in a convergence trap if maintained restrictions on competition hinder that switch at the right time, particularly as the productivity gap increases by leaders' continuing productivity growth and catching up becomes more and more unprofitable.[11]

The models of Acemoglu et al. (2006) are to some extent in line with earlier findings of Aghion et al. (2002) and Aghion et al. (2005) regarding the impact of competition on the incentives of innovation and imitation (see also section 2.2). They all argue that leading firms at the frontier perceive competition and selection as a driving force to conduct R&D for creating innovations. In contrast, for followers and lagging firms, the relationship between imitation expenditures and competition is monotonically decreasing. Hence, those types of firms are likely to spend additional costs for imitation (by R&D or human skills) if competition is low.

2.4 Importance of a national frontier

Related to the distinction of convergence clubs is the relevance of some kind of national frontier. As far as we know, Bartelsman et al. (2006) addressed this issue in an empirical evidence based study for the first time. They put it to a test and find significant evidence that within a country lagging firms more likely converge to the leading firm of that country rather than to the global frontier. This leading firm represents the national frontier, i.e. the firm with

[10] Note that followers can only leapfrog the leaders by creating innovations, as the knowledge or technology resulting in a productivity level above the level of the leader is currently lacking.

[11] This argument is to some extent similar to the underlying intuition of the third convergence club of notorious laggards of Howitt and Mayer-Foulkes, and is in line with the theory of Aghion et al. (2002).

the highest productivity level of an industry at the national level. The empirical results for the UK confirm that "…the national frontier exerts a stronger pull on domestic firms than does the global frontier. However, the pull from the global frontier falls with technological distance, while the pull from the national frontier does not…" (see Bartelsman et al., 2006). Moreover, the authors argue that imitation and learning by firms at the national frontier may become more difficult and declines if the gap between the national and the global frontier increases. The latter argument also points to the emergence of convergence clubs across countries.

Why should a national frontier be plausible? We think the following arguments support the relevance of a national frontier. The first argument is related to social-geographical issues, which includes barriers like language and culture. Institutional barriers like nation-specific business licensing conditions are a second argument. These barriers are linked to policy. The third argument for having a national frontier is associated with a lack of absorptive capacity. Domestic firms may not catch up directly with the global frontier as they have insufficient R&D and human skills. The fourth and fifth argument concern the lack of (tacit) knowledge spillovers and lack of information respectively due to little or no international trade or absence of international contacts with firms at the global frontier. Both arguments are also connected to physical distance.

To some extent, these arguments are also related to differences in scope of the relevant market. Some industries are mainly oriented to the national market and lagging firms in those industries may only catch up with the national frontier, while the relevant market for other industries is more global, and hence the global frontier becomes more relevant. Broadly spoken, this difference in relevant market is also the case in a comparison of manufacturing industries versus services industries. The former are more likely to focus on international markets, whereas many services industries regard the national or even regional market as their relevant market.

3 Model and econometric issues

Section 3.1 introduces the formal model to explain TFP-growth by several determinants, including catch up effects to either the global or the national frontier. In section 3.2 we discuss several technical and/or econometric issues. We investigate those issues in quantitative sense in more detail in Chapter 6.

3.1 Framework to explain TFP-growth

Econometric model

This section introduces the basic model that is similar to the main model of Griffith et al. (2004). In fact, we assume that the TFP-growth at the firm level is a function of a number of determinants. The (basic) econometric specification reads as

$$\begin{aligned}\Delta \ln A_{ijt} &= \alpha + \beta \ln\left(\frac{A^G_{jt-1}}{A_{ijt-1}}\right) + \gamma \ln\left(\frac{A^N_{jt-1}}{A_{ijt-1}}\right) \\ &+ \delta X_{ijt-1} + \lambda \ln\left(\frac{A^G_{jt-1}}{A_{ijt-1}}\right) \times X_{ijt-1} + \phi \ln\left(\frac{A^N_{jt-1}}{A_{ijt-1}}\right) \times X_{ijt-1} \\ &+ \tau_t + \xi_j + \varepsilon_{ijt}\end{aligned} \tag{3.1}$$

with for firm i in industry j in period t[12]:

$\Delta \ln A_{ijt}$	TFP-growth
$\ln\left(A^G_{jt-1} / A_{ijt-1}\right)$	Lagged distance to the global frontier, i.e. distance between the lagged average TFP-level of the global frontier for industry j ($\ln A^G_{jt-1}$) and the lagged TFP-level of firm i in industry j ($\ln A_{ijt-1}$)
$\ln\left(A^N_{jt-1} / A_{ijt-1}\right)$	Lagged distance to national frontier, i.e. distance between the lagged TFP-level of the Dutch national frontier for industry j ($\ln A^N_{jt-1}$) and the lagged TFP-level of firm i in industry j ($\ln A_{ijt-1}$)
X_{ijt-1}	Vector of explanatory variables
τ_t	Time dummy for each year t
ξ_j	Industry dummy for each industry j

The variables on the right-hand side of the equation reflect the determinants of the firms' TFP-growth put forward in Chapter 2. Table 3.1 provides an overview of the expected results that emerge from the theoretical notions. Below we will discuss the explanatory variables in more detail.

[12] The subscript country/Netherlands (*k*) is skipped here, but will be used in the appendix A.

Table 3.1 Expected effects of determinants on productivity growth

Determinant	Expected effect	Explanation
$ln\left(A^G/A\right)$	+	direct effect of catch up to global frontier
$ln\left(A^N/A\right)$	+	direct effect of catch up to national frontier
R&D	+	productivity growth by R&D
R&D x $ln\left(A^G/A\right)$	+	R&D to adopt foreign innovations
R&D x $ln\left(A^N/A\right)$	+	R&D to adopt domestic innovations
Human capital	+	productivity growth due to human capital
Human capital x $ln\left(A^G/A\right)$	+	ability/skills to absorb foreign innovations
Human capital x $ln\left(A^N/A\right)$	+	ability/skills to absorb domestic innovations
Competition	+	stimulant to reduce X-inefficiencies, innovation of firms
Competition x $ln\left(A^G/A\right)$	– or +	prevalence/predominance of (+) enhanced imitation of leading firms of global frontier (–) diminished imitation of lagging firms of global frontier
Competition x $ln\left(A^N/A\right)$	– or +	prevalence/predominance of (+) enhanced innovation of leading firms (–) diminished imitation of lagging firms of national frontier

The first group of explanatory variables (i.e. the first line of the right-hand side of equation 3.1) refer to costless imitation. In fact, a positive coefficient of the distance to the global frontier (β) reflects the catch up of any firm (in the Netherlands) to the global frontier. The positive coefficient of the distance to the national frontier (γ) captures the (costless) catch up of lagging firms to the national frontier.

The second group of explanatory variables (the second line of the right-hand side of equation 3.1) refer to the direct and indirect impact of R&D, human capital and competition on the firm's TFP-growth.

The R&D-intensity, for instance, captures the firm's effort to create own innovations, and thus should have a (positive) direct effect on productivity growth. The R&D intensity may also reflect firm's additional effort to imitate the technology at the national or global frontier, and thus to reduce the distance to both frontiers. The interaction terms with the distance to both frontiers reflect these imitation effects.

Human capital may also have a twofold impact on TFP-growth. It may have a direct and positive impact on productivity growth, as well trained and experienced employees likely produce more (innovative) output than less skilled employees do. More human capital may also improve firm's ability to absorb knowledge and better imitate from the national frontier or the global frontier. The interaction between human capital and the distance to the frontiers captures the additional imitation owing to the absorptive capacity.

The direct and indirect effects of competition comprise all effects related to firms' incentives to reduce inefficiencies, to innovate or to imitate. A positive direct impact of competition on firm's TFP-growth may reflect his incentives to reduce X-inefficiencies. It may also indicate to what extent competition encourages firms at the national frontier to innovate, or to imitate the global frontier. The interaction term between competition and the distance to the global frontier or national frontier indicates the impact of competition on the incentives of (lagging) firms to imitate the global or national frontier.[13] From a theoretical perspective this impact is ambiguous, because it depends on the firm's competitive position and the cost of imitation which are both related to the distance to the global or national frontier.[14] A positive coefficient of the interaction term suggests that more competition stimulates most firms to imitate.[15] A negative coefficient suggests that more competition induces firms to abstain from innovation as the cost of imitation outweighs its benefit. The latter case may particularly hold for firms at further distance from the global or national frontier, because the cost of imitation increases with the distance to the frontier.

Adjustment to cyclical and industry specific effects

Besides the explanatory variables outlined above, TFP-growth may occur as consequences of other reasons. For instance, the TFP-growth is directly related to cyclical effects. Additionally, the size of TFP-growth may vary across industries. For example, TFP-growth in innovative industries, such as chemicals and telecommunication, is generally higher than TFP-growth in mature industries, such as food processing or business services. To control for such unobserved heterogeneity that is correlated with explanatory variables we include year-dummies and industry dummies in the regression equation. In doing so, we also control for co-movements in (changes in) national frontier and TFP-growth due to for instance cyclical effects.

3.2 Econometric issues

This section discusses four econometric issues that may emerge in estimating the regression equation (3.1). These issues are endogeneity of R&D, endogeneity of the national frontier, measurement errors in TFP and potential inconsistency of the model in case of leapfrogging. We check these issues in Chapter 6 and in appendix C (endogeneity of R&D). More precisely, we analyse the relevant correlations to check the endogeneity of determinants and run additional regressions to check impact of measurement errors and the robustness of the model.

Endogeneity of R&D

R&D can be endogenous for two reasons. First, Griffith et al. (2004) suggest that R&D may also be determined by anticipation of future profits. Firms invest more in R&D in periods when TFP is growing more rapidly (for example in a cyclical upswing) and high profits provide

[13] More precisely, if the national frontier does not represent the global frontier, then firms at the national frontier may also put more effort to absorb the technology at the global frontier. Firms behind the national frontier may learn from the global frontier and/or from the national frontier.

[14] The issue is similar to the escape competition effect versus the Schumpeter effect (see section 2.1).

[15] In this case as the benefit of imitation outweigh its cost.

sufficient financial funds. This observation makes the causal relationship between R&D and TFP ambiguous. To some extent, the lagged R&D intensity in equation 3.1 solves this issue, unless firms anticipate on future (upward) TFP-shocks and instantaneously adjust their R&D in light of their anticipations. In that case, the (lagged) R&D would still be correlated with the residual of the regression.[16]

Further, R&D might pick up the impact of competition on TFP-growth. The theory of section 2.1 points out that more competition may stimulate firms at the national frontier to innovate, but may also induce laggards to give up imitation. The interaction term between competition and the distance to the national frontier should pick up the latter indirect effect of competition on TFP-growth. But as these indirect effects go through (the incentives for conducting) R&D, R&D and its interaction with distance to the national frontier might be correlated with competition.

Endogeneity of national frontier with global frontier

Section 2.4 has put forward a number of arguments why the national frontier can exist independently of the global frontier. If those arguments are not valid, then the national frontier might be endogenously and positively related to the global frontier. Movements of the national frontier are then due to changes in the global frontier. In that case, both the results of the catch up effect to the national frontier and the catch up effect to the global frontier might be biased.

Bartelsman et al. (2006) also point to the potential correlation between the *distance* to the national frontier and the *distance* to the global frontier.[17] Their argument, however, is more technically. In fact, if the TFP-levels of the national frontier converge to the TFP-level of the global frontier, then the distance in TFP-level of lagging firms to the national frontier will converge to their distance to the global frontier.

Measurement errors in TFP

At the outset we use the standard growth-accounting method to calculate TFP (see Chapter 4). However, growth accounting assumes that firms operate under constant returns to scale with perfect competition on input- and output markets. If these conditions do not hold, TFP-levels will be measured incorrectly. Additionally, in our model we allow the competition intensity to be one of the determinants of TFP-growth, this seems to be at odds with the growth accounting assumption of perfect competition. To cope with this issue, at the national level TFP can be measured in another way relaxing the neo-classical assumptions (see Balk, 2008, and appendix B).

[16] More technically, in this case $E(R\&D_{t-1}, \varepsilon_t) \neq 0$ which would eventually result in a biased regression.

[17] Note that the distance to the national frontier may also be correlated with the lagged competition intensity. In fact, fierce competition raises the gap between leading and lagging firms, but only after the leading firms have implemented a new technology. However, this correlation does not affect our regression results, as we include the *lagged* distance to the national frontier as an explanatory variable in the regression equation.

Error Correction Model and inconsistency with leapfrogging

Our model can be considered as a variant of an Error Correction Model (ECM, see also Griffith et al., 2004). It yields that the convergence of lagging firms to the TFP-*level* of the frontier (by imitation) is captured by a positive impact of the distance to the national or global frontier to the TFP-growth of the lagging firms. However, adding firm's independent efforts to generate TFP-growth may result in an inconsistency of the regression model in case of leapfrogging. Intuitively, lagging firms can leapfrog the frontier only by conducting R&D to create own new innovations, not by imitating existing technologies. Indeed, one has to create a new technology to become the frontier firm.[18] In fact, given the *lagged* impact of the distance to the frontier on TFP-growth, leapfrogging firms would still learn from the (ex-frontier) firm who has been leapfrogged. This is inconsistent.

[18] This argument is in line with the argument of Acemoglu et al. (2006), see section 2.2.

4 Data and stylized facts

Section 4.1 discusses the data used for our econometric analysis. It describes the sources of the data, and the most important variables that are applied in our econometric models. Section 4.2 presents some stylized facts about the TFP distribution of firms in the Netherlands, compared to both the national and the global frontier.

4.1 Description of data

4.1.1 Main sources

This study uses four sources: PS, R&D and CIS-survey, and the EUKLEMS-database. The first three of these are Statistics Netherlands surveys, while the EUKLEMS-database is the product of a comprehensive international research project. We will now describe these main sources of information.

PS

Data on productivity is derived from the Production Statistics (=PS), produced by Statistics Netherlands on a yearly basis. Data from this PS is available for the years 1995 to 2004.[19] The PS is a sampled survey; only the largest firms are included in the sample each year. For decreasing firm size, sampling fractions also decrease, and most smaller firms will have gaps in the data for several years. The number of observed firms varies between about 26,000 and over 42,000 (see table 4.1).

Table 4.1 Number of observations, 1997-2004

	1997	1998	1999	2000	2001	2002	2003	2004
Manufacturing	8345	7982	8013	6428	7778	6925	6965	6332
Services[a]	18122	20391	18634	27431	33333	33600	35266	28767
Total PS	26467	28373	26647	33859	41111	40525	42231	35099
PS + CIS	865	3756	1098	2344	1646	2320	1276	2225

Source: own computations based on PS and CIS.
[a] Services includes also construction, trade and transport.

CIS and R&D Survey

Data on R&D has been gathered in two separate surveys: the Community Innovation Survey (CIS), and the R&D survey. The CIS is a European harmonized questionnaire, held every two years, containing questions about innovative activities in enterprises, and their effects. In the other years, the R&D survey is held. This survey contains a subset of the questions of the CIS, and covers mainly expenditures on R&D. The dataset covers the period 1996-2004.

[19] Except for transport and telecom, data for these industries cover the period 2000-2004.

The number of observations in the CIS is low compared to that of the PS, as shown in table 4.1. In odd years, the amount of data is especially small because the sample for the R&D survey is not drawn randomly; it is biased towards the firms that have been classified as innovators in the preceding CIS. We use the full PS-sample for calculating the national frontier and the measure of competition; the much smaller sample of the PS combined with the CIS is used for the regressions in Chapter 5.

EUKLEMS

We use the EUKLEMS database to define the global frontier. The aim of the EUKLEMS-project was to create comparable time series on production output and input factors across a number of countries to produce internationally comparable productivity figures. The countries included in the project are the United States, Japan, and 15 major countries of the European Union. One result of this research is a database of TFP-levels. This database contains a complete set of data for most of the participating countries for the years 1993 to 2004. The TFP-levels of Japan and four European countries (i.e. Greece, Ireland, Luxembourg and Portugal) are not available. Data are given for 20 industries, corresponding to individual 2-digit NACE classes or a combination of those.

4.1.2 Key variables

TFP growth

Using the growth accounting method, TFP growth of a firm is based on the growth of value added minus the weighted inputs of labour and capital services.

We use as output measure the value added of an enterprise, Y_{it}, in 1995 prices. To calculate this, the value added in real prices from the PS is deflated with an appropriate price index from the Make and Use tables of the National Accounts.

The input of labour is expressed in number of people employed (in full time equivalents). As detailed information for measuring capital services at the firm level is missing, the depreciation expenditures deflated with the price index for user costs of capital (sourced from National Accounts) approximate capital input. Appendix A further explains the construction of TFP growth.

TFP level

The distances to frontiers are based on TFP levels, hence we need calculation of TFP levels. To make comparisons between TFP levels at the micro level we use the superlative index procedure (see Caves et al. 1982, and appendix A for further elaboration).

Constructing real TFP levels that allow a comparison between firms at a given point of time (the spatial differences) and (simultaneously) between years for the same firm (the intertemporal differences), as one needs both for our econometric specification, raises various difficulties. Interspatial comparisons are hampered by the complication that TFP ratios that are 'built' from TFP levels of different firms are not transitive.[20] One way out of this mathematically unsolvable problem concerns the use of an artificial unit as the point of reference in the TFP calculations. In our application this artificial unit is the average firm in the market. Caves et al. (1982) have shown that for this choice of the artificial unit the resulting TFP ratio's have the desired property of transitivity. Nevertheless, this choice remains more or less arbitrary as other points of references may be equally valid and results can be dependent on the reference point used.

National frontier

In theory, the highest TFP-level of all firms in a given industry in the Netherlands represents the national frontier. However, this definition for the frontier is very sensitive to the presence of outliers in the data. To reduce this sensitivity, we look at the highest quartile in the TFP distribution in each 3-digit NACE class instead of the highest single TFP-level. The average TFP-level of these firms will be taken as the national frontier. Using this definition, about 10 percent of all firms have a TFP that is higher than the national frontier. The distance to the frontier of these firms is set to zero. For all other firms, the distance to the frontier is defined as a positive number.

Other definitions of the national frontier are possible. In chapter 6, we check the dependence of the outcome of our analysis on the choice of the national frontier.

Global frontier

Ideally, the global frontier would be defined in the same way as the national frontier, being the highest productivity level of all individual firms in whatever country. This definition is hardly feasible in practice, because we do not have worldwide micro data. In principle, we have two datasets at our disposal for measuring the global frontier.

First, the EUKLEMS database gives the average TFP per industry for 14 countries, relative to the United States. The distance to the global frontier is based on the difference between the Dutch average TFP level and the highest average TFP level in the database.

The definition of the global frontier given above does not capture the spread of TFP levels within a country. Bartelsman et al. (2006) even state that the global frontier based on industry averages may result in a "poor proxy" of the actual technological frontier. In fact, if there are large differences between firms within the leading country, the distance of the Netherlands to the global frontier will be underestimated. It is possible that the leading firms on a global level are located in a country that on average does not have the highest TFP (see box for an example).

[20] So, if country A is related to country B and country B is related to country C, then country A is related to country C.

This misidentification of the global frontier cannot be prevented, as the EUKLEMS data does not contain information on the distribution of TFP levels within a country.

Definition of the global frontier

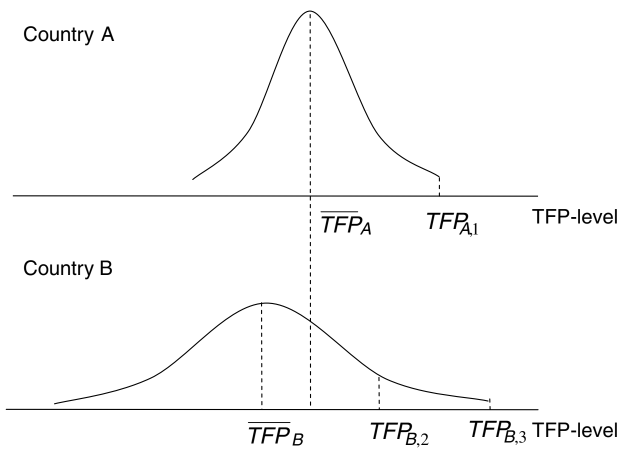
Many studies use industry level data to investigate the convergence of TFP-levels to the global frontier. More precisely, they first calculate the average TFP-level (or labour productivity) levels of each industry and each country (see e.g., Griffith et al,. 2004). Then for each industry (and each year) the global frontier is defined as the highest TFP-level across all the countries (denoted as the Average-based Global Frontier, in short AGF).

Bartelsman et al. (2006) point to an important caveat of the AGF. Their main idea is that individual firms may have higher TFP-levels than the AGF. This may also hold for firms in other countries and therefore may have an impact on the assignment of the global frontier.

An example will illustrate the main consequences. The figure below compares the distributions of TFP-level of individual firms in two countries, A and B. It shows that the average TFP-level in country A ($\overline{TFP}_A$) is higher than the average TFP-level in country B ($\overline{TFP}_B$). Then, according to the traditional definition country A would hold the global frontier, which gives $AGF = \overline{TFP}_A$. However, firm 1 has the highest TFP level in country A, say $TFP_{A,1}$, and thus a TFP-level that is (by definition) above the country's average representing the global frontier. In this example firm 2 in country B also has a TFP-level, say $TFP_{B,2}$, that is higher than the global average. Then, it is unlikely that firm 1 in country A and firm 2 in country B will learn from the technology of the "average firm" in country A with TFP-level $\overline{TFP}_A$, and the TFP-levels of firm 1 and firm 2 will *not* converge to the global frontier. Further, note that in this example the distribution in TFP-levels of country B is more dispersed than the distribution of country A. In fact, firm 3 in country B has a TFP-level, say $TFP_{B,3}$, that is higher than the TFP-levels of any other firm in both countries. So then, it is more likely that firm 1 in country A and firm 2 in country B will learn from the technology of firm 3 in country B.

All in all, it is more accurate to define a global frontier as the highest productivity level of *all individual firms* of whatever country (denoted as Firm based Global Frontier, in short FGF). So in the example $FGF = TFP_{B,3}$. As the example shows, the FGF is (by definition) higher than the AGF, but may also refer to another country.

Distributions of productivity levels in country A and country B



The second dataset used in Bartelsman et al. (2006) provides an alternative for the determination of the global frontier. Besides the average TFP for all firms in an industry, this dataset also includes limited data on the TFP distribution. The firms in each industry class are divided into quartiles based on TFP, and the average TFP is given for each quartile. This dataset therefore provides a definition of the global frontier that is comparable to the national frontier given above. Unfortunately, Bartelsman's dataset has a number of considerable drawbacks compared to the EUKLEMS data:

- The selection of countries is smaller, and the absence of the United States data for most years is especially detrimental
- The data is only available for the years up to 2001
- For most countries, there is only information for manufacturing industries

Considering these facts, we have decided to primarily use the EUKLEMS data to define the global frontier. We will use the second dataset for robustness checks of our outcomes.

R&D-intensity

The expenditures on R&D related to the valued added are used as a measure of the R&D intensity of a firm. This ratio comes from the CIS and the R&D-survey. The R&D expenditure consists of the total costs of both contracted R&D and intramural R&D, including wages, exploitation costs, and capital expenditure on buildings and equipment for R&D.

Human capital

The indicator used for human capital is the average wage per employee at the firm level. Both the expenditure on wages and the number of employees are derived from the PS. A priori, this variable is not an ideal measure of human capital as it is closely connected to labour productivity. However, at the firm level we cannot measure human skills directly, because we have no specific data of the (average) education level and experience of the employees within each firm.

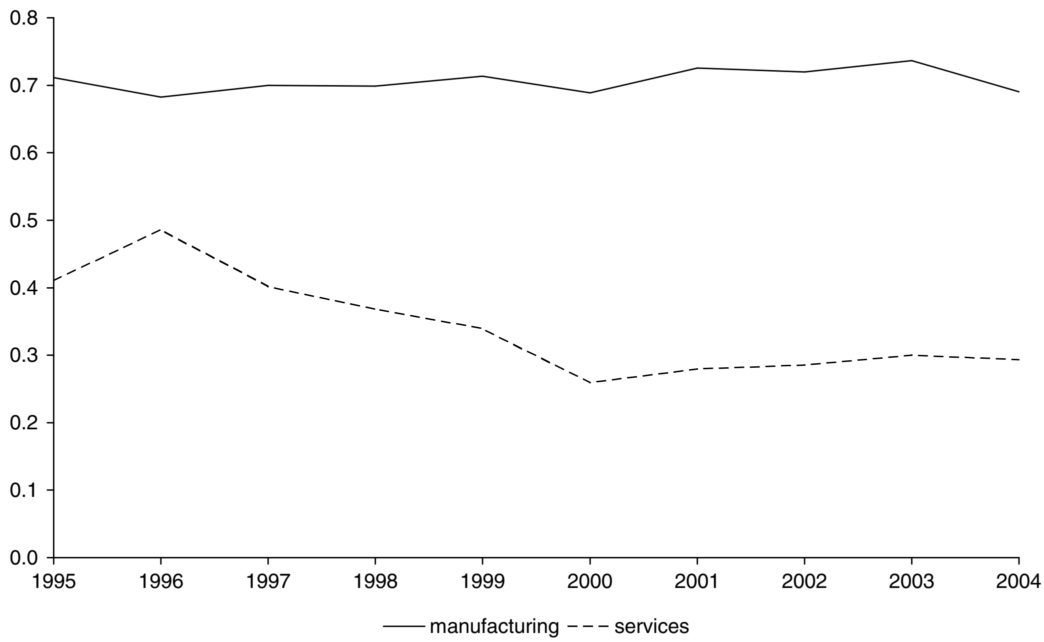
PE

With the data at hand there are several routes open for measuring competition. In this document we use the profit elasticity (PE, see Boone et al. 2007). It is implemented by using a regression model that relates profits to marginal costs. This regression is applied to firms belonging to one and the same market. The parameter of this regression measures the PE and comparing this parameter over time enables us to make inferences on changes in competition. The main idea of the PE is that fiercer competition enables efficient firms to earn relatively higher profits than their inefficient competitors. As TFP (growth), amongst others, mirrors (changing) differences in real profitability, the PE measure is natural choice for investigating the contribution of competition to TFP growth.

4.2 Stylized facts

Figure 4.1 shows the evolution of the average distance to the global frontier between 1997 and 2004. A low figure indicates that the distance to the global frontier is small. This distance is clearly stable throughout this period for the Dutch manufacturing industry and to a lesser degree for the Dutch services sector.[21] It can be seen that the (average) services sector is on average closer to the global frontier than the (average) manufacturing industry.

Figure 4.1 Average distance to the global frontier (=0): 1995-2004



To some extent, this finding is surprising. Dutch manufacturing has been long known for its high labour productivity level in an international perspective. Recent new figures for services also point to relatively high productivity levels for the Dutch services (see Inklaar et al., 2007). In services, the Netherlands are especially close to the global frontier in trade and in transport, two important sectors in the Dutch economy (see also table 4.2).

Figure 4.2 shows the evolution of the average TFP relative to the national frontier between 1995 and 2004. In contrast to the developments with respect to the global frontier, both for manufacturing and services, the lines show an upward trend indicating that the average TFP has dropped relative to the national frontier during that period.[22] On average, the distance to the

[21] In this document, services include also construction.

[22] Actually, the spread of TFP levels among firms has also become slightly larger in the Netherlands over time.

national frontier is lower in the manufacturing sector than in services. Although the manufacturing sector as a whole performs relatively badly compared to the global frontier (see figure 4.1), the differences between domestics firms are relatively small. The services sector, which is much closer to the global frontier on average, has a wider distribution of TFP levels of domestic firms.

Figure 4.2 Average TFP (not truncated) relative to the national frontier (=0), 1995-2004

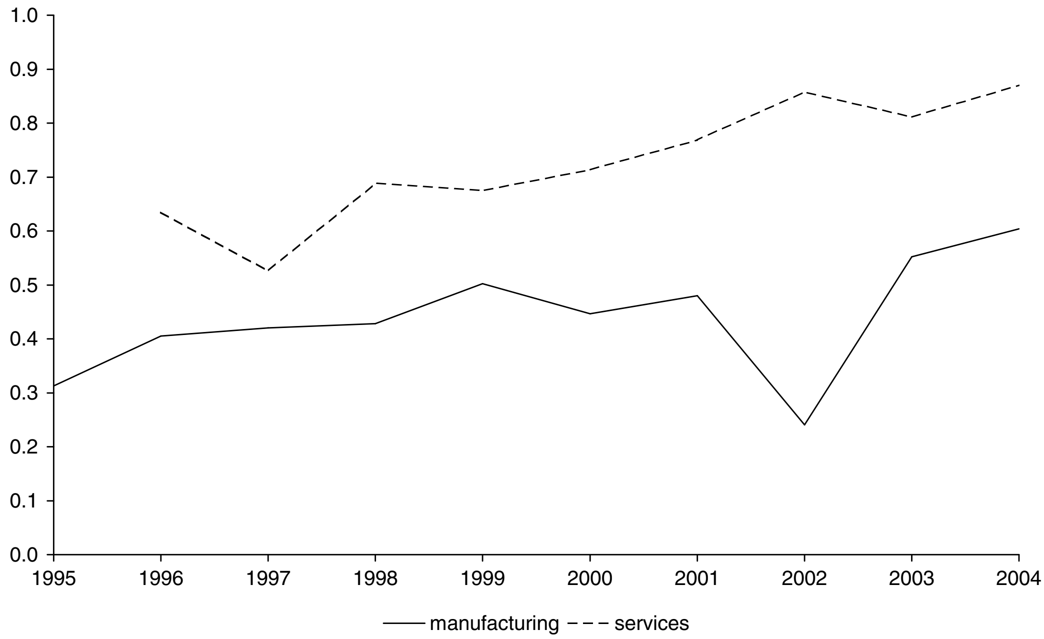


Table 4.2 and figure 4.3 make those distributions more explicit. Table 4.2 shows that the difference in mean distance to the national frontier between manufacturing and services is clearly visible. Moreover, there is a lot of variation between two-digit level industry classes. Even in some of the manufacturing industries the Netherlands is itself the global frontier. This is for example the case in food manufacturing (NACE 15-16), textiles and leather (17-19) and chemical manufacturing (24).

Figure 4.3 presents the spread of TFP levels. This figure shows the distance to the national frontier of all firms in manufacturing and services for the year 2004.[23] The figure also shows that the latter has definitely a fatter right tail. This is also reflected in the characteristics of the distributions as shown in table 4.2. The distance between the first and third quartiles (i.e. the interquartile range) is given as a measure for the width of the TFP distributions. For most industries, this distance is about equal to the average of the relative log (TFP). In a few industries, there is a large difference between these two numbers, indicating a different shape of

[23] Firms on the national frontier are not shown here. These firms have a distance to the frontier that is truncated at zero. They constitute around 10 percent of the total panel in all industry classes.

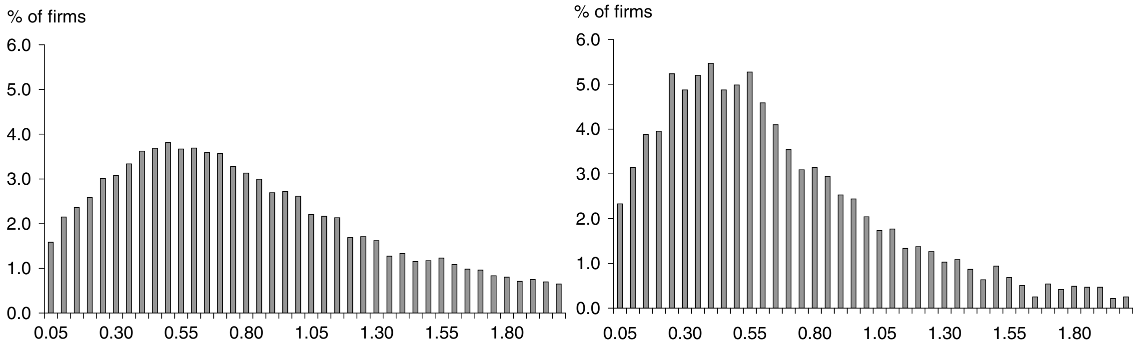
the TFP distribution. For example, in two-digit NACE class 26, the interquartile range is about double the average TFP, indicating a long tail of firms with a low TFP.

Table 4.2 Distances to frontier, in 2004

	NACE-code	No. of observations	Distance to national frontier		Distance to global frontier	
			average[a]	q75-q25	average[a]	% of firms above
Sectors						
Manufacturing	15-37	6332	– 0.60	0.65	–0.69	4.0
Services	45-74	28767	– 0.87	0.96	–0.29	5.7
Two digit industries						
Food products	15t16	923	– 0.52	0.78	0.00	9.3
Textiles and leather	17t19	286	– 0.82	0.84	0.00	10.8
Wood products	20	158	– 0.42	0.42	– 2.00	1.3
Paper products and publishing	21t22	977	– 0.73	0.71	– 0.55	2.5
Coke, petroleum products	23	20	– 1.85	0.63	– 3.01	5.0
Chemical products	24	384	– 0.67	0.68	0.00	10.4
Rubber and plastic	25	279	– 0.53	0.52	– 1.21	2.2
Other mineral products	26	298	– 0.34	0.64	– 0.67	3.0
Metals	27t28	985	– 0.53	0.49	– 0.57	2.2
Machinery	29	717	– 0.40	0.51	– 1.11	1.0
Electrical, optical equipment	30t33	593	– 0.39	0.59	– 0.94	2.5
Transport equipment	34t35	345	– 0.46	0.69	– 1.28	0.9
Other manufacturing	36t37	367	– 1.60	2.15	– 1.53	1.6
Construction	45	3472	– 0.58	0.55	– 0.86	1.0
Wholesale and retail trade	50-52	10009	– 0.70	0.72	– 0.02	8.2
Hotels and restaurants	55	1192	– 0.79	0.81	– 0.29	3.8
Transport and storage	60t63	3436	– 0.97	0.98	0.00	9.9
Post and telecommunications	64	340	– 1.28	1.48	– 1.48	0.9
Business services	71t74	10318	– 1.09	1.26	– 0.43	3.7

[a] The arithmetic mean of RTFP: i.e. the log of ratio MTFP/MTFP(frontier).

Figure 4.3 Distribution of distance to the national frontier: services (left) and manufacturing (right), 2004



5 Main results

This chapter discusses the main regression results of firm's TFP-growth. Actually, it presents five variants based on the period 1996-2004. The discussion particularly focuses on the relevance of the national frontier and on the impact of competition, as both potential sources for productivity growth are contributions to the existing literature. The first three variants extend the analysis step-by-step towards the full model discussed in section 3.1. These three variants are based on the extensive dataset with all industries included and will be discussed in section 5.1. In section 5.2, we also estimate the full model for two major sectors separately, i.e. the manufacturing and the services industries respectively. These two regressions may provide additional insight whether the impact of the explanatory variables differs across the economy.

5.1 Aggregated level

Restricted models point to correct direct effects

The first and simplest LS-regression variants focuses on the catch up to the global frontier and the direct impact of R&D, competition and human capital on TFP-growth (see column 1 in table 5.1).[24] Most of the results are in line with the theory, except for human capital.[25]

The catch up to the global frontier is limited and not significant, suggesting that firms hardly learn from foreign firms at the global frontier. The positive impact of R&D fits with the general intuition that R&D used to create innovations will eventually result in higher productivity. The results also reveal that more competition on the Dutch market stimulates firms to operate efficiently and reduce X-inefficiencies, and to innovate. Finally, the results on human capital are remarkable, because the negative and significant impact of human capital on TFP-growth contrasts with theoretical intuition.

The theory in Chapter 2 asserted that more R&D, human capital and in some cases competition might enhance the catch up to the global frontier. However, the results of column 2 in table 5.1 provide no empirical evidence for these indirect effects. More precisely, all the interaction terms of R&D, human capital and competition are not significant. This suggests that firms do not effectively use those possibilities to adopt technologies from the global frontier.

This second variant comes close to the work of Griffith et al. (2004), but our results provide less evidence for the importance of productivity growth through the speed of technology transfers. For instance, the direct effect of R&D corresponds to their results, but the interactive effect of R&D with the distance to the global frontier is absent.

[24] We do not use a firm fixed effect model since we look at firm's TFP-growth and not their TFP-*level*. In fact, the most obvious determinants that may be firm specific are separately included in the regression equation. We do not report the intercept in the tables due to abundance in relation with industry and time dummies.

[25] Inherent in the model, we find strong correlations between the interaction terms and the direct determinants, whereas the correlations between the direct determinants are low. The former points to a multicollinearity problem.

Table 5.1 Regressions results basic model: 4 variants[a]

Variant	(1)	(2)	(3) Baseline	(4) No human capital
Determinant (and expected effect)				
Distance global frontier (+)	0.027	0.077	0.167	0.156
	(0.70)	(0.95)	(2.08) *	(3.69) ***
Distance national frontier (+)			0.557	0.270
			(10.51) ***	(16.51) ***
R&D (+)	0.209	0.218	– 0.100	– 0.082
	(6.23) ***	(4.46) ***	(– 1.41)	(– 1.15)
R&D x distance global frontier (+)		– 0.019	– 0.007	– 0.006
		(– 0.26)	(– 0.09)	(– 0.08)
R&D x distance national frontier (+)			0.304	0.279
			(4.04) ***	(3.69) ***
Human Capital (+)	– 0.104	– 0.101	0.058	
	(– 12.37) ***	(– 8.97) ***	(3.99) ***	
Human Capital x distance global frontier (+)		– 0.008	– 0.004	
		(– 0.43)	(– 0.20)	
Human Capital x distance national frontier (+)			– 0.086	
			(– 5.68) ***	
Competition (+)	0.005	0.007	0.010	0.012
	(2.68) **	(2.57) **	(2.96) ***	(3.44) ***
Competition x distance global frontier (+ or –)		– 0.004	– 0.007	– 0.007
		(– 1.14)	(– 1.94)	(– 2.09) *
Competition x distance national frontier (+ or–)			0.007	0.005
			(1.67)	(1.21)
R-squared	0.0251	0.0252	0.1225	0.1223
Serial correlation[b]	– 0.126	– 0.125	0.005	0.015
Number of observations	12255	12255	12255	12264
Sectors	All industries	All industries	All industries	All industries
Year dummies	yes	yes	yes	yes
Industry dummies (EUKLEMS branch level)	yes	yes	yes	yes
Estimation method	LS	LS	LS	LS

[a] Between brackets z-value (based on panel robust standard errors); ***, ** or * indicates significant at respectively 1%-level, 5%-level or 10%-level.
[b] Estimated serial correlation of standard errors assuming that errors are correlated within firms.

Baseline model stresses relevance of national frontier

The third regression also includes the impact of catch up to the national frontier. This regression corresponds with equation 3.1(see column 3 in table 5.1). The results emphasize the importance of catch up to the national frontier. More precisely, the positive impact of the distance to the national frontier confirms that lagging (domestic) firms do learn from the firms at the national frontier.

Now, the results also point to a significant catch up to the global frontier. Still, the higher elasticity of the distance to the national frontier reveals that costless imitation from the national frontier is more important for TFP-growth than from the global frontier.

Competition has a positively significant effect on TFP growth. Furthermore, it has opposite effects on the catch up of firms to both frontiers. More competition stimulates (non-frontier) firms to imitate and catch up to the national frontier. From a theoretical perspective, this result indicates that the escape competition effect prevails the Schumpeter effect, and thus that the initial level of competition is relatively low such that for lagging firms the benefits of imitation can outweigh its cost. In contrast, more competition seems to induce firms to abstain from technology transfers from the global frontier. Apparently, the costs of imitating global technologies are too high and they cannot be recovered in times of fierce competition. Both effects of competition on the catch up, however, are small and not significant at high-significance levels.

The empirical results of the baseline model also stress the importance of the second face of R&D. Indeed, the figures reveal that more R&D helps lagging firms to catch up with the national frontier.[26] In the Netherlands, firms more likely use R&D to learn and implement current but leading technologies rather than to create own inventions and new technologies.

Finally, the results on the impact of human capital are to some extent puzzling, but keep in mind that our indicator is only a proxy for human capital. Compared to the previous variants so far, the direct effect of human capital of TFP-growth reverses and becomes positive as one would expect. This effect confirms the idea that higher skills of employees directly contribute to TFP-growth. However, the findings also suggest that human capital has a negative and significant impact on the catch up to the national frontier, which contrasts with theory.

Note that the impact of human capital is important in the policy debate, particularly in the debate on enhancing the level of education of (future) employees. The last column (4) shows the estimation results if we leave out the human capital variable. The other coefficients are not affected much. Section 6.4 performs further robustness checks of the specification of human capital. Again the other coefficients appear to be robust to different specifications.

To sum up the main results, we find that the national frontier is important for firms to catch up in TFP. Firms particularly use R&D to imitate the national frontier, which underlines the second face of R&D. Competition stimulates firms to operate efficiently, and to improve their productivity. Weak indications exist that competition also stimulates lagging firms to put more effort to imitate their (efficient) competitors at the national frontier.

[26] The direct effect of R&D in the first regression also seems to pick up the positive impact of R&D on the catch up, as in that regression the interaction term is not included.

5.2 Comparisons between sectors

It is interesting to look at the results for the manufacturing and services industries separately, as the characteristics of those industries differ in many ways (see table 5.2 column 2 and column 3 respectively). Across the explanatory variables, the results are largely similar in signs (except for competition), but different in the size of the parameters. For instance, a priori we expected that convergence to the national frontier might be more relevant for services and construction industries as they operate more likely on national or even regional markets, while convergence to the global frontier might be more relevant for manufacturing industries as they are focussed on international markets. Moreover, given their gap to either the national or global frontier, the stylized facts in chapter 4 suggest that services firms could learn more from their domestic competitors, whereas manufacturing firms could learn more from abroad. The regression results, however, hardly confirm this expectation. In fact, in both sectors catch up to the national frontier is more important (and significant) than to the global frontier. This suggests that the scope of the market, which differs between the two main sectors, seems to be less relevant for catch up opportunities.

Competition, however, affects TFP growth differently. This finding might be attributed to the difference in competition intensities in both sectors. Recent CPB-research reveals that the level of competition intensity in manufacturing industries is much higher than in services and construction industries (see Creusen et al. 2006). In the manufacturing industries, intensified competition induces firms in a direct way to reduce X-inefficiencies or stimulates firms to innovate. Further increases in competition do not induce laggards to imitate the leading firms. The reason is that for those firms the benefits of imitation are too low to recover the cost of imitation due to the high level of competition in manufacturing. In the services industries, however, competition is relatively lower such that for laggards imitation of technologies from the national frontier is relatively more profitable.

With respect to R&D, the results for manufacturing firms underline the outcomes of the baseline model implicating that the second face of R&D in relation with the national frontier is more important than its traditional face, i.e. creating new inventions. In contrast, in services, R&D has no significant impact on TFP growth anyway. To some extent, this is not surprising because in services R&D is less important than in manufacturing industries.

Finally, the direct impact of human capital on the TFP-development is particularly evident in the services industries supporting the idea of services being specific to clients. For both sectors, the impact of human capital on the catch up to the national frontier remains negative (and significant for services), and thus puzzling.

Table 5.2 Regressions results for separate sectors[a]

Variant	(1) Baseline	(2) Manufacturing	(3) Services
Determinant (and expected effect)			
Distance global frontier (+)	0.167	0.151	0.395
	(2.08) *	(1.81)	(1.57)
Distance national frontier (+)	0.557	0.329	0.533
	(10.51) ***	(3.90) ***	(6.96) ***
R&D (+)	– 0.100	– 0.155	– 0.087
	(– 1.41)	(– 1.83)	(– 0.63)
R&D x distance global frontier (+)	– 0.007	– 0.097	0.025
	(– 0.09)	(– 1.27)	(0.08)
R&D x distance national frontier (+)	0.304	0.660	0.149
	(4.04) ***	(6.43) ***	(1.27)
Human Capital (+)	0.058	0.048	0.057
	(3.99) ***	(2.13) *	(2.43) **
Human Capital x distance global frontier (+)	– 0.004	– 0.010	– 0.003
	(– 0.20)	(– 0.48)	(– 0.06)
Human Capital x distance national frontier (+)	– 0.086	– 0.031	– 0.098
	(– 5.68) ***	(– 1.29)	(– 4.76) ***
Competition (+)	0.010	0.008	– 0.009
	(2.96) ***	(2.35) **	(– 0.76)
Competition x distance global frontier (+ or –)	– 0.007	– 0.005	– 0.003
	(– 1.94)	(– 1.61)	(– 0.06)
Competition x distance national frontier (+ or–)	0.007	0.005	0.045
	(1.67)	(1.10)	(3.77) ***
R-squared	0.1225	0.1253	0.1305
Serial correlation[b]	0.005	– 0.019	0.057
Number of observations	12255	7071	5184
Sectors	All industries	Manufacturing industries	Services and construction
Year dummies	yes	yes	yes
Industry dummies (EUKLEMS branch level)	yes	yes	yes
Estimation method	LS	LS	LS

[a] Between brackets z-value (based on panel robust standard errors); ***, ** or * indicates significant at respectively 1%-level, 5%-level or 10%-level.
[b] Estimated serial correlation of standard errors assuming that errors are correlated within firms.

To conclude this section, we find for both manufacturing industries and services convergence to the national frontier to be more relevant than to the global frontier. Tougher competition in services industries stimulates firms to imitate the national frontier, whereas in manufacturing industries, it more likely stimulates firms to innovate.

6 Robustness checks

This chapter compares the results of the baseline model with variants that deal with econometric issues as a way of robustness checks. More precisely, these variants check for:[27]

- The impact of other definitions of TFP (section 6.1)
- The robustness of the frontiers (section 6.2)
- The link between productivity gap and effects of competition (section 6.3)
- The robustness of human capital effects (section 6.4)

6.1 Other definitions of TFP

This section compares the baseline results with the regression results of two alternative definitions of TFP, i.e. TFP without using the superlative index number procedure (see section 4.1) and TFP based on ignoring the key growth accounting assumptions.

Ignoring interspatial problems

To check the impact of the superlative index number procedure to cope with the interspatial problem, we compare the baseline regression with a regression in which the TFP level is based on the growth accounting method without scaling to (international) industry averages (see column 2 in table 6.1). We find that scaling hardly affects the direct catch up effects, so costless imitation of the national frontier remains important, more than imitation of the global frontier. However, scaling does affect the observed effects of competition and R&D on the catch up to the national frontier. For instance, the results without scaling suggest that more competition induces firms to abstain from learning from domestic firms. The results in column 2 also point to the traditional role of R&D, as R&D has no significant impact on the imitation of the national frontier, but seems to enhance TFP-growth directly. Nevertheless, as scaling ensures that the TFP-levels of firms are comparable between firms, in our view using scaled TFP-levels is more appropriate than applying TFP-levels without scaling.

Relaxing growth accounting assumptions

The second alternative measure of TFP relaxes the growth accounting assumptions and relates TFP to firm's profitability. As indicated in section 3.2, the growth-accounting method assumes perfect competition on input and output markets, and it assumes that firms have constant returns to scale. These assumptions can be relaxed if we relate firms TPF to their profitability. In that sense, TFP-levels and TFP-growth are defined by the difference between firm's value added and its costs of labour and capital (see Balk, 2008, and appendix B).

[27] The results of two other variants, i.e. endogeneity of R&D and importance of export, are reported in appendix C and D respectively.

Table 6.1	**Check for other definitions of TFP and other global frontier**[1]				
Variant	Baseline (1)	No scaling (2)	No perfect markets (3)	Adjusted baseline (4)	Alternative dataset (5)
Determinant (and expected effect)					
Distance global frontier (+)	0.167	0.131	– 0.134	0.151	– 0.058
	(2.08) *	(1.62)	(– 2.21) *	(1.81)	(– 0.88)
Distance national frontier (+)	0.557	0.517	0.191	0.329	0.311
	(10.51) ***	(11.9) ***	(6.13) ***	(3.90) ***	(3.51) ***
R&D (+)	– 0.100	0.242	– 0.245	– 0.155	– 0.202
	(– 1.41)	(3.81) ***	(– 4.32) ***	(– 1.83)	(– 2.24) *
R&D x distance global frontier (+)	– 0.007	– 0.029	0.132	– 0.097	– 0.027
	(– 0.09)	(– 0.40)	(2.39) **	(– 1.27)	(– 0.67)
R&D x distance national frontier (+)	0.304	– 0.076	0.325	0.660	0.665
	(4.04) ***	(– 1.13)	(6.58) ***	(6.43) ***	(5.73) ***
Human Capital (+)	0.058	0.013	0.040	0.048	0.021
	(3.99) ***	(0.91)	(3.92) ***	(2.13) *	(0.80)
Human Capital x distance global frontier (+)	– 0.004	– 0.014	0.039	– 0.010	0.023
	(– 0.20)	(– 0.74)	(2.68) **	(– 0.48)	(1.29)
Human Capital x distance national frontier (+)	– 0.086	– 0.114	– 0.031	– 0.031	– 0.018
	(– 5.68) ***	(– 9.5) ***	(– 3.66) ***	(– 1.29)	(– 0.70)
Competition (+)	0.010	0.014	0.001	0.008	0.013
	(2.96) ***	(4.10) ***	(0.28)	(2.35) **	(3.69) ***
Competition x distance global frontier (– or +)	– 0.007	– 0.006	– 0.003	– 0.005	– 0.004
	(– 1.94)	(– 1.53)	(– 0.98)	(– 1.61)	(– 2.38) **
Competition x distance national frontier (– or +)	0.007	– 0.011	0.023	0.005	0.001
	(1.67)	(– 3.17) ***	(9.06) ***	(1.10)	(0.10)
R-squared	0.1225	0.0434	0.0998	0.1253	0.1375
Serial correlation[2]	0.005	– 0.114	– 0.073	– 0.019	0.000
Number of observations	12255	12255	12255	7071	5505
Sector	All industries	All industries	All industries	Manufacturing industries	Manufacturing industries
Year dummies	yes	yes	yes	yes	yes
Industry dummies (EUKLEMS branch level)	yes	yes	yes	yes	yes
Estimation method	LS	LS	LS	LS	LS
Estimation period	1996-2004	1996-2004	1996-2004	1996-2004	1997-2001

[1] Between brackets z-value (based on panel robust standard errors); ***, ** or * indicates significant at respectively 1%-level, 5%-level or 10%-level.
[2] Estimated serial correlation of standard errors assuming that errors are correlated within firms.

Column 3 in table 6.1 reports the findings of this variant. The results mainly change for the importance of the global frontier. The distance to the global frontier has a negative and significant effect on TFP-growth, but this contrasts to the theory. In contrast, both more human capital and R&D enhance the imitation of technologies at the global frontier.

6.2 Robustness of frontiers

This section analyses the robustness of the global and the national frontier. More precisely, we check for effects of:

- Global frontier based on firm-level data
- Different percentile in national frontier
- Exclusion of frontier firms to check Error Correction Mechanism
- Check of endogeneity of national frontier

Global frontier based on firm-level data

To check the effect of using another definition of the global frontier, we compare the results of the baseline model with the results using a global frontier based on firm-level data from the dataset of Bartelsman et al. (2006). As denoted in the box "Definition of the global frontier" in section 4.1, the global frontier based on firm-level data is more appropriate than based on industry averages.

However, due to data limitations of this alternative dataset, we can only look at manufacturing industries. The differences in the results are minor (see column 4 and column 5 in table 6.1). The most crucial differences are that the impact of competition on the learning of the global frontier, and the direct impact of R&D have become significant with the wrong sign.

More strict definition of national frontier

In the baseline regressions we define the national frontier as the average TFP-level of firms in the highest quartile, i.e. the average of TFP-levels above the 75% quartile. The main reason for applying a boundary is measurement errors. The choice of a boundary at 75% is arbitrary. However, raising this boundary does not affect the outcomes substantially. In fact we recalculated the national frontier as the average of TFP-levels above the 90% percentile, thus sharpening the selection of more efficient firms being the top. Table 6.2 shows that the regression with the boundary of 90% (column 2) gives similar results as the baseline regression with the lower limit of 75% (column 1).

Check for inconsistencies in case of leapfrogging

To check for a potential inconsistency of our model in case of leapfrogging, we estimated the effects for only non-frontier firms (column 3 in table 6.2). The results of these regressions do not point to substantial differences. This suggests that firms at the national frontier have limited impact on the regression results. So, even if the model of section 3.1 would become inconsistent in case of leapfrogging of firms, it is unlikely that this inconsistency will affect the regression results.

Table 6.2 Check for other definitions of national frontier and for impact different gaps on effects of competition[1]

Variant	Baseline (1)	Other boundary nat. frontier (2)	Only non-frontier firms(3)	Only lagging firms (4)	Only advanced firms (5)
Determinant (and expected effect)					
Distance global frontier (+)	0.167	0.189	0.205	0.205	– 0.002
	(2.08) *	(2.36) **	(2.46) **	(1.43)	(– 0.02)
Distance national frontier (+)	0.557	0.607	0.731	1.099	– 0.015
	(10.51) ***	(11.63) ***	(12.46) ***	(11.49) ***	(– 0.05)
R&D (+)	– 0.100	– 0.139	– 0.076	– 0.372	0.04
	(– 1.41)	(– 1.91)	(– 1.01)	(– 2.56) **	(0.35)
R&D x distance global frontier (+)	– 0.007	0.011	0.024	0.145	– 0.224
	(– 0.09)	(0.15)	(0.32)	(1.36)	(– 2.18) *
R&D x distance national frontier (+)	0.304	0.350	0.266	0.432	0.818
	(4.04) ***	(4.70 ***	(3.38) ***	(3.25) ***	(2.49) **
Human Capital (+)	0.058	0.062	0.112	0.263	– 0.037
	(3.99) ***	(4.24) ***	(6.52) ***	(8.22) ***	(– 1.33)
Human Capital x distance global frontier (+)	– 0.004	– 0.006	– 0.011	– 0.009	0.045
	(– 0.20)	(– 0.33)	(– 0.53)	(– 0.25)	(1.86)
Human Capital x distance national frontier (+)	– 0.086	– 0.108	– 0.140	– 0.256	0.038
	(– 5.68) ***	(– 7.33) ***	(– 8.27) ***	(– 8.83) ***	(0.48)
Competition (+)	0.010	0.010	0.011	– 0.006	0.009
	(2.96) ***	(3.01) ***	(3.04) ***	(– 0.69)	(2.03) *
Competition x distance global frontier (– or +)	– 0.007	– 0.007	– 0.009	– 0.006	– 0.010
	(– 1.94)	(– 2.03) *	(– 2.38) **	(– 0.99)	(– 2.42) **
Competition x distance national frontier (– or +)	0.007	0.006	0.008	0.029	0.014
	(1.67)	(1.47)	(1.64)	(3.08) ***	(1.18)
R-squared	0.1225	0.1156	0.115	0.1295	0.0434
Serial correlation[2]	0.005	– 0.010	– 0.015	– 0.036	0.034
Number of observations	12255	12255	11176	5590	5586
Sector	All industries	All industries	All industries	All industries	All industries
Year dummies	yes	yes	yes	yes	yes
Industry dummies (EUKLEMS branch level)	yes	yes	yes	yes	yes
Estimation method	LS	LS	LS	LS	LS

[1] Between brackets z-value (based on panel robust standard errors); ***, ** or * indicates significant at respectively 1%-level, 5%-level or 10%-level.
[2] Estimated serial correlation of standard errors assuming that errors are correlated within firms.

Check of endogeneity of national frontier

We check the potential endogeneity of the national frontier in two ways, i.e. first by a check of relevant correlations, and second by applying a Hausmann test after running an additional IV-regression. Both checks, however, reject the possibility of endogeneity.

First, we calculate for each 2-digit industry the correlation between the (average) TFP-levels of the national frontiers and the average TFP-level of the global frontier over the period 1995-2004. For endogeneity of the national frontier we expect a positive correlation (see section 3.2), but for most industries we find a negative correlation. Table 6.3 shows that the TFP-levels of the national frontier(s) and the global frontier are:

- Positively correlated in 6 industries, with in 2 industries a correlation higher than 0.5
- Negatively correlated in 11 industries, with in 7 industries a correlation lower than –0.5

So these correlations do not point to a direct relation between the (average) TFP-level of the national frontier and the TFP-level of the global frontier.

Table 6.3 **Correlation over time between TFP-level of national frontier and TFP-level of global frontier**[1]

SIC	Industry	Correlation
15-16	Food , beverages and tobacco	0.52
17-19	textiles, textile , leather and footwear	– 0.12
20	wood and of wood and cork	0.25
21-22	pulp, paper, paper , printing and publishing	– 0.71
23	Coke, refined petroleum and nuclear fuel	0.24
24	chemicals and chemical	0.17
25	rubber and plastics	– 0.52
26	Other non-metallic mineral	– 0.71
27-28	Basic metals and fabricated metal	– 0.37
29	machinery, nec	– 0.66
30-33	electrical and optical equipment	– 0.52
34-35	transport equipment	n.a.
36-37	manufacturing nec; recycling	– 0.73
45	construction	0.65
50-52	wholesale and retail trade	– 0.74
55	hotels and restaurants	0.40
60-63	transport and storage	– 0.07
64	post and telecommunications	– 0.04
71-74	renting of machines and equipment, and other business activities	n.a.

Source: Own computations based on EUKLEMS-database and firm-level data of Statistics Netherlands.
[1] For each 2-digit industry, the TFP-levels of the national frontier at 3-digit level are averages.

Second, we also applied a Hausmann test that actually compares the baseline regression with an additional IV regression. This IV-regression allows the distance to the national frontier to be endogenous, with the lagged TFP-level of the global frontier and the lagged distance to the global frontier as instrumental variables (see appendix E for the results). The Hausman test, however, rejects the endogeneity of (the distance to) the national frontier.

Finally, note that the technical argument of Bartelsman et al. (2006) on the correlation between the distances to the global frontier and to the national frontier is not relevant in our empirical model. The reason is that the distance to the national frontier is measured at the firm level, while the distance to the global frontier is measured at the industry level. In that sense it is unlikely that the levels in the distance to the national frontier will correlate with the levels in the distance to the global frontier.

6.3 Does the productivity gap matter in case of more competition?

Part of the theory in chapter 2 points to an ambiguous indirect effect of competition on innovation (of incumbents). Whether competition works out differently for advanced than for laggards, we estimate two additional regressions of the baseline model. One regression includes advanced firms, i.e. non-frontier firms with a distance to the national frontier below the median of all distances. The other regression includes only lagging firms, i.e. firms with a distance above the median of all distances.

Table 6.2 presents the results of the regression with lagging firms (column 4) and advanced (column 5). Both regressions reveal that competition has a positive impact on the imitation of the technologies at the national frontier. This suggests that the theory of the inverted U-curve is not confirmed here. Apparently, the (potential) benefits of lagging firms after imitating the national frontier are sufficient to recover their cost of imitation, particularly if the competition intensity is low. Further, more competition induces advanced firms to abstain from imitating the global frontier.

6.4 Robustness of human capital effects

In section 5, we approximate human capital by the average wage level per firm. The main reason is that we cannot measure human skills at the firm level directly, as we have no specific data such as the (average) education level or experience of the employees within each firm. Our indicator can be criticised on, amongst others, that the wage level is directly related to productivity, since on competitive labour markets wages are equal to the marginal product of labour.

At least, two reasons can be used as counterargument in advance. First, we regress TFP-growth on the *level* of human capital, not on the *change* in human capital. The *level* of human capital reflects the effect of employees' skills on firm's innovativeness, as higher education and experience may ease the extent in which firms can create their own but new technologies. Second, we use the one-year lagged proxy for human capital to circumvent the direct causality between labour productivity and wages.

To what extent are the results on the effects of human capital robust? We checked this in two ways. We consider the impact of two alternative indicators, i.e.:

- The firm's (average) wage level scaled to the industry wage level as an alternative indicator for human capital (column 2 in table 6.4)
- the two year lagged average wage level (column 3 in table 6.4)

Table 6.4 Impact of alternative indicators of human capital[1]

Regression results of variant	Baseline (1)		Relative human capital (2)		Longer lag human capital (3)	
Determinant (and expected effect)						
Distance global frontier (+)	0.167		0.153		0.151	
	(2.08)	*	(3.65)	***	(1.57)	
Distance national frontier (+)	0.557		0.234		0.370	
	(10.51)	***	(13.47)	***	(14.58)	***
R&D (+)	– 0.100		– 0.091		– 0.151	
	(– 1.41)		(– 1.29)		(– 1.47)	
R&D x distance global frontier (+)	– 0.007		– 0.001		0.006	
	(– 0.09)		(– 0.01)		(0.06)	
R&D x distance national frontier (+)	0.304		0.288		0.458	
	(4.04)	***	(3.84)	***	(3.68)	***
Human Capital (+)	0.058		0.106		0.066	
	(3.99)	***	(6.12)	***	(4.39)	***
Human Capital x distance global frontier (+)	– 0.004		– 0.02		– 0.004	
	(– 0.20)		(– 0.92)		(– 0.20)	
Human Capital x distance national frontier (+)	– 0.086		– 0.153		– 0.027	
	(– 5.68)	***	(– 9.76)	***	(– 6.99)	***
Competition (+)	0.01		0.009		0.014	
	(2.96)	***	(2.79)	**	(3.14)	***
Competition x distance global frontier (– or +)	– 0.007		– 0.007		– 0.008	
	(– 1.94)		(– 1.94)		(– 1.63)	
Competition x distance national frontier (– or +)	0.007		0.008		– 0.005	
	(1.67)		(1.84)		(– 0.92)	
R-squared	0.1225		0.1268		0.1296	
Serial correlation[2]	0.005		0.001		0.016	
Number of observations	12255		12255		5982	
Sector	All industries		All industries		All industries	
Year dummies	yes		yes		yes	
Industry dummies (EUKLEMS branch level)	yes		no		yes	
Estimation method	OLS		OLS		OLS	

[1] Between brackets z-value (based on panel robust standard errors); ***, ** or * indicates significant at respectively 1%-level, 5%-level or 10%-level.
[2] Estimated serial correlation of standard errors assuming that errors are correlated within firms.

The results indicate that the regressions with the alternatives indicators provide no substantially different results. These findings suggest that in the baseline model the average wage level per firm is seemingly a robust indicator for human capital, and that additional adjustments of the wage level for potential institutional and cyclical effects are redundant. Further, remember also that skipping human capital does not affect the coefficients of other determinants (see table 5.1, column 4). So apparently, the effects of human capital are largely independent of the effects of other determinants.

7 Wrap-up and concluding remarks

Wrap-up

This document focuses on innovation, human capital, technology transfers and competition as potential sources of productivity growth for firms. It integrates the views of existing literature such as the two faces of R&D, the convergence debate and the existence of firm-level heterogeneity in productivity. The document adds two specific issues to the literature: the relevance of a national frontier besides a global frontier, and the importance of competition.

Using firm-level data of 127 industries in the Netherlands, the document analyses which determinants are most relevant for a catch up to either the national or the global frontier and in that respect are important for the productivity performance of firms. The frontier is defined as the highest Total Factor Productivity (TFP) level at the national or global level respectively. The document provides econometric evidence that technology transfers matters, mainly from the national frontier. Particularly, R&D encourages growth through technology transfers from the national frontier. This suggests that firms mainly conduct investments in own R&D in order to adopt existing technologies from other (domestic) firms. In addition, competition on (Dutch) product markets seems to affect productivity growth directly. Finally, although prudence is called for due to measurement issues, human capital appears to be important for productivity.

The main results hardly differ if we look at the manufacturing and services industries separately. The convergence to the national frontier is more relevant than to the global frontier for both sectors. Regarding manufacturing, the second face of R&D, needed for catching up to the national frontier, is relatively more important than for services. Tougher competition in services industries stimulates firms to imitate the national frontier, whereas in manufacturing industries, it more likely stimulates firms to innovate.

We have also looked whether a distinction between leading and lagging firms alter the overall results. This is particularly relevant for the impact of competition as theory argues that fiercer competition may stimulate productivity of leading firms, while it may induce laggards to abstain from improvements of productivity via innovation. We do not find evidence for an inverted U-curve with respect to the national frontier. Fiercer competition also stimulates the productivity of lagging firms. Apparently, the (potential) benefits of lagging firms after imitating the national frontier are sufficient to recover their cost of imitation.

We have examined the robustness of our main results as a number of (econometric) concerns can be put forward. More precisely, we review concerns related to measurement errors in TFP, the sensitivity to the definition of the frontier including the available data, and to the proxy of human capital. At the firm level we cannot measure human capital directly, because we have no specific data at our disposal of the (average) education level and experience of the employees per firm.

All in all, the results of these robustness tests do not radically change the overall conclusions.

Concluding remarks

The analysis in this document contributes to the productivity research agenda of CPB. So far, mostly industry level studies have focused on the topic of convergence to the frontier, an issue relevant in the endogenous growth theory. This document uses firm-level data taking into account the stylized fact that firms are very heterogeneous. It underlines the importance of R&D, competition and to some extent human capital for productivity growth.

The implications of our findings for additional or new policy measures are not clear-cut without further research including whether or not generic measures or specific measures per industry are required. In general, the importance of knowledge (spillovers) via technology transfers, innovation and sufficient competition as sources for productivity are already thoroughly embedded in existing policy. This document did not investigate whether market failures (or government failures) are at stake and might (not) legitimize government intervention. Like Griffith et al. (2004), we conclude that the social rate of return to investing in R&D may be underestimated in studies that focus solely on countries that are the frontier such as the US economy.

In addition, our results have two interesting findings for policy: the relevance of a national frontier and the importance of competition.

First, the importance of a national frontier implies that although the gap might be too large for firms to learn from the global frontier, they still manage to profit from domestic knowledge. Future work could be directed to what causes the occurrence of this national frontier. One of the main questions that should be addressed is whether market failures or government failures (e.g. too much red tape) determine this frontier. And if so, what are effective policies as the social benefits should be weighted against the costs of these policies.

The second interesting finding is that this document shows that competition is important for the productivity performance of firms and that it provides incentives to learn from others. Furthermore, competition is conducive to productivity both for firms close to the national frontier as well as for firms lagging further behind. Future work could therefore be directed to the issue whether additional innovation policy is needed besides prevailing measures such as the WBSO and the intellectual property rights.

Both findings are also related. Statistics Netherlands recently published the appealing result that foreign firms operating in the Netherlands are more productive than Dutch domestic firms (CBS, 2008). This suggests that those ‘foreign’ firms mainly determine the national frontier.

Hence, it is seemingly important to eliminate redundant institutional entry barriers for foreign firms. Attracting efficient foreign firms to the Netherlands keep domestic firms in touch with the global frontier. In fact, our findings support the idea that the threat of entry from technologically advanced entrants encourages incumbents to innovate.

Options for future work would be to improve the model and use better data. We discuss three challenges.

First, our current model restricts the direction of knowledge transfer as it neglects the intrasectoral spillovers between countries as source for productivity growth. An industry/country can only learn from the international frontier which is synonym to the economy operating the most efficient technology. In practice, we know that knowledge transfers do occur between all countries and all industries. In that respect, the contribution of trade partners to the knowledge exchange process could be more important than that of the frontier country (see e.g. Coe and Helpman, 1995).

Second, the definition of the imitation potential as the highest TFP level presupposes congruence of technological development. This highest TFP level is assumed to embody all existing technological know how. If, however, technological development in different countries is to a certain extent incongruent, then the definition of the imitation potential should include all TFP levels, not just the highest. Economic historians (see e.g. Abramovitz, 1991) have convincingly shown that technological incongruence is important for the potential to imitate. Geographical distance or cultural differences may affect this absorption process.

Finally, information on the composition of human capital is missing at the firm level. In the near future, Statistics Netherlands aims to create the possibility to link employee and employer surveys at the firm level. Then, it is possible to differentiate between more types of labour such as age, education and experience.

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Appendix A: Computation of TFP

To make comparisons between TFP-levels across firms over time, as with distances to the frontier, one needs a system of specific intertemporal and interspatial price index numbers for value added and capital cost. Such a system is not unique and its dependence on some spatio-temporal reference point cannot be circumvented. We follow the superlative number index procedure (see Caves et al. 1982), that restore the transitivity condition. To do so, one has to calculate TFP-levels relative to some common reference point, i.e. whereby the components of the Solow residual are scaled to their means across firms or countries.

Hereafter, we discuss in more detail the procedure to calculate the distance of Dutch industries to the global frontier, then the distance of individual firms to the national frontier and finally the TFP-growth of firms.

Distance to global frontier at industry level

To calculate the distance to the global frontier based on the EUKLEMS-database, for each industry *k* we first scale each country's value added, use of labour and capital, and it's share of labour costs in value added (as proxy of α)[28] by their geometric means over all countries. The relative TFP-level of country *k* then yields (subscripts of industry *j* are dropped here):

$$RTFP_{kt} = ln\left(\frac{Y_{kt}}{\overline{Y}_t}\right) - v_{kt}\, ln\left(\frac{L_{kt}}{\overline{L}_t}\right) - \left(1 - v_{kt}\right) ln\left(\frac{K_{kt}}{\overline{K}_t}\right) \tag{7.1}$$

with $ln\,\overline{Z}_t = \frac{1}{K}\sum_{k=1}^{K} ln\,Z_{kt}$, $ln\,\overline{Z}_t = ln\,\overline{Y}_{t,}\, ln\,\overline{L}_t, ln\,\overline{K}_t$ the geometric average of variable *Z* over all countries

and $v_{kt} = \frac{1}{2}\left(\alpha_{kt} + \overline{\alpha}_t\right)$, with $\overline{\alpha}_t = \frac{1}{K}\sum_{k=1}^{K}\alpha_{kt}$ the arithmetic mean of the share of labour costs in total value added over all countries

Then, we compare the relative TFP-level of country *j* to the relative TFP-level of the US:

$$STFP_{kt} = RTFP_{kt} - RTFP_{USt} \quad \text{with} \quad STFP_{Gt} = max_k\, STFP_{kt} \tag{7.2}$$

The distance of the Dutch industry to the global frontier for one particular year can be derived from

$$\begin{aligned} ln\,A_{kt}^{NL} \big/ A_{kt}^{G} &= RTFP_{NLt} - RTFP_{Gt} \\ &= RTFP_{NLt} - RTFP_{USt} - RTFP_{Gt} + RTFP_{USt} = STFP_{NLt} - STFP_{Gt} \end{aligned} \tag{7.3}$$

[28] We take this share as the proxy of α in the production function $Y = AL^{\alpha}K^{1-\alpha}$, assuming that there are constant returns to scale and that input markets work perfectly.

with $RTFP_{Gt} = max_k \, RTFP_{kt}$

Distance to national frontier at firm level

The distance to the national frontier is calculated in a slightly different way since we are using firm-level data. First, we scale the firm's TFP-level to the industry average TFP-level at the 3-digit level. Then we define the national frontier as the average *in the highest quartile interval* of these relative TFP-levels, and calculate the firms' distances to the national frontier.

So, we first scale a firm's value added, use of labour and capital, and the share of labour costs in value added (as proxy of α) by their means over all Dutch firms. For each firm the relative TFP-level then yields (subscripts of industry *j* and country *k* are dropped here):

$$RTFP_{it} = ln\left(\frac{Y_{it}}{\overline{Y}_t}\right) - v_{it}\, ln\left(\frac{L_{it}}{\overline{L}_t}\right) - \left(1 - v_{it}\right) ln\left(\frac{K_{it}}{\overline{K}_t}\right) \tag{7.4}$$

with $ln\,\overline{Z}_t = \frac{1}{I}\sum_{i=1}^{I} ln\, Z_{it}$, $ln\,\overline{Z}_t = ln\,\overline{Y}_{t,}\, ln\,\overline{L}_t , ln\,\overline{K}_t$ the geometric average of variable Z over all firms

and $v_{it} = \frac{1}{2}\left(\alpha_{it} + \overline{\alpha}_t\right)$, with $\overline{\alpha}_t = \frac{1}{I}\sum_{i=1}^{I} \alpha_{it}$ the arithmetic mean of the shares of labour costs in value added over all firms

Griffith et al. (2004) also replace α_{it} in (7.4) by the fitted value of α applying a simple regression of firms' shares of labour costs in value added on their capital intensity:

$$\alpha_{ijt} = \xi_{ijt} + \varphi_j\, ln\left(K_{ijt} / L_{ijt}\right) \tag{7.5}$$

However, this additional regression is beyond the scope of our research, so the empirical results presented in this document are based on the regular cost shares α_{it} .

We define the relative TFP-level of national frontier as the average of relative TFP-levels of all firms in the upper quartile interval:

$$RTFP_{Nt} = \frac{1}{4I} \sum_i \left\lfloor RTFP_{it} \middle| RTFP_{it} > Q_{75;RTFP_{it}} \right\rfloor \tag{7.6}$$

Then the distance to the national frontier is defined as

$$ln\left(A_{ijt} / A_{it}^{N}\right) = RTFP_{it} - RTFP_{Nt} \tag{7.7}$$

For firms with $RTFP_{it} \geq RTFP_{Nt}$ we put $ln\left(A_{ijt} / A_{it}^{N}\right)$ equal to 0.

TFP-growth at firm level

Finally, the TFP-growth is calculated in a similar way as the relative TFP-levels. It is measured as volume growth of the firm's value added minus the weighted volume growth of inputs of labour and capital (subscripts of industry *j* and country *k* are dropped here):

$$\Delta TFP_{it} = ln\left(\frac{Y_{it}}{Y_{it-\ell}}\right) - v_{it}\, ln\left(\frac{L_{it}}{L_{it-\ell}}\right) - \left(1 - v_{it}\right) ln\left(\frac{K_{it}}{K_{it-\ell}}\right) \qquad (7.8)$$

with $v_{it} = \frac{1}{2}\left(\alpha_{it} + \alpha_{it-\ell}\right)$, and $\alpha_{it}, \alpha_{it-\ell}$ the (lagged) share of firm's labour costs in its value added

Appendix B Alternative calculation of TFP

In contrast to the traditional growth accounting method, Balk and Spijker (2003) suggest to base TFP on firms' profitability or mark up. More precisely, they define TFP-growth (based on value added) as

$$\Delta \ln TFP_i = \ln\left(\frac{TFP_{it}}{TFP_{i,t-1}}\right) \tag{7.9}$$

in which

$$TFP_{it-1} = \frac{Y_{it-1}}{CK_{it-1} + CL_{it-1}} \text{ and} \tag{7.10}$$

$$TFP_{it} = \frac{Y_{it} / P_{it}^{Y}}{CK_{it} / P_{it}^{K} + CL_{it} / P_{it}^{L}} = \frac{Y_{it} / P_{it}^{Y}}{C_{it} / P_{it}^{C}} \text{ with } P_{it}^{C} = \frac{CK_{it-1}}{C_{it-1}} P_{it}^{K} + \frac{CL_{it-1}}{C_{it-1}} P_{it}^{L} \tag{7.11}$$

In these equations P_{it}^{Y} represents the price index of value added. P_{it}^{C} represents the composite price-index of all factor inputs, which is based on the price indices for capital (P_{it}^{K}) and for labour (P_{it}^{L}), and on the cost of capital (CK_{it-1}) and of labour (CL_{it-1}) of the previous year.

The input- and output prices are not available at firm level but only on industry level. In that sense, we assume that the average input- and output prices at the industry level are representative for any firm. So for any firm *i* in industry *j* we assume $P_{it}^{Y} = P_{jt}^{Y}$, $P_{it}^{K} = P_{jt}^{K}$ and $P_{it}^{L} = P_{jt}^{L}$.

We define the national frontier as the average of (log) TFP-levels of all firms in the upper quartile interval of industry *j*:

$$\ln TFP_{Nt} = \tfrac{1}{4I} \sum_i \left\lfloor \ln TFP_{it} \middle| \ln TFP_{it} > Q_{75;\ln TFP_{it}} \right\rfloor \tag{7.12}$$

The distance to the national frontier then simply boils down to

$$\ln\left(A_{ijt} / A_{it}^{N}\right) = \ln TFP_{it} - \ln TFP_{Nt} \tag{7.13}$$

For firms with $\ln TFP_{it} \geq \ln TFP_{Nt}$ we put $\ln\left(A_{ijt} / A_{it}^{N}\right)$ equal to 0.

Appendix C Endogeneity R&D and selection bias

Here, we investigate two issues related to R&D. The first issue concerns the endogeneity of R&D as discussed in section 3.2. The second issue refers to potential selection bias, which may be due to the limited number of observations in the CIS and R&D-survey, and to the fact that only a small part of firms report that they innovate and conduct R&D.

Endogeneity of R&D

Table C.1 compares the baseline regression with other variants that may cope with the endogeneity of R&D. The first variant (column 2 in table C.1) is similar as the baseline regression, but includes the two-year lagged R&D intensity and the two year lagged interaction terms between R&D and catch up to the global/national frontier. The second variant (column 3 in table C.1) is based on a 2SLS regression in which the (one year lagged) R&D and interaction terms are first estimated by all other explanatory variables as instrumental variables.

The results of these two variants do not point to substantial differences for the direct effect and indirect effects of R&D, except that in the 2SLS variant the negative direct effect becomes significant.[29] So even if R&D is endogenously related to other variables, endogeneity hardly affects the outcome on the direct and indirect effect of R&D.

We applied a formal test to check for the endogeneity of R&D, but also for the endogeneity of the interaction terms between R&D and catch up to global/national frontier. Obviously, if R&D is endogenously then all the interaction terms with R&D become endogenous as well.

Hausman showed that one can test the endogeneity of a variable adding the error term (or the predicted value) from the IV regression of that variable to the main regression (see Cameron and Trivedi, 2005). Significance of the error term in the main regression points to endogeneity of that variable. So in the first step we regressed the firms' R&D, an interaction terms between R&D and catch up to global /national frontier on all other determinants.[30] Then, in the second step we added the residuals to the baseline equation. The results of the second step (see column 4 in table C.1) reject the endogeneity of R&D and the interaction term with the global frontier, but do point to endogeneity of the interaction term with the national frontier. Even though R&D may not be endogenous, the distance to the national frontier might still be endogenous. Appendix E checks for the endogeneity of the distance to the national frontier.[31]

[29] Surprisingly, adopting the two-year lagged R&D makes the indirect effects of human capital and competition via catch up significant.

[30] I.e. distance to the global frontier, distance to the national frontier, human capital, competition and all interaction terms of human capital and competition with the distance to the global or national frontier.

[31] The F-test of these auxiliary IV regressions point in similar directions: the determinants in the auxiliary regressions cannot significantly explain R&D and its interaction with the global frontier, but does significantly explain the interaction between R&D and the distance to the national frontier.

Table C.1 Endogeneity of R&D and check for selection bias[1]

Variant	(1) baseline		(2)		(3)[3]		(4)[3]		(5)[4]	
Determinant (and expected effect)										
Distance to global frontier (+)	0.167		0.48		0.272		0.298		0.168	
	(2.08)	*	(3.57)	***	(1.49)		(1.64)		(2.09)	*
Distance to national frontier (+)	0.557		0.811		0.363		0.339		0.560	
	(10.51)	***	(8.24)	***	(2.08)	*	(1.99)	*	(10.55)	***
R&D (+)	– 0.100		– 0.109		– 0.516		– 0.179		– 0.100	
	(– 1.41)		(– 1.14)		(– 1.93)		(– 1.16)		(– 1.41)	
R&D x distance to global frontier (+)	– 0.007		– 0.006		– 0.130		– 0.112		– 0.007	
	(– 0.09)		(– 0.06)		(– 0.82)		(– 0.72)		(– 0.10)	
R&D x distance to national frontier (+)	0.304		0.254		1.377		0.947		0.304	
	(4.04)	***	(2.44)	**	(2.49)	**	(2.88)	***	(4.03)	***
Human Capital (+)	0.058		0.175		0.099		0.086		0.059	
	(3.99)	***	(7.33)	***	(2.60)	**	(2.34)	**	(4.02)	***
Human Capital x distance global frontier (+)	– 0.004		– 0.108		– 0.060		– 0.064		– 0.004	
	(– 0.20)		(– 3.40)	***	(– 1.32)		(– 1.42)		(– 0.23)	
Human Capital x distance national frontier (+)	– 0.086		– 0.175		– 0.057		– 0.046		– 0.087	
	(– 5.68)	***	(– 6.37)	***	(– 1.16)		(– 0.98)		(– 5.73)	***
Competition (+)	0.010		– 0.002		0.006		0.005		0.010	
	(2.96)	***	(– 0.50)		(0.97)		(0.78)		(2.97)	***
Competition x distance global frontier (– or +)	– 0.007		– 0.001		– 0.005		– 0.004		– 0.007	
	(– 1.94)		(– 0.11)		(– 0.78)		(– 0.71)		(– 1.95)	
Competition x distance national frontier (– or +)	0.007		0.019		0.010		0.011		0.007	
	(1.67)		(2.95)	***	(1.20)		(1.34)		(1.67)	
IV-residual of R&D							– 0.329			
							(– 1.48)			
IV-residual of R&D to dist. to global frontier							0.023			
							(0.10)			
IV-residual of R&D x dist. to national frontier							– 0.847			
							(– 2.39)	**		
Mill's lambda									– 0.002	
									(– 0.23)	
R-squared	0.1225		0.0975		0.0858		0.1055			
Serial correlation[2]	0.005		– 0.03							
Rho[5]									– 0.00562	
Number of (censored) observations	12255		6450		3097		3097		12255	
Number of uncensored observations									136824	
Year dummies	yes		yes		yes		yes		yes	
Industry dummies (EUKLEMS branch level)	yes		no		yes		yes		yes	
Estimation method	LS		LS		2SLS		Hausman		Heckman	

[1] Between brackets in variant (1) and (2) z-value (based on panel robust standard errors), and in variant (3) and (4) t-value; ***, ** or * indicates significant at respectively 1%-level, 5%-level or 10%-level.

[2] Estimated serial correlation of standard errors assuming that errors are correlated within firms.

[3] First-stage regressions of (one year-lagged) R&D and interaction-terms with R&D are not presented here, but are available on request.

[4] Regression of selection equation (in first stage) is not presented here, but is available on request.

[5] I.e. correlation between errors of selection equation and errors of main equation.

Selection bias

We apply Heckman's two-step procedure to test for the selection bias (see Cameron and Trivedi, 2005). In the first step we regress a dummy whether a firm is included in the baseline regression on the distance of that firm to the national frontier and the firm's number of employees.[32] This regression provides Mill's lambda, which is in this case the *conditional probability* that the firm will be included in the baseline regression. In the second step, we include Mill's lambda as an explanatory variable. Then, a significant coefficient of Mill's lambda points to existence of selection bias.[33]

The results of the Heckman procedure (column 5 in table C.1), however, reject the existence of selection bias. More precisely, the coefficient of Mill's lambda is non-significant. Further, the estimated coefficients of all other determinants in the Heckman regression are very similar to the estimated coefficients in the baseline regression.

[32] Note that both explanatory variables are derived from the PS-data, and thus also for firms that are excluded in the baseline regression.

[33] Non-significance points to absence of selection bias.

Appendix D Importance of export

Intuitively, one would expect that export-intensive firms are more focussed on developments of international markets, and thus would be more eager to learn from the global frontier than export-extensive firms. The latter type of firms is more likely to benefit from domestic developments, and hence learn from the national frontier. Table D.1 presents the results for firms with an export rate below the median (column 2), and for firms with an export rate above the median (column 3).[34]

The regression results for the separate groups hardly support our hypothesis. In fact, firms with a relatively high export rate mostly learn from the national frontier and hardly from the global frontier. Moreover, none of the interaction terms with the global frontier is significant. Both findings underline one of the major conclusions of the main text stressing the importance of the national frontier. Some results are even counterintuitive, for instance the negative impact of R&D of export-extensive firms on their learning from the global frontier. Apparently, competition seems to play a more eminent role in improving the productivity performance for export-extensive firms than for export-intensive firms.

[34] I.e. the median of export rate for only those firms that are included in the (baseline) regression.

Table D.1 Impact of export rate[1]

Variant	(1) (baseline)		(2)		(3)	
Determinant (and expected effect)						
Distance to global frontier (+)	0.167		0.194		0.126	
	(2.08)	*	(1.84)		(1.03)	
Distance to national frontier (+)	0.557		0.569		0.551	
	(10.51)	***	(4.91)	***	(8.98)	***
R&D (+)	– 0.100		0.103		– 0.167	
	(– 1.41)		(0.77)		(– 1.93)	
R&D x distance to global frontier (+)	– 0.007		– 0.262		0.089	
	(– 0.09)		(– 2.25)	**	(0.93)	
R&D x distance to national frontier (+)	0.304		0.378		0.276	
	(4.04)	***	(2.30)	**	(3.15)	***
Human Capital (+)	0.058		0.041		0.065	
	(3.99)	***	(1.54)		(3.54)	***
Human Capital x distance global frontier (+)	– 0.004		– 0.007		– 0.001	
	(– 0.20)		(– 0.27)		(– 0.02)	
Human Capital x distance national frontier (+)	– 0.086		– 0.094		– 0.086	
	(– 5.68)	***	(– 2.84)	***	(– 4.88)	***
Competition (+)	0.010		0.011		0.007	
	(2.96)	***	(2.26)	**	(1.53)	
Competition x distance global frontier (– or +)	– 0.007		– 0.001		– 0.011	
	(– 1.94)		(– 0.28)		(– 2.09)	*
Competition x distance national frontier (– or +)	0.007		– 0.003		0.017	
	(1.67)		(– 0.47)		(2.98)	***
R-squared	0.1225		0.1059		0.135	
Serial correlation[2]	0.005		– 0.011		0.011	
Number of observations	12255		4384		7869	
Sector	All industries		All industries		All industries	
Year dummies	yes		yes		yes	
Industry dummies (EUKLEMS branch level)	yes		yes		yes	
Estimation method	LS		LS		LS	
Estimation period	1996-2004		1996-2004		1996-2004	

[1] Between brackets z-value (based on panel robust standard errors); ***, ** or * indicates significant at respectively 1%-level, 5%-level or 10%-level.
[2] Estimated serial correlation of standard errors assuming that errors are correlated within firms.

Appendix E Tests for endogeneity national frontier

This appendix provides a Hausman test for the endogeneity of the national frontier. We apply a similar procedure as in appendix C, except that here we add the *predicted value* from the IV regression to the main regression (see Cameron and Trivedi, 2005). Then again, significance of the predicted value in the main regression points to endogeneity of that variable.

Table E.1 Check for endogeneity of the distance to the national frontier[1]

Variant	(1) baseline		(2)[2]	
Distance to global frontier	0.390		0.333	
	(2.90)	***	(2.07)	*
Distance to national frontier	0.289		0.289	
	(23.73)	***	(23.73)	***
R&D	0.146		0.146	
	(2.07)	*	(2.07)	*
R&D x distance to global frontier	– 0.037		– 0.039	
	(– 0.36)		(– 0.38)	
Human Capital	0.048		0.048	
	(2.78)	**	(2.76)	**
Human Capital x distance to global frontier	– 0.066		– 0.065	
	(– 2.06)	*	(– 2.03)	*
Competition	0.011		0.011	
	(3.01)	***	(3.00)	***
Competition x distance to global frontier	– 0.007		– 0.007	
	(– 1.51)		(– 1.48)	
Predicted distance to national frontier			– 0.588	
			(– 0.65)	
R-squared	0.1112		0.1112	
Number of observations	5981		5981	
Sectors	All industries		All industries	
Year dummies	yes		yes	
Industry dummies (EUKLEMS branch level)	yes		yes	
Estimation method	OLS		Hausman procedure	
Estimation period	1996-2004		1996-2004	

[1] Between brackets t-value; ***, ** or * indicates significant at respectively 1%-level, 5%-level or 10%-level.
[2] Regression of auxiliary equation (in first stage) is not presented here, but is available on request.

Following this procedure, we first regressed the distance to the national frontier on the TFP-level of the global frontier and on the distance to the global frontier. Then, in the second step we added the predicted distances to the national frontier values derived from this auxiliary regression, but omitted the indirect effects related to the catch up to the national frontier.
The result of the main regression (see column (2) in table E.1) point to absence of the endogeneity in the distance to the national frontier, as the predicted value of distance up to the national frontier is not significant.