CENTRE OF PLANNING AND ECONOMIC RESEARCH (KEPE)

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THEODORE TSEKERIS
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AGGLOMERATION ECONOMIES AND PRODUCTIVITY IN THE EU REGIONS

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CENTRE OF PLANNING AND ECONOMIC RESEARCH (KEPE)

The Centre was initially established as a research unit, under the title "Centre of Economic Research", in 1959. Its primary aims were the scientific study of the problems of the Greek economy, the encouragement of economic research and cooperation with other scientific institutions.

In 1964, the Centre acquired its present name and organizational structure, with the following additional objectives: first, the preparation of short, medium and long-term development plans, including plans for local and regional development as well as public investment plans, in accordance with guidelines laid down by the Government; second, the analysis of current developments in the Greek economy along with appropriate short and medium-term forecasts, the formulation of proposals for stabilization and development policies; and, third, the additional education of young economists, particularly in the fields of planning and economic development.

Today, KEPE is the largest economics research institute in Greece, focuses on applied research projects concerning the Greek economy and provides technical advice to the Greek government and the country's regional authorities on economic and social policy issues.

In the context of these activities, KEPE has issued more than 700 publications since its inception, and currently produces several series of publications, notably the Studies, *which are research monographs;* Reports *on applied economic issues concerning sectoral and regional problems;* Discussion Papers *that relate to ongoing research projects.* KEPE also publishes a tri-annual *review entitled* Greek Economic Outlook, *which focuses on issues of current economic interest for Greece.*

PREFACE

One of the main institutional roles of KEPE, which also serves as the National Productivity Board of Greece, is the systematic study of productivity and its driving forces, and the recommendation of policies to treat sources of inefficiency. The study of Drs Tsekeris and Papaioannou employs a comprehensive and theoretically grounded methodological framework for measuring the technical efficiency and total factor productivity of the EU regions, considering a unique set of spatial determinants of (in)efficiency, including the regional sprawl of developed land uses and their mix, employment density, specialisation, sectoral concentration, market access and human capital.

The findings of the study highlight the crucial role of the regional dimension for the consistent analysis of the productivity and relevant gaps between and within the EU countries. Moreover, it underscores the importance of efficiency in addressing current policy challenges faced by the EU and national authorities. In light of the new programming period 2021–2027, it is shown that policy objectives and fiscal measures should also target raising the levels of efficiency and reducing technology gaps to accelerate regional convergence. The results have further implications for productivity-related policies aiming to enhance the sustainability and resilience of regional economies, through re-allocating land uses, reorganising value chains and deploying advanced technologies, such as those of telecommuting and e-commerce.

The study places special emphasis on investigating factors inhibiting the productivity of laggard regions in the EU. Regarding Greece, it suggests the possibility of achieving efficiency gains and lower interregional inequalities through investing in physical connectivity and human capital, managing urbanisation, land uses and space-intensive investments in con-

nection with economic policies, and implementing structural reforms to align and coordinate regional and sectoral growth plans.

PANAGIOTIS G. LIARGOVAS
Chairman of the Board
and Scientific Director

CENTRE OF PLANNING AND
ECONOMIC RESEARCH
March 2021

Greece is one of the EU countries whose productivity falls considerably behind the EU average. At the same time, the country experiences one of the largest and most persistent core-periphery disparities in the EU, as the best performing region of Attiki significantly outperforms the efficiency and total factor productivity (TFP) of the rest of the Greek regions. By using an integrated and theoretically sound methodological framework for consistently monitoring and benchmarking efficiency, and a unique dataset of regional variables, this study measures the efficiency scores and TFP of the Greek and the EU regions during the period 2009–2016. In the same framework, it identifies the main determinants of inefficiency and technology gaps, and formulates productivity-enhancing policies.

The findings of the study corroborate the considerable spatial inequalities between the regions of northern and central-western Europe (with efficiency scores exceeding 90%) and the regions of eastern and southern Europe, as well as the existence of a multi-speed convergence process within the EU. The results also demonstrate the complexity of the relationships between regional efficiency and agglomeration economies. They indicate the need for harnessing positive spatial agglomeration economies, managing negative agglomeration externalities, improving physical connectivity and advancing human capital, in order to support sustainable development and cohesion among the European regions.

We acknowledge three anonymous referees for their insightful comments that helped us to substantially improve our study, Helen Soultanakis for her valuable editorial help and the Editorial Office and Library staff of KEPE for their kind assistance in producing this study.

THEODORE TSEKERIS
SOTIRIS PAPAIOANNOU

March 2021

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ΣΥΝΟΨΗ

Η βελτίωση της παραγωγικότητας και της αποτελεσματικότητας μιας χώρας ή μιας περιφέρειας είναι απαραίτητη για τη μακροπρόθεσμη οικονομική άνθησή της, αφού ευνοεί τη δημιουργία βιώσιμων θέσεων εργασίας, την αύξηση των μισθών, καλύτερες συνθήκες ζωής και άλλες διαστάσεις της ευημερίας των πολιτών. Η επιβράδυνση του ρυθμού αύξησης της παραγωγικότητας και οι έντονες χωρικές ανισότητές της στην Ευρωπαϊκή Ένωση καθιστούν αναγκαία τη βαθύτερη κατανόηση των πηγών της αναποτελεσματικότητας στη χρήση των συντελεστών παραγωγής και τη διαμόρφωση κατάλληλα στοχευμένων πολιτικών περιφερειακής ανάπτυξης και συνοχής. Η παρούσα μελέτη παρέχει ένα ολοκληρωμένο και θεωρητικά στέρεο μεθοδολογικό πλαίσιο για τη συνεπή εκτίμηση και συγκριτική ανάλυση της αποτελεσματικότητας, της συνολικής παραγωγικότητας των συντελεστών παραγωγής, και των τεχνολογικών χασμάτων στις ευρωπαϊκές περιφέρειες. Εντός του πλαισίου αυτού, εντοπίζονται οι κύριοι προσδιοριστικοί παράγοντες της αναποτελεσματικότητας και διαμορφώνονται προτάσεις για την ενίσχυση της παραγωγικότητας.

Σε αντίθεση με προηγούμενες έρευνες, διερευνούμε την επίδραση στην (αν)αποτελεσματικότητα διαφορετικών μεταβλητών χωρικής συσσώρευσης (spatial agglomeration), αναγνωρίζοντας ότι τόσο οι επενδύσεις σε υποδομές όσο και οι μεταβολές σε χρήσεις γης δύνανται να επηρεάζουν την εγκατάσταση και την αποδοτικότητα των οικονομικών δραστηριοτήτων. Ειδικότερα, διαχωρίζεται η επίδραση της οικονομικής πυκνότητας από αυτή της γεωγραφικής διάχυσης της ανάπτυξης (ως προς την ποσότητα των ανεπτυγμένων χρήσεων γης συνολικά και για επιμέρους κατηγορίες ανά κάτοικο). Επίσης διαχωρίζονται οι επιδράσεις της οικονομικής σύνθεσης (ως προς την περιφερειακή εξειδίκευση και την τομεακή διαφοροποίηση) από την επίδραση της σύνθεσης (μείγματος) των χρήσεων γης. Άλλες περιφερειακές μεταβλητές που λαμβάνονται υπόψη αφορούν την πρόσβαση σε αγορές (και εναλλακτικές μεταβλη-

τές γεωγραφικής κεντρικότητας) και το ανθρώπινο κεφάλαιο. Για τον σκοπό αυτό, εκτιμούμε μια περιφερειακή συνάρτηση παραγωγής ταυτόχρονα με μια εξίσωση που αναπαριστά την αναποτελεσματικότητα σε ένα υπόδειγμα δύο σταδίων, το οποίο ενσωματώνει τη χωρική δομή της οικονομικής δραστηριότητας στο επίπεδο NUTS-2 των περιφερειών της Ευρωπαϊκής Ένωσης.

Τα αποτελέσματα δείχνουν ότι το μέσο επίπεδο τεχνικής αποτελεσματικότητας των ευρωπαϊκών περιφερειών παρέμεινε ουσιαστικά το ίδιο (περίπου 80%) κατά τη διάρκεια της περιόδου (2010-2016). Παρατηρούνται ορισμένες σημαντικές ανισότητες, αφού περιφέρειες της Κεντροδυτικής και Βόρειας Ευρώπης είχαν τιμές αποτελεσματικότητας άνω του 90%, σε σύγκριση με τις πολύ λιγότερο αποτελεσματικές περιφέρειες της Ανατολικής και Νότιας Ευρώπης. Επιπροσθέτως, παρατηρούνται σημαντικά διαπεριφερειακά χάσματα παραγωγικότητας εντός συγκεκριμένων χωρών, όπως στο Ηνωμένο Βασίλειο, την Ιταλία, την Ισπανία και την Ελλάδα.

Η αποτελεσματικότητα όλων των ελληνικών περιφερειών, η οποία κατά μέσο όρο κυμάνθηκε στο 54% κατά την περίοδο μελέτης, υπολείπεται σημαντικά έναντι της μέσης τιμής αποτελεσματικότητας των υπολοίπων χωρών της Ευρωπαϊκής Ένωσης. Η μέγιστη τιμή αποτελεσματικότητας (66%), η οποία αντιστοιχούσε στην Αττική, ήταν άνω των 20 ποσοστιαίων μονάδων υψηλότερη από την ελάχιστη τιμή αποτελεσματικότητας (44%), η οποία αντιστοιχούσε στην Πελοπόννησο και αποτελούσε την 8η χαμηλότερη τιμή αποτελεσματικότητας σε ολόκληρη την Ευρωπαϊκή Ένωση (το 2016). Η Κεντρική Μακεδονία και οι νησιωτικές περιφέρειες του Νοτίου Αιγαίου, της Κρήτης, του Βορείου Αιγαίου (το 2010) και των Ιονίων Νήσων (το 2016) είχαν τιμές αποτελεσματικότητας άνω του μέσου όρου της χώρας. Επίσης, εντοπίζονται σημαντικές διαφορές στη διαχρονική εξέλιξη της αποτελεσματικότητας μεταξύ των περιφερειών, υποδεικνύοντας την ύπαρξη μιας διαδικασίας σύγκλισης πολλαπλών ταχυτήτων εντός της Ευρωπαϊκής Ένωσης. Η διαδικασία αυτή αντανακλά κυρίως την επιβράδυνση της παραγωγικότητας στις πιο ανεπτυγμένες χώρες/περιφέρειες και την πορεία κάλυψης της υστέρησης που εμφανίζουν οι οικονομίες των χωρών/περιφερειών της Ανατολικής Ευρώπης.

Τα ευρήματα δείχνουν ότι η σχέση μεταξύ των οικονομιών συσσώρευσης και της αποτελεσματικότητας είναι πολύπλοκη και εξαρτώμενη από το χωρικό πλαίσιο της ανάλυσης. Από τη μία πλευρά, η περιφερειακή αποτελεσματικότητα επηρεάζεται θετικά από τον ρυθμό αύξησης της γεωγραφικής διάχυσης της ανάπτυξης πέρα από ένα σημείο, τη συγκέντρωση των χρήσεων γης καθώς και την τομεακή συγκέντρωση των οικονομικών δραστηριοτήτων, την προαγωγή του ανθρώπινου κεφαλαίου και την ενίσχυση της πρόσβασης σε αγορές (και άλλων μεγεθών γεωγραφικής κεντρικότητας). Από την άλλη πλευρά, σημαντικές πηγές αναποτελεσματικότητας αποτελούν ο ρυθμός αύξησης της πυκνότητας απασχόλησης πέρα από ένα σημείο και ο αυξημένος βαθμός εξειδίκευσης εργασίας, σε σύγκριση με τον ευρωπαϊκό μέσο βαθμό εξειδίκευσης εργασίας. Παράγοντες οι οποίοι είναι κοινοί σε επίπεδο χώρας, όπως μακροοικονομικές πολιτικές, στρατηγικές χωρικού σχεδιασμού και το στάδιο της ανάπτυξης, επίσης επηρεάζουν σημαντικά –αλλά ετερογενώς– την περιφερειακή αποτελεσματικότητα. Τα συγκεκριμένα ευρήματα υποστηρίζονται από ένα πλήθος διαφορετικών εξειδικεύσεων και επεκτάσεων του βασικού υποδείγματος, συμπεριλαμβάνοντας εναλλακτικές επεξηγηματικές μεταβλητές και όρους αλληλεπίδρασης μεταβλητών.

Τα αποτελέσματα της μελέτης μπορούν να χρησιμοποιηθούν για να προσφέρουν χρήσιμες συμβουλές για τη διαμόρφωση πολιτικών, οι οποίες είναι προσαρμοσμένες στα ιδιαίτερα χαρακτηριστικά, τις ανάγκες και τα συγκριτικά πλεονεκτήματα κάθε ευρωπαϊκής περιφέρειας, έτσι ώστε να αντιμετωπιστούν πηγές αναποτελεσματικότητας και ανισότητες μεταξύ τους. Ειδικότερα, η κατάλληλη αξιοποίηση οικονομιών χωρικής συσσώρευσης, η βελτίωση της συνδεσιμότητας –μέσω στρατηγικών επενδύσεων σε φυσικές υποδομές– και η προαγωγή του ανθρώπινου κεφαλαίου αποτελούν κρίσιμους παράγοντες για τη βιώσιμη ανάπτυξη και συνοχή των ευρωπαϊκών περιφερειών. Για τον σκοπό αυτό, ο σχεδιασμός και η υλοποίηση επενδυτικών προγραμμάτων και περιφερειακών-τομεακών σχεδίων οφείλει να εμπεριέχει εργαλεία πολιτικής που θα λειτουργούν συνεργατικά μεταξύ τους. Τα εργαλεία αυτά μπορεί να αναφέρονται στην ενίσχυση των θεσμών χωρικού σχεδιασμού και διακυβέρνησης, έτσι ώστε να εξασφαλίζεται ότι η διαχείριση των χρήσεων γης προωθεί την παραγωγικότητα, και τη θεραπεία των αρνητικών οικονομιών συσσώρευσης.

Συνιστάται να δοθεί έμφαση στις περιφέρειες με χαμηλές επιδόσεις, αναφορικά με παράγοντες που ευνοούν την αποτελεσματικότητα και τη συνολική παραγωγικότητα των συντελεστών παραγωγής, και αμβλύνουν τα τεχνολογικά χάσματα με τις περιφέρειες με υψηλές επιδόσεις. Στην περίπτωση των περιφερειών της Ανατολικής Ευρώπης, η συμπαγής χωρική ανάπτυξη και η διαφοροποίηση των οικονομικών δραστηριοτήτων μπορεί να αποφέρει σημαντικά οφέλη αποδοτικότητας. Σχετικά με την Ελλάδα, αντίστοιχα οφέλη δύνανται να προκύψουν από τον ολοκληρωμένο χωρικό σχεδιασμό για τη διαχείριση της αστικοποίησης και τις επενδύσεις υψηλής έντασης γης σε περιφερειακό επίπεδο.

Η παρούσα μελέτη υπογραμμίζει ορισμένες μεγάλες προκλήσεις στην άσκηση πολιτικών σε ευρωπαϊκό και εθνικό επίπεδο κατά την προγραμματική περίοδο 2021–2027. Μεταξύ αυτών είναι η συμπερίληψη στόχων και κριτηρίων που ευνοούν την αύξηση της παραγωγικότητας και αποτελεσματικότητας, τη μείωση των τεχνολογικών χασμάτων, και την επιτάχυνση της σύγκλισης των περιφερειών, τόσο σε ευρωπαϊκό όσο και σε εθνικό επίπεδο. Οι προτάσεις πολιτικής είναι επιπλέον συναφείς με σύγχρονες ή μελλοντικές εξελίξεις που αναμένεται να επηρεάσουν σημαντικά την παραγωγικότητα των περιφερειών, είτε μέσω της ανακατανομής των χρήσεων γης για δραστηριότητες γεωργίας, βιομηχανίας, υπηρεσιών και στέγασης, είτε μέσω της αναδιοργάνωσης αλυσίδων αξίας. Μεταξύ άλλων, οι εξελίξεις αυτές σχετίζονται με τεχνολογικές καινοτομίες (π.χ., αυτόνομα οχήματα, προηγμένες τεχνολογίες μεταποίησης, τηλεργασία) και δράσεις για την αποτροπή ή τον έλεγχο της εξάπλωσης μεταδοτικών ασθενειών, όπως η COVID-19, και την ενδυνάμωση της ανθεκτικότητας στην κλιματική αλλαγή.

EXECUTIVE SUMMARY

The improvement of productivity and efficiency is essential for the long-term economic prosperity of countries and regions, through fostering sustainable job creation, wage growth, better living standards and other dimensions of well-being. Therefore, the productivity slowdown and increased spatial inequalities in the EU call for a deeper understanding of the sources of inefficiency and a thorough formulation of more regionally targeted growth and cohesion policies. This study provides an integrated and theoretically sound methodological framework for consistently monitoring and benchmarking efficiency, total factor productivity (TFP) and technology gaps of EU regions. Within this framework, we identify main determinants of inefficiency and formulate productivity-enhancing policies.

Unlike previous research, our study explores the (in)efficiency impact of spatial agglomeration economies, recognising that both infrastructure investments and changes in land uses may affect the location and performance of economic activities. In particular, we disentangle the impact of economic density from the geographical sprawl of development (developed land in total and for specific uses per capita) as well as the effects of economic composition (specialisation and diversification) from those of land-use composition (or mixture). Other regional variables are also considered here, such as market access (and alternative measures of geographical centrality) and human capital. In doing so, we estimate a regional production function along with an inefficiency equation in a two-stage stochastic frontier model which accounts for the spatial structure of economic activity at the EU regional (NUTS-2) level.

We show that the average level of technical efficiency across the EU regions has basically remained the same (about 80%) during the period 2010–2016. Considerable spatial inequalities are observed, since regions of the northern and central-western Europe, which have efficiency scores above 90%, significantly outperform the regions located in the eastern and southern Europe. Additionally, there are significant interregional productivity gaps within specific countries, such as in the U.K., Italy, Spain, and Greece.

All Greek regions fell considerably behind the EU average, with an average level of technical efficiency approximately equal to 54% during this period. The efficiency score (66%) of the best performing region (Attiki) was more than 20 percentage points higher than the efficiency score (44%) of the lowest performing region (Peloponnisos), which was the 8th least efficient region of the EU (in 2016). The region of Kentriki Makedonia and the island regions of Notio Aigaio, Kriti, Voreio Aigaio (in 2010) and Ionia Nisia (in 2016) had efficiency scores above the country's average.

There are also considerable differences in the dynamism among regions, which imply the existence of a multi-speed convergence process within the EU. This process primarily reflects the productivity slowdown in most developed countries/regions and the catching-up of eastern EU regions. Our findings signify that the agglomeration-efficiency nexus is complex and largely context-specific. On the one hand, efficiency is positively affected by the growth of land development sprawl above a threshold point, the geographical (land-use) and sectoral concentration of broad economic activities, the enhancement of human capital and market access (or other types of geographical centrality). On the other hand, sources of inefficiency refer to the growth in employment density above a threshold point and the much less uniform or more specialised pattern of employment with respect to the average EU pattern. Country-specific features like macroeconomic/planning policies and the level/stage of development do also significantly influence regional efficiency. These results are supported by a range of regressions encompassing different specifications and extensions of the baseline model, including alternative explanatory variables and interaction effects.

The findings offer useful implications for policy measures which are tailored to the intrinsic characteristics, needs and comparative advantages of EU regions to address inefficiencies and inequalities among them. Harnessing agglomeration economies, improving connectivity —through strategic investment in physical infrastructure— and advancing human capital are all crucial elements for the sustainable and fair development and cohesion among the European regions. For this purpose, the formulation and implementation of investment programmes and regional sectoral plans should involve a bundle of policy measures to work in synergy. Among others, these measures may include the strengthening of spatial planning institutions, so that land-use management promotes efficiency, and treatment of agglomeration diseconomies.

Special emphasis should be given to the laggard EU regions as regards the factors promoting efficiency and TFP and reducing technology gaps vis-à-vis the frontier EU regions. For the eastern EU regions, it is shown that compact development and diversity of socio-economic activities and land uses should bring about substantial efficiency gains. Regarding Greece, the need for establishing an integrated spatial planning framework is stressed for the management of urbanisation and land-intensive developments at the regional level.

The present study underscores a major challenge for policy-makers in the EU and national authorities over the programming period 2021–2027. This challenge concerns the need to encompass policy objectives and investment criteria to raise the levels of productivity and efficiency, to reduce productivity gaps, to tackle income disparities and accelerate convergence. The policy suggestions are also quite relevant to current and near-future developments which are expected to have a strong impact on regional productivity, through the re-allocation of physical space (especially, for industry, and services and residential purposes in urban areas) and the reorganization of some value chains. These developments include technological innovations, such as autonomous vehicles, advanced manufacturing systems and telecommuting, and actions to prevent or control the spread of infectious diseases, such as COVID-19, and increase the resilience to climate change.

CHAPTER 1

INTRODUCTION

The improvement of productivity determines the quantity and quality of jobs and living standards in a country and exerts a durable effect on long-run economic growth. In turn, the treatment of productivity slowdowns and increasing inequalities among countries, regions, industries and firms is considered as a key policy priority for sustainable and inclusive growth in the European Union (Rincon-Aznar et al., 2014; Juncker et al., 2015; Van Ark and Jäger, 2017). This is because lower productivity undermines the stability and resilience of economic growth, while increased imbalances or disparities inhibit convergence and entail the misallocation of resources, higher social costs and conflicts/movements that adversely affect democracy (Dijkstra et al., 2020; McCann, 2020). Given that labour productivity and total factor productivity (TFP) growth in the EU were in decline well before the crisis, productivity and TFP slowdowns can be regarded as mostly a structural problem of the economies of European countries and regions, rather than the impact of exogenous macroeconomic/financial shocks (EC, 2019).

According to the OECD (2018a), most regions of its member-countries have witnessed higher productivity, but larger inequalities have emerged, rendering their growth process less inclusive. Although this tradeoff between regional productivity growth and inequalities cannot be regarded as the general rule, regional cohesion policies should be strengthened in countries pertaining to considerable core-periphery disparities. Greece has repeatedly shown significant and persistent productivity gaps between its core region (of Attiki, where the capital city of Athens is located) and its peripheral regions.[1] Papaioannou et al. (2017) examined a

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[1] The names of Greek regions follow the second-level classification of the Nomenclature of Territorial Units for Statistics (NUTS) for the sub-national division of EU regions and are translated to English as follows: Attica (Attiki), Central Greece (Sterea Ellada), Central Macedonia (Kentriki Makedonia), Crete (Kriti), Eastern Macedonia and Thrace (Anatoliki

wide range of regional factors influencing the productive efficiency of the Greek economy, underlying the favourable effect of agglomeration economies, connectivity and human capital.

The current study extends and enriches this comprehensive analysis of regional productivity to the European scale in order to allow the estimation of productivity indices, technology gaps, and technical efficiency scores across EU regions.[2] In this manner, benchmarking can be carried out by estimating productivity/efficiency gaps, and inefficiency determinants can be identified and interpreted, not only among regions of the same country, but at the EU level as a whole. The analysis of productivity and efficiency in the current literature is rather fragmented, focusing only on a handful of determinants, mostly at the country level. The current literature usually overlooks the impact of the regional dimension of productivity, particularly when the analysis focuses on a set of countries, such as those of the EU. In fact, there is a multitude of driving factors, several of which have not yet been disentangled, well understood or identified at the regional level. A comprehensive analysis with the use of production functions that account for the spatial structure of economic activity at the EU level is still lacking.

Existing empirical studies, which measured and analysed disparities of productivity across European regions, employed either nonparametric or stochastic frontier models (Ezcurra et al., 2009; Ramajo and Hewings, 2017) and attempted to identify drivers of productivity growth, typically in terms of TFP (Marrocu and Paci, 2012; Marrocu et al., 2013; Capello and Lenzi, 2015; Beugelsdijk et al., 2018). In these studies, the determinants of productivity in the regional context are typically examined either in isolation or as a limited set of explanatory variables. More specifically, existing literature has mostly focused on the efficiency-enhancing impact of economic density-related agglomeration across EU regions. These spa-

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Makedonia-Thraki), Epirus (Ipeiros), Ionian Islands (Ionia Nisia), North Aegean (Voreio Aigaio), Peloponnese (Peloponnisos), South Aegean (Notio Aigaio), Thessaly (Thessalia), Western Greece (Dytiki Ellada), Western Macedonia (Dytiki Makedonia) (Accessed online at: <https://publications.europa.eu/code/en/en-5001000.htm>).

[2] In this study, the analysis of the productivity of the EU regions includes the UK regions, since the time period under examination covers the pre-Brexit period.

tial agglomeration economies are typically expressed in terms of the population density or employment density in each region, signifying the productivity gains due to urbanisation. The role of regional specialisation and sectoral diversification economies has also been investigated. Their positive effect on TFP and/or technical efficiency has sometimes been identified; however, their impact tends to largely vary across regions. Market access and human capital are also considered as factors that can significantly contribute to how efficiently inputs, such as labour and capital, are being used in the economy of European regions to produce a given level of output (Dettori et al., 2012; Beugelsdijk et al., 2018).

The present study aims to offer a more integrated framework for estimating the European regional efficiency and its determinants. We incorporate within a two-stage estimation model a stochastic production function and an inefficiency equation, which uniquely encompasses all the aforementioned determinants as well as original variables representing the disagglomeration or sprawl and mixture of developed land. In fact, an increase in population/employment density may be accompanied by a proportional or disproportionate increase in the sprawl of developed land (OECD, 2017). According to the EEA (2016), an increase in population (employment) density relates to increased (urban) sprawl, but, beyond a point, this relationship becomes neutral and, then, negative.

In fact, the phenomenon of shrinking cities in Europe and elsewhere has been found to combine declining population and employment in core areas, but more developed land in the whole region (Haase et al., 2014; Denis, 2020). When an amount of developed land is left behind, e.g., due to technological progress and decline or closure of firms, it is often up to governments and developers to decide whether it will be redeveloped (brownfield investment) or new land will be developed elsewhere (greenfield investment). This relationship may depend on various factors, such as the elasticity of substitution between capital and land in new construction and the rent elasticity of the demand for housing size (Brueckner and Kim, 2003).

In this context, the present study analyses regional efficiency and TFP through separating the concept of economic density (job concentration) from the physically based concept of the geographical sprawl of development (developed land in total and for specific uses per capita), as well as the economic composition (specialisation and diversification) effects from the land use composition (land use mixture) effects. The construction of a regional production function, which considers the efficiency impacts of various agglomeration externalities and developed land sprawl and composition effects, is necessary in order to accurately capture productivity changes, since both infrastructure investments and changes in land uses may affect the location and performance of economic activities.

Compared to other relevant econometric studies in the existing literature, the methodology used here offers an extended, more comprehensive two-stage stochastic frontier analysis for the panel estimation of technical efficiency scores. This analysis accounts for a whole range of agglomeration economies as determinants at the second stage (inefficiency equation) and spans the whole sample of EU regions. In this way, it attempts to contribute to a more accurate measurement and better understanding of how spatial (land-use) planning policies influence efficiency at the regional level. Additionally, we extend the existing two-stage stochastic frontier analysis to determine levels of regional TFP and technology gaps, which are derived along with the technical efficiency scores. Special emphasis is given to the estimation of efficiency and technology gaps of laggard EU regions, including the regions of Greece, in order to identify main differences, as regards the determinants of productive efficiency, and problems of convergence vis-à-vis the frontier EU regions.

The main research hypothesis that is developed and tested here refers to the existence of a strong association between land uses and efficiency. Our estimates show that (a) the developed land per capita and (b) the mixture of land uses, exert a significant impact on the technical efficiency of the EU regions. A number of additional hypotheses are tested, following the extension of the baseline model, which concern: (i) the effect of different types of developed land uses on regional inefficiency, (ii) the particular efficiency impact of land-use variables in laggard (Eastern EU and Greek) regions, and (iii) the effects of land-use variables on TFP and technology gaps across the EU regions. Additionally, several secondary hypotheses are tested as regards the impact of: (1) other agglomeration forces related to economic density or urbanisation, specialisation and sectoral concentration, (2) market access and other alternative measures of geographical centrality, and (3) human capital.

Briefly, the objectives of the present study are to

i. measure the technical efficiency scores, TFP growth rates and technology gaps of the Greek and EU regions at the NUTS-2 level, using well-behaved regional production functions;
ii. estimate the key determinants of regional efficiency scores, TFP and technology gaps, offering a deeper understanding of spatial factors, which, either individually (sprawl and mix of developed land uses) or in combination, have not yet been considered in the existing literature. Special emphasis is given to how the effect of these determinants differs in the laggard (Eastern European and Greek) regions;
iii. provide of theoretically sound policy guidelines concerning the strengthening of the linkages between various agglomeration economies and productive efficiency.

It should be stressed that the aim of this study is to provide a useful and potentially effective guideline for the implementation, coordination and evaluation of a wide range of EU, national and regional planning policies. Such policies may include strategic investment in physical infrastructure, spatial development plans, human capital development programmes and fiscal policies, such as the taxation and provision of incentives for developing specific land uses, in order to boost regional efficiency and diminish productivity gaps at the national and European levels. The requirement for monitoring productivity, identifying its main determinants, formulating and coordinating productivity-enhancing policies across Europe is reflected in the recent establishment of National Productivity Boards in each euro area member state (Juncker et al., 2015). In this context, the measurement and analysis of the determinants of productivity at the regional level is of utmost importance for countries like Greece, where the economic crisis has adversely affected core-periphery disparities, TFP and the competitiveness of peripheral regions with respect to the best-performing EU regions (KEPE, 2019).

By and large, the findings of the study verify the existence of considerable disparities in the efficiency performance between the regions of northern and central-western Europe and those located in eastern and southern Europe. At the same time, they indicate significant interregional productivity gaps within specific countries, such as in the UK, Greece, Italy and Spain. We conclude that the efficient development within the EU should involve more regionally targeted growth and cohesion policies to work in synergy with each other. In addition to supporting technological progress and the accumulation of physical and human capital stock, there is a need for a more efficient allocation of productive resources and their management through harnessing agglomeration economies and promoting market access. Particularly, the nonlinear effects of employment density and developed land per capita on regional efficiency underline the importance of strengthening spatial planning institutions and policies to address agglomeration diseconomies and exploit positive scale economies, respectively. These policies also relate to the dispersion of specialisation patterns with respect to the EU average, and the sectoral concentration of employment and land resources, according to the comparative advantages of each region.

Special emphasis is given to the adjustment of economic policies in regions that lag significantly, in terms of efficiency performance, in order to reinforce the convergence process. For the eastern EU regions, it is shown that the compact development and diversity of socio-economic activities and land uses are expected to bring about substantial efficiency gains. Regarding Greece, the need for establishing an integrated spatial planning framework is stressed for the management of urbanisation and land-intensive developments at the regional level, and the reduction of the divergence of the economic structure of Greek regions from the average economic structure of the EU regions, in order to enhance efficiency and expedite the catching-up process at both the EU and the national level.

The study is organised as follows: Chapter 2 discusses theoretical issues and presents findings of the empirical literature as regards the impact of economic and land-use variables and other regional determinants the productivity of the EU. Chapter 3 presents the specification of the econometric model and provides definitions of the explanatory variables. Chapter 4 describes the estimation of TFP and technology gaps across EU regions and presents descriptive statistics of all explanatory variables that enter in the econometric analysis. Chapter 5 discusses the baseline econometric results as regards the impact of regional determinants on technical efficiency. It also encompasses several robustness-checking results and baseline model extensions in order to a) distinguish the efficiency impact of regional variables across the eastern EU and Greek regions, and b) provide estimates by using different types of developed land use. In addition, the role of regional determinants is investigated with respect to their impact on TFP and technology gaps, based on alternative estimation approaches. Chapter 6 summarises by placing emphasis on policies that enhance the efficiency and productivity of Greek and other EU regions and reduce inequalities between them.

CHAPTER 2

THEORY AND EMPIRICS ON THE DETERMINANTS OF REGIONAL PRODUCTIVITY

2.1. The role of land uses on productivity

Land-use patterns contribute to regional economic performance by affecting productivity and property prices. These patterns are typically expressed by the sprawl of land development and the mixture of land uses. Sprawl can be expressed in terms of the ratio of the developed area (for all types of land use) per capita, while land-use mix concerns how the developed land is allocated for different types of land use in a region. These land-use variables constitute key elements of the spatial structure of regions and are employed in spatial planning policies and regulations to interlink local development needs with EU and national growth and cohesion policies. They are also associated with policies connected to broader agendas, such as the transition to a low-carbon economy and the reduction of social and spatial inequalities. Despite the profound role of land uses in regional development and cohesion, the examination of the productivity or efficiency implications of land-use patterns is scarce in the existing literature and is mostly focused on the local or urban context, and only to a limited extent at the regional level, either from a country or an international perspective.

From an economic perspective, it can be argued that compact land development patterns have an efficiency-enhancing impact, due to the fact that firms that require less space for their operations are likely to be more knowledge-intensive and contribute more to productivity growth than those that require more space (OECD, 2017). However, it can also be argued that higher levels of public amenities (and, hence, increased sprawl) are linked to attracting more skilled and educated people, which is regarded as one of the underlying factors of productivity. According to the OECD (2017), a strongly negative empirical relationship exists between the developed area per capita and economic growth, as urban and rural regions with more densely developed land uses tend to be more productive, compared to those having less densely developed land uses.[3] Furthermore, compact land development favours the efficient use of network infrastructure, such as roads, telecommunication, electricity, water and sewerage systems, as it requires fixed investments that are independent from the intensity with which it is used. Specifically, the more people who can use the same infrastructure, the less infrastructure per capita is required. In turn, this reduces the cost of infrastructure provision as well as the operating costs.

Similar arguments also apply for many public services. As many people live within the catchment area of public facilities, the costs of public services that are subject to economies of scale are diminished. Moreover, compact regional development has been found to reduce carbon emissions from transport (Kennedy et al., 2009), to prevent the loss of biodiversity (McKinney, 2002) and to retain the amount of land for agricultural uses. By contrast, vacant or abandoned land tends to increase marginal costs of infrastructure and network service provision and inhibits the implementation and effectiveness of land-use consolidation and the coordination of regional development plans.

Nonetheless, theoretical economic models have been used to show that, in most cases, sprawl improves economic efficiency (Anas, 2020). Specifically, more sprawl can reduce traffic congestion and is typically accompanied by population growth, which raises productivity with only a modest increase in travel times. It is noted that, in the long run, space-intensive developments may conversely reduce productivity when they increase travel times, worsen congestion and perhaps raise land prices because they reduce the amount of land that is available for other uses (OECD, 2017). However, even those long-term negative effects of expansive land developments in a region may be cancelled out by some significant positive effects on economic growth, for instance, due to the construction itself in the short run, the temporary alleviation of traffic conges-

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[3] Particularly, it has been found that, on average, an OECD region that used 10% less developed land per capita than another grew by around 0.1 percentage points faster per year.

tion, the reduction of property prices and the attraction of firms that require much space.

Firms can also benefit from the substitution of land for labour at suburban locations, making labour units more productive and —to some extent— compensating for productivity loss due to weakened agglomeration economies. This is because, in those locations where developed land per capita is higher, rents on land are cheaper, wages to workers are lower and firms can charge higher prices to customers who avoid congestion when they travel. Moreover, in sprawling urban areas, workers could possibly live closer to work, which suggests that they would accept lower wages and, hence, firms may be willing to trade-off lower productivity for lower wages (Fallah et al., 2011).

From a policy point of view, the management of the sprawl of land development has been considered in terms of several fiscal and spatial policy measures in order to correct market failures and adjust the amount of developed land per capita when it yields efficiency losses. Nevertheless, land-use regulations and restrictive planning or anti-sprawl policies have often been proven to render market outcomes inefficient, whereas, under various circumstances, property taxation or other fiscal measures improve welfare by increasing (urban) sprawl (Cheshire and Sheppard, 2002; Cheshire and Hilber, 2008; Gaigné et al., 2012; Anas and Pines, 2013; OECD, 2018b; Anas, 2020).

The efficiency-enhancing effects of employing regional or metropolitan land-use plans are potentially large, as they can overcome problems/conflicts and co-ordinate policies between local governments (Ahrend et al., 2014). In particular, the region-wide consideration of the linkages between land uses and productivity can be justified by the intense urban sprawl and the increased interdependencies of cities with each other and their neighboring towns or suburban areas in the same region. It is estimated that countries employing such regional strategic plans use, on average, 32% less developed land per capita, compared with other countries (OECD, 2017). This is due to the good land-use practices followed for infrastructure investments, including the development of brownfield sites in advance of greenfield ones, only in areas where there is existing infrastructure to support them, and the protection of agricultural and forested areas. Other good practices may encompass the design of suitable fiscal policies so as the costs associated with the development of housing and industrial uses in peri-urban areas are reflected in locational choices, including the cost of roads and access to public services.

The sprawled land development can also be linked with nonlinear effects on productivity, as a result of variable returns to scale, changes in transport costs, and spatial and environmental constraints in some regions. In other words, space-intensive development —after exceeding a specific threshold— may disproportionally affect regional efficiency. Moreover, the effect of land uses on the productivity performance of a region may vary with their type and composition (mix), depending upon how the different land uses interact with each other and magnify or shrink the net economic outcome.

The above findings and considerations underline the need for employing theoretically sound and integrated methodological approaches and reliable data on land-use patterns to investigate their impact on the levels of regional efficiency and productivity gaps between the laggard and frontier regions of the EU. However, the scholarly literature has historically focused on (mostly, with the use of exploratory analysis) the characteristics of the morphological structure or the land cover of urban areas. These characteristics refer to the setting in which human action takes place, in relation to artificial constructions (mainly, built-up areas) covering the land surface. Specifically, existing studies (e.g., Harvey and Clark, 1965; Ewing, 2008) have investigated the effects of urban sprawl on the efficient provision of infrastructure and services, predominantly for geographical areas of the US. Urban sprawl has also been defined in terms of the intra-metropolitan dispersion of population density to examine, with the use of regression analysis, its impact on labour productivity (Fallah et al., 2011). In all these previous studies, the efficiency impact of the use to which the entire land surface of regions is put for socio-economic purposes has been neglected. The very few exceptions refer to studies focusing on the productivity of specific regions and/or economic activities corresponding to certain types of land-use categories, such as for services and residential purposes (Cheshire and Sheppard, 2002; Cheshire et al., 2015) and for industrial uses (Wheeler, 2006).

It should be further mentioned that several studies in the scholarly literature have employed information originating from pan-European land cover and land-use datasets, such as the CORINE land cover inventory (Gardi et al., 2015; Rusu et al., 2020), the Urban Atlas land cover and land-use database for large functional urban areas (Masini et al., 2019; Lemoy and Caruso, 2020), as well as remote sensing imagery worldwide originating from other satellite data (Landsat) (Shahraki et al., 2011; Sharaf et al., 2018). These data have been exploited to identify cross-regional changes in land cover and specific land-use patterns over time and to detect correlations between land development sprawl, employment/population and traditional economic performance variables, such as income, output or GDP at the national or sectoral level of economic activity, rather than to investigate systematic impacts on productivity or efficiency. The next section provides a presentation and discussion of how additional factors related to various agglomeration economies, geographical centrality and human capital contribute to regional productivity and efficiency.

2.2. Other regional determinants of productivity

2.2.1. Employment density

Economic density, as measured by the number of workers (or inhabitants) per unit area, is the most commonly used variable considered to examine the effect of spatial economic structure on productivity performance of a regional entity. The basic hypothesis is that denser places are, on average, more productive than less dense places. In line with this hypothesis, Ahrend and Schumann (2014) found that the population density of a region has been a strong predictor of its economic performance. Ahlfeldt and Pietrostefani (2019) examined the economic density elasticities obtained from more than hundred studies and verified the productivity-related benefits on wages, patent activity and preservation of scarce resources. However, economic density —beyond a specific threshold— may adversely affect productivity through significant negative externalities, such as traffic congestion, increased rents and environmental pollution.

Regarding European regions, Ciccone (2002) estimated that the elasticity of their labour productivity with respect to employment density is 4.5%, slightly lower than that of the US states (equal to 5%). Brülhart and Mathys (2008) verified the significant productivity-boosting effects of economic density using a panel of sectoral data for European regions. Foster and Stehrer (2009) also found that employment density exerts a significantly positive effect on the labour productivity of the EU regions in five major economic sectors and at the aggregate level. However, these effects tend to be stronger —at both the aggregate and the sectoral level— for the regions of the new EU member states. More recently, Capello and Lenzi (2015) demonstrated the significantly positive impact of population density on the TFP of European regions.

2.2.2. Market access

Market access, typically expressed with the variable of market potential (see section 3.2), represents the centrality of a region, in terms of the relative physical proximity to market opportunities of other regions (and in the same one). Despite that the concept of market potential dates back to Harris (1954), its theoretical foundations are also met in various models of the new economic geography (Fujita, Krugman and Venables, 2001; Redding and Venables, 2004; Hanson, 2005; Head and Mayer, 2011). This variable incorporates both scale economies and transport/trade costs, recognising that the attractivity of a region to firms is favored by the proximity to other sizeable firms, customers or output markets for selling their products/services in that and neighboring regions.

Market potential has been proved to exert a significantly positive impact on the TFP of EU regions (Beugelsdijk et al., 2018). Furthermore, it can adequately explain income differentials, in terms of Gross Domestic Product (GDP) per capita (López-Rodríguez and Faíña, 2006) and wage differences (Brakman et al., 2009; Bruna et al., 2016) and, hence, the uneven distribution of economic activity across European regions. Several studies have also empirically demonstrated that the importance of spatial spillovers for the improvement of productivity of European regions declines with distance (Foster and Stehrer, 2009; Dettori et al., 2012; Marrocu et al., 2013; Ramajo and Hewings, 2017).

2.2.3. Regional specialisation

The theoretical contribution of regional specialisation has been formulated by Glaeser et al. (1992), who integrated the works of Marshall

(1890), Arrow (1962) and Romer (1986), explaining how knowledge spillovers originating from the proximity of firms within a sector promote innovation, productivity and growth. Porter (1990) has also justified the importance of the geographical concentration of firms through the benefits of local competition, which provides them with incentives to develop/adopt new technologies, innovate and become more productive. The processes of globalisation and the international fragmentation of labour and value-added production are considered as important contributors for the geographical dispersion of specialisation, in order for local (and more vulnerable) industries to retain their productivity levels and be protected from the exposure to globalised competition (IGEAT–ULB, 2008; Vegeulers, 2017).

On the one hand, regional specialisation is regarded as a catalyst for higher industrial productivity and technological progress (De Lucio et al., 2002; Ejermo, 2005), given that a critical market mass has been achieved. On the other hand, increased geographical concentration in manufacturing and tradable services is likely to bring about further divergence within countries (OECD, 2018c). The net benefits of geographical concentration may significantly vary across space and over time, as they can be mostly realised in the short run (Hanson, 2001). Marrocu et al. (2013) established a significantly positive impact of regional specialisation on TFP growth only in the new member states of the EU, while its effect on more developed western countries is non-significant, possibly suggesting the prevalence of congestion (and competitive) effects whose additional costs offset the advantages of the geographical concentration of firms.

2.2.4. Sectoral diversification

The measurement of sectoral diversification/concentration is critical, because it represents how the intensity of local economic activity is spread across sectors. Increased concentration on (internationally) tradable goods and services, such as those referring to agriculture, manufacturing and tourism, may enhance efficiency, as it often reinforces positive scale economies, intangible investment and intra-sectoral network effects. The benefits of the concentration of economic activity on productivity may depend on various factors, such as the increased size of firms and their aging/maturing processes (Henderson, 1997; Combes, 2000; Lee et al., 2010).

Nonetheless, increased concentration can also be associated with market barriers, lack of competition, higher prices and a shortage of cooperation networks. According to Jacobs (1969), industrial diversity enhances innovation and productivity growth when the source of local spillover is external to the industry where the firm operates. This is because of the higher interaction among firms in different sectors in search of productive and competitive sources, which facilitates the imitation and recombination of ideas, cross-fertilisation and knowledge transfer between dissimilar industries and increasing returns in production (Siegel et al., 1995; Frenken et al., 2007). The diversification externalities are usually more pronounced in densely populated regions, whose economies are more adaptive and innovative, as far as they are not offset by the typical congestion effects of large urban/metropolitan areas (Paci and Usai, 1999; van der Panne, 2004; Prager and Thisse, 2012). The net effect of sectoral concentration on productivity is rather ambiguous, and empirical evidence is limited for Europe and not robust, but rather specific to the context of the regional economy. According to Marrocu et al. (2013), the average impact of diversification (concentration) externalities on TFP growth is negative (positive) in Europe; however, in wealthier regional economies, diversity externalities tend to be positive and are more effective than in poorer ones.

2.2.5. Human capital

Human capital, typically expressed as the share of highly educated workers (usually those with tertiary education), is regarded as a key element for regional resilience, adaptation to social, economic and technological changes and successful integration into local labour markets. At the EU policy level, it is considered as a major driver for regional productivity and growth, since it supports innovation and entrepreneurial competencies of local actors, while it can potentially counterbalance demographic challenges in Europe (Foster-McGregor et al., 2014; OECD, 2019; Vandeplas and Thum-Thysen, 2019).

Economic growth theories that stem from Becker (1964), Nelson and Phelps (1966) and Schultz (1971) argue that a higher stock of human capital, as obtained from investment in education, makes workers more efficient. This is explained by the relative advantage of well-trained employees to innovate, assimilate new technologies and improve their specialisation, leading to increased aggregate productivity and higher economic growth. Lucas (1990) and Mankiw et al. (1992) also argued that human capital accumulation fosters economic growth by helping countries attract investments and make more efficient use of their resources.

At the regional level in Europe, Brülhart and Mathys (2008) demonstrated the significantly positive effects of human capital on labour productivity. Along the same lines, Dettori et al. (2012), Marrocu et al. (2013) and Beugelsdijk et al. (2018) showed that TFP is higher in regions that have a well-educated workforce. Furthermore, Schwellnus et al. (2018) showed that the enhancement of human capital through education and training can play a crucial role in reducing regional inequalities, as it encourages workers to benefit more from technological progress, broadening the share of productivity gains. Finally, Diebolt and Hippe (2019) signified the important persisting effects of human capital on innovation and economic development of EU regions.

2.2.6. Country-specific fixed effects

In addition to spatial factors that vary over time, time-invariant effects related to geographical characteristics, such as access to the sea, topography, fertility, availability of raw material/energy resources and climate conditions, can play a significant role in shaping the distance of each country from the international production frontier. Likewise, national macroeconomic policies, institutional settings for domestic market integration, the promotion of competition, investment grants, subsidies and tax allowances may also influence the technical efficiency of regions at the country level (Gallup et al., 1999; Acemoglu, 2008; Ioannides, 2013). Such country-specific fixed effects constitute comparative advantages that have historically proven to exercise a strong influence on the productivity of regions, as they affect the return of investments in physical and human capital.

The relationship between land-use variables and efficiency is rather ambiguous and quite overlooked in the current literature. This relationship may depend on diverse factors, which may considerably vary among regions according to the local and national level/stage of development, the implementation and effectiveness of macroeconomic and spatial planning policies, and the interplay with other efficiency determinants, including urbanisation, specialisation and diversification economies, market access and human capital. The present study deepens and extends the investigation of these relationships to quantify and explain the way that development sprawl (in total and by land-use type) and land-use mix impact the productivity and efficiency of EU regions. The Pan-European land-use dataset employed here (see section 4.2) encompasses information about distinct types of land use for the whole sample of EU regions. In addition, a comprehensive analysis is carried out to determine how other types of agglomeration economies (including those related to job density, regional specialisation and sectoral concentration), geographical centrality, human capital and country-specific effects influence the technical efficiency of EU regions.

CHAPTER 3

MODEL SPECIFICATION AND MEASUREMENT ISSUES

3.1. Econometric specification of the model

A stochastic frontier analysis is used to estimate the technical efficiency levels of EU regions and explore their determinants. The usual two-stage estimation procedure, in which the efficiency scores are initially estimated through a production function and, then, are regressed on several explanatory variables, renders coefficient estimates biased if the vector of the efficiency variables is correlated with the vector of production function parameters (Wang and Schmidt, 2002). Therefore, we rely on the model specification proposed by Battese and Coelli (1995), in which a stochastic production function along with a technical inefficiency model are jointly estimated.

In order to model for the existence of regional inefficiency within a stochastic frontier model, at the upper (first) stage, we rely on the use of a Cobb-Douglas production function of logarithmic form, as follows:

$$\ln(Y_{it}) = \beta_0 + \beta_1 \ln(L_{it-1}) + \beta_2 \ln(K_{it-1}) + \lambda t + U_{it} + V_{it}, \qquad (3.1)$$

where Y_{it} is the gross domestic product of each region i at time t (in 2010 constant prices and in purchasing power parities); λ is the rate of technical change; variable t is a time trend that captures technical progress over time; L_{it-1} is the labour input expressed as the number of total hours worked; and K_{it-1} represents total physical capital (in 2010 constant prices and in purchasing power parities). The parameters β_1 and β_2 are the output elasticities of labour and physical capital, respectively. The two components of the error structure, V_{it} and U_{it} compose the main feature of the stochastic frontier. The stochastic component V_{it} is related to random shocks of production, which are region specific and are assumed to be independently and identically distributed (i.i.d.) following a normal distribution $N(0, \sigma_V^2)$. The stochastic component U_{it}, which is associated with technical inefficiency, is independently distributed from V_{it} and has an asymmetrical distribution equal to the upper half of the $N(0, \sigma_U^2)$. Technical efficiency is a non-negative random variable, denoted as $TE_{it} = \exp\{-U_{it}\}$, which is output-oriented and reaches its maximum level when $TE_{it} = 1$.

We model the mean μ_{it} of the truncated distribution of inefficiency U_{it} as follows:

$$\begin{aligned}\mu_{it} = {} & \delta_0 + \delta_1 \times devlandpc_{it-1} + \delta_2 \times devlandpc_{it-1}^2 + \\ & + \delta_3 \times landmix_{it-1} + \delta_4 \times empdens_{it-1} + \delta_5 \times empdens_{it-1}^2 + \\ & + \delta_6 \times mpi_{it-1} + \delta_7 \times spec_{it-1} + \delta_8 \times div_{it-1} + \\ & + \delta_9 \times tert_{it-1} + c_i + f_t + u_{it},\end{aligned} \tag{3.2}$$

where δ_0 is a constant; $\delta_{i=1,\ldots,9}$ are coefficient estimates of explanatory variables of technical inefficiency; *devlandpc* is the developed land per capita; *landmix* is the variable of land-use mixture that measures the dispersion (or concentration) of different types of land uses; *empdens* is the employment (job) density; *mpi* is the market potential index; *spec* is regional specialisation; *div* is the degree of sectoral diversity; and *tert* is the human capital variable (for a detailed definition of the above variables, see subsection 3.2).

In order to mitigate endogeneity issues related to reverse causality, the explanatory variables of equations (3.1) and (3.2) enter with their once lagged values. In addition, equation (3.2) includes country-specific dummies (c_i) to account for cross-country unobserved heterogeneity and time dummies (f_t) to control for common production shocks. The term u_{it} is a random variable, defined by the truncation of the normal distribution. All parameters included in the log-linear production function (3.1) and the technical inefficiency model (3.2), along with the model variances $\sigma^2 = \sigma_V^2 + \sigma_U^2$ and $\gamma = \sigma_U^2/(\sigma_V^2 + \sigma_U^2)$, are jointly estimated at one stage by using the maximum likelihood estimator. By applying likelihood ratio tests, several hypotheses can be tested. Particularly, rejection of the null hypothesis ($\gamma = 0$), in favour of the alternative one ($\gamma > 0$), would imply that deviations from the frontier are due to inefficiency effects.

3.2. Construction of variables

3.2.1. Construction of the capital stock variable

Since we estimate a regional production function, we need to have a suitable measure of capital stock for each region in each country. However, data for physical capital stock in EU regions are not officially available. We have, therefore, created annual capital stock series for each region (for the period 2008–2016), based on the perpetual inventory method. This method is regarded as the most widely used approach for measuring stocks and flows of fixed assets, assuming that stocks constitute cumulated flows of investment, which are corrected for retirement and efficiency loss. The full derivation and different variants of the capital stock estimation based on the perpetual inventory method can be found in OECD (2009).

According to this method, the physical capital stock K_{ijt+1} of region i in country j at year $t+1$ is equal to the previous year's capital stock K_{ijt}, which is adjusted by the country-wide depreciation rate δ_j of physical capital, plus the current year's gross fixed capital formation I_{ijt+1}:[4]

$$K_{ijt+1} = I_{ijt+1} + (1-\delta_j)\, K_{ijt}. \tag{3.3}$$

Initial measures for physical capital stock in 2008 are given by the formula:

$$K_{ijt} = \frac{I_{ijt}}{g_{ijt} + \delta_j}, \tag{3.4}$$

where g is the average five-year period growth rate of real GDP of each region i. The value of δ_j was chosen to be consistent with the observed current price data for consumption of fixed capital, as provided by the STAN Industry Database, and the physical capital stock for each country, so that it holds:

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[4] Data for gross fixed capital formation were provided in current prices at the regional level by Eurostat and were converted to 2010 constant prices by using the economy-wide GDP deflator of each country. These prices are also expressed in international purchasing power parities.

$$\delta_j = \frac{C_j}{K_j}, \tag{3.5}$$

where C_j is the consumption of fixed capital in country j.

A number of empirical studies at the regional level have utilised the perpetual inventory method to create estimates of physical capital stocks. Derbyshire et al. (2013) performed the perpetual inventory method to estimate capital stocks of EU regions and, then, showed the robustness of these estimates as regards their impact on productivity. Furthermore, Berlemann and Wesselhöft (2014) presented a critical assessment of several empirical implementations of the perpetual inventory method and its variants to construct capital stock data for 103 countries. Example studies of the application of the perpetual inventory method, encompassing the equations shown above for the estimation of the physical capital stock series (3.4) and the initialisation of the physical capital stock (3.5), into laggard areas of the EU include those of Levenko et al. (2019), for countries of eastern Europe, and Bournakis (2012) for Greece.

3.2.2. Definition and measurement of regional determinants of inefficiency

This subsection describes the variables that enter the inefficiency equation, including the land-use variables of developed land per capita and land-use mix, other variables representing agglomeration economies and the remaining regional control variables. It should be mentioned that some of these variables correspond to different types of regional concentration or diversification, which, although they are theoretically related with each other, correspond to distinct measures of agglomeration economies. In particular, the developed land per capita refers to the deagglomeration or sprawl of development in terms of land utilisation, whereas employment density refers to the urbanisation of a region in terms of the geographical concentration of jobs. Likewise, land-use mix refers to the diversity of land-use types, in terms of the evenness of the amount of land occupied for broad socio-economic purposes, whereas sectoral diversification refers to the spread of employment across sectors of economic activity in the region. It is stressed here that we have used all available variables influencing regional efficiency and have ensured that they are consistent with each other, in terms of their definition and measurement, as they originate from Eurostat (see section 4.2), rather than diverse data sources, to avoid possible inconsistencies and conflicts which typically arise in such cases. Moreover, the inclusion of additional variables concerning the economic activity at the regional level is very likely to result in increased correlation with the existing variables and lead to problems of multicollinearity (see section 4.2).

Developed land per capita (land use or development sprawl): Developed land per capita is the ratio of total developed land area (in km^2), that is, the area of land occupied for various socio-economic uses (see for details subsection 4.2.2), in some region i to the population P_i of that region:

$$devlandpc_i = \frac{L_i}{P_i}. \tag{3.6}$$

An increased value of $devlandpc_i$ indicates an increased sprawl of land development, and vice versa. Likewise, sprawl can be defined with respect to specific land uses (see subsection 4.2.2), by replacing the numerator (total developed land area) with the developed land area for a specific land use. Thus, *devlandpc* denotes how much developed land is utilised per inhabitant for all or specific purposes in some region and signifies the sprawl of development, which may depend on land availability, the type and intensity of socio-economic activities in the region. Its relationship with efficiency is not definite; namely, it may be positive or negative depending on the regional context and the purpose of land-use category.

Land-use mix: Provided that there are two or more types of land uses in all regions, a multidimensional measure of land-use mixture can be defined, in terms of the land-use entropy index (Turner et al., 2001; Song et al., 2013). Such a measure is symmetric with respect to land uses and sensitive to the number of land-use types. Let p_{ij} be the proportion of each land-use type j in region i and k_i be the number of land-use types in that region. Then,

$$landmix_i = -\left[\frac{\sum_{j=1}^{k_i} p_j \ln(p_j)}{\ln(k_i)}\right]. \tag{3.7}$$

The expression of *landmix*$_i$*,* in terms of the entropy index, has a clear physical analogue and intuitive range from 0 to 1. Specifically, the maximum value of *landmix*$_i$ is unity, and it can only be achieved by a perfectly equal balance of land uses, such as 25%, 25%, 25%, 25%, if there are four land-use types. Conversely, values of *landmix*$_i$ closer to 0 indicate less evenness, that is, higher concentration or dominance by one or a few land-use types in the region. Its empirical relationship with regional inefficiency is ambiguous and may vary with the regional settings.

Employment density: By defining E_i as the number of workers in region i and A_i its land area (in km^2), the average employment density of that region is

$$empdens_i = \frac{E_i}{A_i}. \tag{3.8}$$

Employment density is expected to positively affect efficiency, although its net impact may vary greatly with the scale and type of urbanisation, and its growth beyond a threshold is typically associated with congestion externalities in the region.

Market potential: We use a measure of market access based on the concept of market potential (Harris, 1954), which is defined as the discounted sum of a region's GDP plus the GDP of all other regions:

$$mpi_i = \sum_j \frac{GDP_j}{D_{ij}^{\sigma}}, \tag{3.9}$$

where D_{ij} is the transport network distance (in km) between regions i and j and σ is a distance-decay parameter, which depicts how mp_i attenuates with distance from the origin region i. This value is typically set equal to $\sigma = -1$, implying that the effect of region j on the market potential of region i is inversely proportional to the transport costs (as proxied by the distance) between them.

The measure of market potential has the intuitive property that it weights transport links by the size of demand (proxied by the GDP) in each destination j. The above measure captures both the effect of external demand and the local demand of region i itself in order to account for the whole spatial extent of agglomeration economies. The intra-regional distance D_{ii}

is calculated as

$$D_{ii} = \frac{\sum_{jk} D_{jk}}{N}, \tag{3.10}$$

where D_{jk} is the distance between any two constituent (NUTS-3) prefectures j and k within (NUTS-2) region i, and N refers to the number of the constituent prefectures. Otherwise, in the case of regions including only one prefecture, namely, where the geographical definition of NUTS-2 coincides with that of NUTS-3, the following conventional measure of intra-regional distance D_{ii} is used (Batty, 1976):

$$D_{ii} = \frac{T_i}{\sqrt{2}}. \tag{3.11}$$

The above measure relies on the assumption that the shape of region i can be represented as circular and that its population is spread evenly across the area. Then, r_i is the radius of the circle equivalent in area to region i, which can be defined as $r_i = \sqrt{A_i/\pi}$, where A_i is the area of region i.

The definition of market potential provides two basic advantages, compared with alternative measures of (road) accessibility to markets: First, it can plausibly incorporate road network improvements (through changes in travel distance) and, second, it explicitly accounts for spatial externalities, i.e., the possible existence of spatial spillover effects across other regions, thus reducing the potential for biased results in the econometric estimation (Combes et al., 2008; Baum-Snow et al., 2020; Matas et al., 2018). It is stressed that the above definition of market potential has been widely proved to be qualitatively robust to the use of alternative (more sophisticated) transport/trade cost functions and distance-decay parameter values, thus providing reliable estimates of market access (Bruna et al., 2016; Baum-Snow et al., 2020; Matas et al., 2018).

In order to test whether the impact of market potential on inefficiency depends on the specification of the market potential function, we propose an alternative measure of the market potential index, which is based on the generalised transport cost (GTC), instead of the network distance, as follows:

$$gmpi_i = \sum_j \frac{GDP_j}{GTC_{ij}^{\sigma}}, \tag{3.12}$$

where GTC_{ij} is the generalised transport cost between regions i and j, and $\sigma = -1$. In addition to the distance-related costs, GTC also considers travel time-related costs. Hence, by combining distance- and time-related economic costs, it may account for changes in: (i) the monetary cost of transport operations, e.g., fuel prices and toll charges, (ii) travel time savings due to transport network improvements, e.g., through road capacity upgrading and higher travel speeds, and (iii) institutional/regulatory conditions, e.g., related to wages in the labour market. In this way, GTC can be regarded as reflecting sources of comparative advantages across regions caused either by higher market integration and accessibility to the road network or by lower time-related costs (Persyn et al., 2021).

Furthermore, given that market access expresses a measure of the geographical centrality of a region, namely, how central it is in relation to the GDP and the transport cost to access all the other regions in the EU, two alternative indices of geographical centrality are constructed based on population size (instead of the GDP) and the GTC. These indices refer to the gravity index and the population potential index (see Petrakos and Psycharis, 2004). First, the gravity index gi_i of region i is expressed as follows:

$$gi_i = \sum_{j \neq i} \frac{P_j}{GTC_{ij}^{\sigma}}, \tag{3.13}$$

where P_j is the population of all the other regions $j \neq i$, and GTC_{ij} is the generalised transport cost between regions i and j (with $\sigma = -1$). The population potential index ppi_i of region i is expressed as follows:

$$ppi_i = \sum_{j \neq i} \frac{P_i P_j}{GTC_{ij}^{\sigma}}, \tag{3.14}$$

where P_i is the population size in region i, and P_j is the population size of the remaining regions $j \neq i$, respectively; GTC_{ij} is the generalised transport cost between regions i and j (with $\sigma = -1$). Compared to the gravity index, the population potential index accounts simultaneously for the *relative* position of a region across the European territory (as it is interconnected by the road transport networks) and its *relative* market size, in terms of the population, considering both its own population and the population of all the other regions. High values of the gravity index and of the population potential index are expected to exert a positive impact on regional efficiency, as they relate to increased market size and a more central position, compared to the regions having lower index values, due to their lower population size and poor access or peripheral position in the EU territory. The variables of the market potential index, the GTC-based market potential index, the gravity index and the population potential index are normalised and expressed in the scale 0 to 1.

Regional specialisation: This variable is expressed through the dissimilarity entropy index (Cutrini, 2010), where the measure of specialisation $spec_i$ of some region *i* denotes the dissimilarity of the economic structure of this region compared to that of the whole EU sample, as follows:

$$spec_i = \sum_{s}^{S} \frac{E_{is}}{E_i} \ln\left(\frac{E_{is}/E_i}{E_s/E} \right), \tag{3.15}$$

where E_{is} denotes the employment (number of workers) of sector *s* in region *i*; E_i is total employment (of all sectors) in region *i*; E_s is the EU-wide (of all regions) employment in sector *s*; and *E* the EU-wide (of all regions) employment in all sectors. Higher (lower) values of $spec_i$ imply an increased (reduced) degree of specialisation or a less (more) uniform pattern of production in region *i*, relative to the rest of the EU. As regional specialisation is shaped by diverse factors, which may often counteract with each other across spatial scales, its efficiency impact may considerably vary across diverse EU regions.

We consider ten sectors of economic activity, which follow the second revision of NACE (Statistical classification of economic activities in the European Community) of Eurostat, by NUTS-2 region. These are: 1) Agriculture, forestry and fishing, 2) Industry, 3) Construction, 4) Wholesale and retail trade; transport, accommodation and food service activities, 5) Information and communication, 6) Financial and insurance activities, 7) Real estate activities, 8) Professional, scientific and technical activities; administrative and support service activities, 9) Public administration, defense, education, human health and social work activities, and 10) Arts, entertainment and recreation; other service activities; activities of household and extra-territorial organisations and bodies.

Sectoral diversification: The measurement of sectoral diversification relies on the Herfindahl-Hirschman (HH) index of concentration, which is based on the employment of each region. It is defined as the weighted arithmetic mean of the sectoral employment shares of a region, with the sectoral shares themselves being used as the weights. In order to get a direct measure of diversity and interpret the sign of the coefficient in a straightforward way, the inversed index is computed as follows:

$$div_i = \frac{1}{HH_i} = \frac{1}{\sum_s^S \left(\frac{E_{is}}{E_i} \right)^2} . \qquad (3.16)$$

The larger (lower) the value of div_i, the higher the degree of sectoral diversification (concentration) in region *i*. The sectoral shares are constrained to values between zero and unity, however, $div_i \leq S$, which is reached when all shares are equal, i.e., $div_i \leq 10$. Since sectoral diversification is associated with a range of factors causing gains as well as losses in regional efficiency, the sign of its impact on inefficiency cannot be considered as known in advance.

Human capital: This variable is obtained from the following ratio:

$$tert_i = 100 \times \frac{WH_i^{tert}}{WH_i}, \qquad (3.17)$$

where WH_i^{tert} is the number of hours worked by persons having completed tertiary education and WH_i is the total amount of hours worked in region *i*. High values of human capital are expected to have a positive impact on the efficiency of EU regions.

CHAPTER 4

TFP GROWTH RATES, TECHNOLOGY GAPS AND PRESENTATION OF VARIABLES

We use a balanced panel dataset, which includes variables corresponding to 245 regions (at the NUTS-2 level) of 23 EU countries.[5] The sample size is spatially and temporally constrained by the availability of data for all variables of interest. Given the time-lagged specification of the econometric model and that observations for land uses are provided for three distinct years (2009, 2012, 2015), the sample spans from 2009 to 2016. Consequently, equations (3.1) and (3.2) are estimated for three distinct years (2010, 2013, 2016). Next, we present the estimation of the measures of TFP and the technology gap across EU regions in the study period by using the regional production function. Although the main variable of interest is regional technical inefficiency, estimates of regional TFP and technology gaps also enter as dependent variables to offer a more detailed analysis of the impact of regional determinants. We then present descriptive statistics of all explanatory variables that enter into equations (3.1) and (3.2).

4.1. Total Factor Productivity and technology gaps of EU regions

We derive total factor productivity (TFP) estimates by using the following Cobb-Douglas production function:

$$Y_{it} = A_{it}\left(L_{it-1}\right)^{\beta_1}\left(K_{it-1}\right)^{\beta_2} e^{U_{it}+V_{it}}, \qquad (4.1)$$

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[5] These countries are Austria, Belgium, the Czech Republic, Germany, Denmark, Estonia, Greece, Spain, Finland, France, Hungary, Ireland, Italy, Lithuania, Luxemburg, Latvia, the Netherlands, Poland, Portugal, Sweden, Slovenia, the Slovak Republic and the United Kingdom.

where Y_{it} represents the GDP of each region i in year t; L_{it-1} is the labour input, measured in total hours worked; K_{it-1} is an estimate of the physical capital stock of region i in year $t-1$; A is a labour and capital neutral technology parameter, associated with TFP. It bears noting that the labour and physical capital inputs are entered in their once lagged terms to avoid severe biases caused by the simultaneity-endogeneity of production factors against GDP (for a thorough discussion, see Olley and Pakes (1996)). The component V_{it} is related to random shocks of production, which are region specific, while the term U_{it} is associated with technical inefficiency. An analytical discussion of their properties is provided in section 3.1. The parameters β_1 and β_2 are the output elasticities of labour and physical capital, respectively, which are estimated by the two-stage estimator of equations (3.1) and (3.2). In this way, we specify a formulation where inefficiency and TFP are jointly estimated within the same model. Then, annual measures of TFP for each region i at time t during the period 2010–2016 are obtained with the following formula:

$$TFP_{it} = \frac{Y_{it}}{(L_{it-1})^{\beta_1}(K_{it-1})^{\beta_2}}, \tag{4.2}$$

In this respect, we can define the technology gap $TECHNOLOGY\ GAP_{it}$ of each region i at time t as the log ratio of the level of TFP of the best-performing (frontier) region (TFP_{ft}) to its own level of TFP_{it}:

$$TECHNOLOGY\ GAP_{it} = \ln\left(\frac{TFP_{ft}}{TFP_{it}}\right). \tag{4.3}$$

A high value of the technology gap indicates that a region remains far away from the productivity (technology) frontier, while a low value implies that this region operates close to the frontier.

In order to further understand the dynamics and heterogeneity of productivity growth, the catch-up or convergence hypothesis is tested for the whole sample of EU regions as well as for a sample that excludes regions of (the later entrant) eastern European countries (see section 5.3). In brief, let $TFP_{i,t,t+T} \equiv log(TFP_{i,t+T}/TFP_{i,t})/T$ be the average annual growth rate of TFP of region i between the initial year t and the final year $t+T$, T be the length of the time period of analysis, and $log(TFP_{i,t})$

the logarithm of each region's *i* initial productivity at year *t*. We estimate the regression:

$$TFP_{i,t,t+T} = \alpha - \beta log(TFP_{i,t}) + \varepsilon_{i,t}. \tag{4.4}$$

If we find that β is positive and statistically significant, then it is considered that the sample regions show (absolute or unconditional) β-convergence during the given time period (Barro and Sala-i-Martin, 1992; Bernard and Jones, 1996). Subsequently, the speed of convergence β_s can be calculated as follows:

$$\beta_s = \frac{\ln(1+bT)}{T}. \tag{4.5}$$

The estimate of β_s allows us to calculate the time it takes to reduce the interregional productivity gap by half $(t_{0.5})$, as follows:

$$t_{0.5} = \frac{\ln 2}{\beta_s}. \tag{4.6}$$

4.2. Presentation of explanatory variables

Table 4.1 presents the correlation coefficients of all explanatory variables that enter the regressions. These coefficients provide evidence that no serious multicollinearity problem exists. The presence of multicollinearity in the model can also be checked by measuring the inflation of the variance of each explanatory variable in the inefficiency equation. Specifically, we calculate the variance inflation factor (VIF) of each independent variable in equation (3.2) as follows:

$$\mathrm{VIF}_i = \frac{1}{1-R_i^2}, \tag{4.7}$$

where R_i^2 is the coefficient of determination that is obtained when independent variable x_i is regressed on all other independent variables in the model (inefficiency equation). Equation (4.7) suggests that, if $R_i^2 = 0$, then $\mathrm{VIF}_i = 1$; contrarywise, as R_i^2 gets closer to 1, VIF_i approaches infinity. According to Marquardt (1980), as a practical rule-of-thumb, a VIF greater than 10 indicates the presence of strong multicollinearity, while a VIF less than 10 shows that multicollinearity is not of serious concern. Alternatively, the measure of tolerance for an independent variable x_i is also used often to check on the degree of collinearity. This measure can be defined as the reciprocal of VIF, namely

$$\text{Tolerance}_i = \frac{1}{\text{VIF}} = 1 - R_i^2 . \tag{4.8}$$

According to Belsley et al. (1980), a practical rule-of-thumb is that a tolerance value less than 0.1 may indicate the presence of multicollinearity. As shown in the last two rows of Table 4.1, all independent variables of the inefficiency equation have VIF values in the range between 1 and 2, or, alternatively, tolerance values in the range between 0.5 and 1. This outcome verifies that no serious problem of multicollinearity arises in the model.

The construction of all variables used in the model is based on regional statistics of Eurostat at the NUTS-2 level. In order to create the land-use variables, we use the database of the Land Use/Cover Area frame Survey (LUCAS) of Eurostat. This survey encompasses three waves (in years 2009, 2012 and 2015) of harmonised data for various land uses in the EU regions. Land uses can be classified into five main types/categories, as follows:

1. *Agriculture*: This mainly refers to arable land, permanent crops and grassland. Small portions of other land cover types can also be in agricultural use, such as artificial land (for instance, farm buildings or roads) and water (for example, irrigation ponds). In this category, some minor land uses (covering less than 1% of the total developed land) for other primary production purposes (other than forestry) may also be considered, such as fishing.

2. *Forestry*: This typically indicates the primary or main economic use of forests/woodland. Not all this land is used for forestry, as there may be alternative uses, including recreation, hunting, protected areas, or no visible use.

3. *Heavy environmental impact activities*: These include mining and quarrying, energy production, manufacturing industry, water and waste

TABLE 4.1
Correlation coefficients between explanatory variables

	ln*(K)*	ln*(L)*	*time trend*	*devlandpc*	*landmix*	*empdens*	*mpi*	*spec*	*div*	*tert*
ln*(K)*	1.000									
ln*(L)*	0.534	1.000								
time trend	0.003	0.129	1.000							
devlandpc	-0.056	-0.237	-0.004	1.000						
landmix	0.354	0.268	0.112	-0.166	1.000					
empdens	0.131	0.191	0.007	-0.155	-0.084	1.000				
mpi	0.129	0.319	0.061	-0.364	-0.019	0.552	1.000			
spec	-0.260	-0.166	0.004	0.008	-0.005	0.174	-0.212	1.000		
div	0.241	0.326	-0.065	-0.181	0.192	0.153	0.026	-0.010	1.000	
tert	0.019	0.096	0.221	0.005	-0.024	0.351	0.317	-0.129	0.033	1.000
VIF				1.24	1.06	1.80	1.94	1.24	1.03	1.22
Tolerance				0.804	0.948	0.556	0.515	0.805	0.974	0.822

Note: K denotes physical capital; L denotes total hours worked.

treatment, and construction, encompassing transport and communication networks, storage facilities and protective works.

4. *Services and residential purposes*: These include commerce, finance and business, community services, recreation, leisure and sport, residential purposes and nature reserves.
5. *Vacant/unused and abandoned areas*: These are determined on the basis of visible signs of land use when surveyed and reflect —at least, to some degree— the prevalence of sparsely populated, rural and arid regions. As it relates to currently unexploited land or green spaces, it composes an integral part of the landscape of each region and suggests the existing potential for land-use development.

As far as the variable of market potential is concerned, network-kilometre distances are used on the basis of the interregional distance matrix of Eurostat, according to the TERCET initiative.[6] It is noted that, in addition to considering the network distances among NUTS-2 regions, the network distances between all the constituent NUTS-3 regions (prefectures) within each NUTS-2 region are also taken into account, in order to compute the average intra-regional distance, using equation (3.10). For the alternative variable of GTC-based market potential, as well as for the gravity index and the population potential index, as specified in equations (3.12), (3.13) and (3.14), respectively, a unique transport cost dataset is used, which has been constructed and recently published by the Joint Research Centre of the European Commission (Persyn et al., 2019; 2020). The GTC refers to the total estimated average cost of driving a representative 40-tonne articulated truck between the centroids of the EU regions and is calculated as the arithmetic mean of all distance-based and travel time-based economic costs.[7]

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[6] TERCET is an interactive search tool for the support of European statistics at the regional level. It offers NUTS-postal codes matching tables and allows for distance calculation between NUTS regions. The calculation of the distance between two mainland regions relies on the average road distance traveled between them. For distances from/to island regions, 'as-the-crow-flies' distances between pairs are calculated by use of the great circle formula (minimum distance on a spherical line).

[7] These transport costs have been computed both between and within the EU regions. They rely on a sampling approach that allows for the precise calculation of the average

The descriptive statistics of the explanatory variables make obvious the increased geographical concentration of labour and human capital and the intense urbanisation economies that exist in large metropolitan areas, such as those of Inner London and Île de France (Table 4.2). Inner London is characterised by the highest market potential and the lowest land-use balance, as it disposes the highest proportion of land for services and residential purposes (ranging between 70-80% in the study period) and no developed land for agriculture and forestry purposes. On the contrary, the region of Praha presents an almost perfect balance (evenness) of developed land uses. Peripheral regions in northern Europe, especially, Övre Norrland in Sweden, have the lowest urbanisation economies, that is, the smallest employment density, and the highest developed land per capita, while Åland in Finland has the smallest amount of physical capital and labour inputs.

Regarding Greece, its regions have a limited market potential, with Dytiki Makedonia having the lowest index among the EU regions. The region of Sterea Ellada has the highest value of the market potential index in the country, which is equal to 0.06 (in 2013). It is worth mentioning that Greece includes the region with the most concentrated (or dissimilar with respect to the EU) specialisation pattern, Peloponnisos, whose economy largely specialises in agriculture, as well as the most sectorally concentrated (or the least diversified) region, Notio Aigaio, whose economy heavily relies on tourism (accommodation and food service activities), as compared to the other local economic activities.

It should be noted here that the economic structure of all Greek regions presents increased dissimilarity (with relative index values higher than 0.1, except for Attiki), compared to the average economic structure of the other EU countries. This fact possibly reflects an alternative aspect of the catching-up process involved in the whole national economy. Conversely, smaller values of the dissimilarity index signify a falling regional

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road freight transport costs along the optimal (cost-minimising) routes of all combinations of centroids taken from a high resolution 1 km x 1 km population grid, making use of the digitalised network of OpenStreetMap, which contains an up-to-date network for roads and ferries reflecting the actual state of the European roads.

TABLE 4.2
Descriptive statistics of explanatory variables and the between (across regions) and within (over time) variations

Variable	Mean	Standard deviation	Minimum	Maximum
ln*(K)*	12.42	1.06	8.75 Åland (2009)	15.64 Severozápad (2009)
Between		1.06	8.78	15.55
Within		0.05	12.12	12.71
ln*(L)*	7.19	1.12	3.38 Åland (2009)	10.54 Île de France (2012)
Between		1.03	3.40	9.73
Within		0.44	5.60	8.00
devlandpc	10.43	20.19	0.09 Övre Norrland (2012)	223.57 Inner London (2015)
Between		20.17	0.10	206.80
Within		1.41	-10.97	27.20
landmix	0.71	0.10	0.31 Inner London (2012)	0.99 Praha (2012)
Between		0.09	0.33	0.97
Within		0.03	0.55	0.87
empdens	168.71	440.28	1.51 Övre Norrland (2012)	5570.21 Inner London (2015)
Between		440.09	1.53	5070.06
Within		26.37	-244.78	668.88
mpi	0.26	0.15	0 Dytiki Makedonia (all years)	1 Inner London (all years)
Between		0.15	0	1
Within		0.01	0.22	0.30

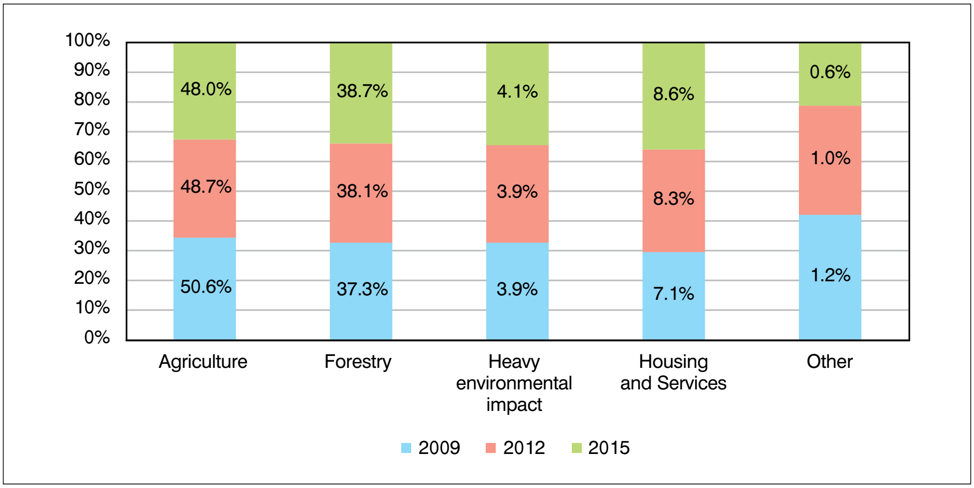
TABLE 4.2 (continued)

Variable	Mean	Standard deviation	Minimum	Maximum
spec	0.06	0.07	0.003 Provincia di Trento (2015)	0.50 Peloponnisos (2015)
Between		0.067	0.004	0.47
Within		0.01	-0.02	0.17
div	5.23	0.45	3.46 Notio Aigaio (2015)	6.70 Mazowieckie (2015)
Between		0.33	4.42	6.20
Within		0.31	3.97	6.48
tert	27.80	8.92	8.40 Severozápad (2009)	62.30 Inner London (2012)
Between		8.57	11.23	58.32
Within		2.51	19.20	37.13

specialisation or substantial despecialisation of the internal structure of some major national economies, such as those of Italy and Germany (Cutrini, 2010). In particular, the Autonomous Province of Trento in northern Italy is found to have the least specialised production pattern relative to the rest of the EU.

As far as the allocation of developed land for main categories is concerned, the average shares for agricultural and forestry purposes are considerably higher (48% and 38.7%, respectively, in 2015) than those for heavy environmental impact, and services and residential purposes (4.1% and 8.6%, respectively, in 2015) (Figure 4.1). Nonetheless, the average amount of land per capita occupied for agricultural and forestry purposes is substantially lower than that occupied for services and residential purposes and, particularly, for heavy environmental impact activities (Table 4.3).

FIGURE 4.1
Shares of developed land for main categories across all EU regions



Note: Authors' processing of LUCAS database, Eurostat.

It is further noted that these developed land-use shares significantly vary between regions (Table 4.3). In the case of Greek regions, the average share for agricultural purposes is consistently higher (60.8% in 2015) than the EU average, while the average shares are much lower for forestry (30.4% in 2015) and, particularly, for services and residential purposes (4.3% in 2015). However, this latter share increased significantly, by almost 50%, during the period 2009–2015 (Figure 4.2).

It should also be mentioned that the average share of total developed land to total land area in the EU has slightly decreased over time, i.e., from 85.4% in 2009 to 83.8% in 2015. The reduction of this share was larger for Greek regions, i.e., from 73.4% in 2009 to 69.4% in 2015. In addition to the different planning institutions and socio-economic and geographical characteristics, this considerably lower (than the EU average) share in Greece and its reduction over time can be possibly attributed to the adverse effects of the economic crisis and the associated problems of disinvestment and increased unused/vacant land. The geographical footprint of the crisis in Greece has been investigated in several studies in the literature,

TABLE 4.3
Developed land per capita for different uses and between (across regions) and within (over time) variations

Variable	Mean	Standard deviation	Minimum	Maximum
Agriculture	4.39	4.13	0.00[a]	37.52 Highlands and Islands (2009)
Between		4.06	0.00	25.28
Within		0.78	-5.23	19.44
Forestry	4.70	15.79	0.00[b]	169.08 Övre Norrland (2012)
Between		15.80	0.00	161.60
Within		0.63	-2.48	12.18
Heavy environmental impact	0.37	0.48	0.02 Brussels (2012)	5.54 Övre Norrland (2015)
Between		0.48	0.02	4.87
Within		0.08	-0.49	1.24
Services and residential purposes	0.85	2.67	0.06 Praha (2009)	39.15 Övre Norrland (2015)
Between		2.51	0.06	29.63
Within		0.94	-15.12	10.37

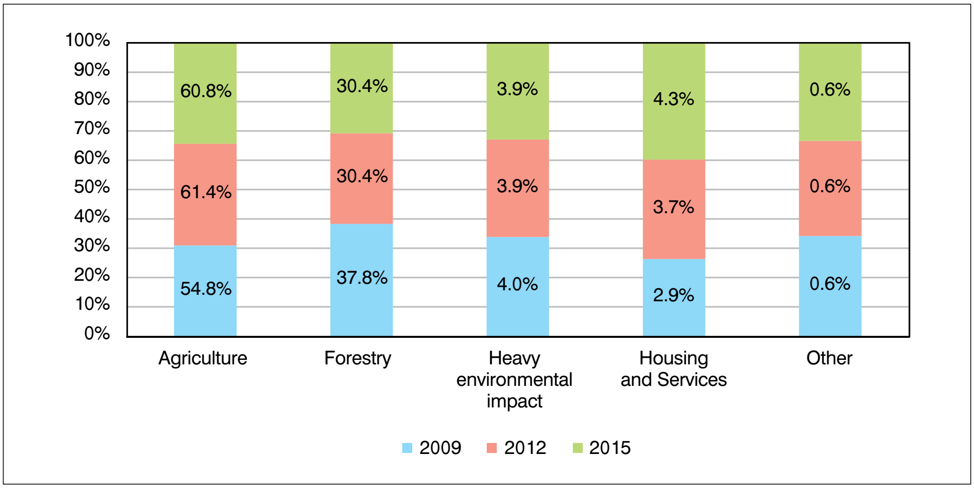
Notes:

a. The lowest values refer to the regions of Inner London and Brussels in all years.

b. The lowest values refer to the regions of Inner London, Greater Manchester, Merseyside, West Midlands and Bremen in all years.

such as those of Psycharis et al. (2014a; 2014b) and Petrakos and Psycharis (2016), which demonstrated the negative impact on regional output, income and employment. Petrakos and Psycharis (2016) also indicated

FIGURE 4.2
Shares of developed land for main categories across Greek regions



Note: Authors' processing of LUCAS database, Eurostat.

that the crisis has intensified regional inequalities by strengthening the prominent role of the Athens metropolitan region in the development map of the country. Moreover, Papaioannou et al. (2017) showed the adverse effect of the economic crisis on the efficiency of Greek regions and the disparities among them.

Nonetheless, as the OECD (2020) suggests, urban areas bore the bulk of population losses in the post-crisis period. While the metropolitan areas of Athens and Thessaloniki dominate in terms of economic activity, their corresponding regions, i.e., Attiki and Kentriki Makedonia (whose principal city, Thessaloniki, is the second largest city in the country) were less resilient than others during the crisis (Giannakis and Bruggeman, 2017a). These two metropolitan areas experienced urban degradation —particularly in the core— as investment declined, leading to deindustrialisation and the formation of abandoned brownfields. Also, their working age population incurred the largest losses, due to high unemployment rates and the migration of people elsewhere for jobs. The intense problems of ageing and low birth rates have added up to the urban population decline, especially in the metropolitan areas of Athens and Thessaloniki. The overall loss of population in urban regions between 2007 and 2019 explains 84% of Greece's national population loss of 311,390 individuals. In contrast, urban regions in the EU and other OECD countries absorbed 71% of the population gains in the same period.

It is also noted that the advent of the economic crisis in 2008, in conjunction with accelerating globalisation and technological change, triggered diverging forces and had an uneven effect on European regions. According to Gómez-Tello et al. (2020), these forces, on the one hand, strengthened the competitive advantages of some large metropolitan regions, reinforcing the role of agglomeration in their economic growth, while they eroded the comparative advantages and growth potential of low- and middle-income regions. Additionally, Giannakis and Bruggeman (2017b) demonstrated the resilience of (most of the) regions in the northern-central EU countries, compared to the non-resilience of the regions in the southern periphery. As it is also explained by Petrakos et al. (2020), the implemented austerity programmes and 'horizontal' cuts in public expenditure during the crisis have arguably increased the inequalities in the EU. The crisis has adversely affected the (speed of) GDP/income and productivity convergence, especially between the countries of eastern and western Europe (Stanišić, 2012; Männasoo et al., 2018; Rapacki and Prochniak, 2019). In particular, the weaker regions of the eastern EU lost a large part of their industrial base, although capital and western regions of those countries performed relatively well, benefiting from agglomeration economies, market size and proximity to western EU markets (Psycharis et al., 2020).

In addition to the impact of the economic crisis and the rise of interregional inequalities, the observed differences in the share of developed land can be attributed to the north-south dualism and urbanisation trends across the EU. Specifically, this dualism (or spatial core-periphery pattern), pertaining to the production structure and development process of Europe (Basile, 2009) —particularly after 2000, for Greece, with its accession to the Eurozone— implies the existence of considerable differences in the industrialisation and urban land sprawl of central-western European regions, compared to the regions of southern Europe. Moreover, Greece has one of the highest proportions of agricultural land and forest and natural vegetated areas in the EU (JRC, 2019).

Additionally, the typical urban continuum patterns of northern and western Europe, largely characterised by a polycentric structure and built-up area dispersion, contrast with the existence of a few very large (albeit heterogeneous) metropolitan regions and many small and medium-sized towns in southern Europe (EEA, 2016). Despite the increasing built-up area, coupled with population decline in core cities ('urban shrinkage') of Mediterranean regions (reinforced by the impact of economic crisis on their socio-spatial structure), the substantial differences in urbanisation patterns between northern and southern regions remain (Salvati and Morelli, 2014; Zambon et al., 2017), together with a marked heterogeneity in the eastern European regions (Psycharis et al., 2020).

Finally, the regional distribution of total developed land per capita is quite heterogeneous and rather persistent over time (see Map A.1 of the Appendix). In particular, the regions having less sprawled (more compact) development are largely situated across the so-called 'blue banana' development zone between south-eastern England and north-central Italy. More compact land use development patterns are also identified in the capital regions of several EU countries, and a few other areas, such as the eastern part of Spain. However, it should be stressed that small changes in the demand for residential, commercial and industrial uses, e.g., due to changes in local economic opportunities, transport accessibility, financial incentives and regulations, can significantly affect land values and the capital stock of the regional economy through the investment decisions of firms and individuals (OECD, 2017).

Before proceeding with the presentation of econometric results, Table 4.4 provides a synopsis of all explanatory variables that enter in the inefficiency equation (3.2), as they were specified in subsection 3.2.2. It presents the sources of data that were used to create them and the time coverage of each variable. The last column shows the anticipated effect of each explanatory variable on regional efficiency/productivity, as theoretically outlined in sections 2.1 and 2.2.

TABLE 4.4
Variables, data sources, time coverage and expected impact on efficiency

Variable name	Data source	Time coverage	Expected impact[b]
Developed land per capita	LUCAS/Eurostat	2009, 2012, 2015	– / +
Land-use mix	LUCAS/Eurostat	2009, 2012, 2015	– / +
Employment density	Eurostat	2009–2016	– / +
Geographical centrality[a]	Eurostat/JRC	2009–2016	+
Specialisation	Eurostat	2009–2016	– / +
Diversification	Eurostat	2009–2016	– / +
Human capital	Eurostat	2009–2016	+

Notes:

a. Geographical centrality encompasses the variables of market potential (weighted by the network distance, which is the baseline model variable, and the generalized transport cost), the gravity index and the population potential index.

b. The signs indicate that the expected impact on efficiency is negative (–), positive (+), or it may be either negative or positive (–/+).

CHAPTER 5

ECONOMETRIC RESULTS

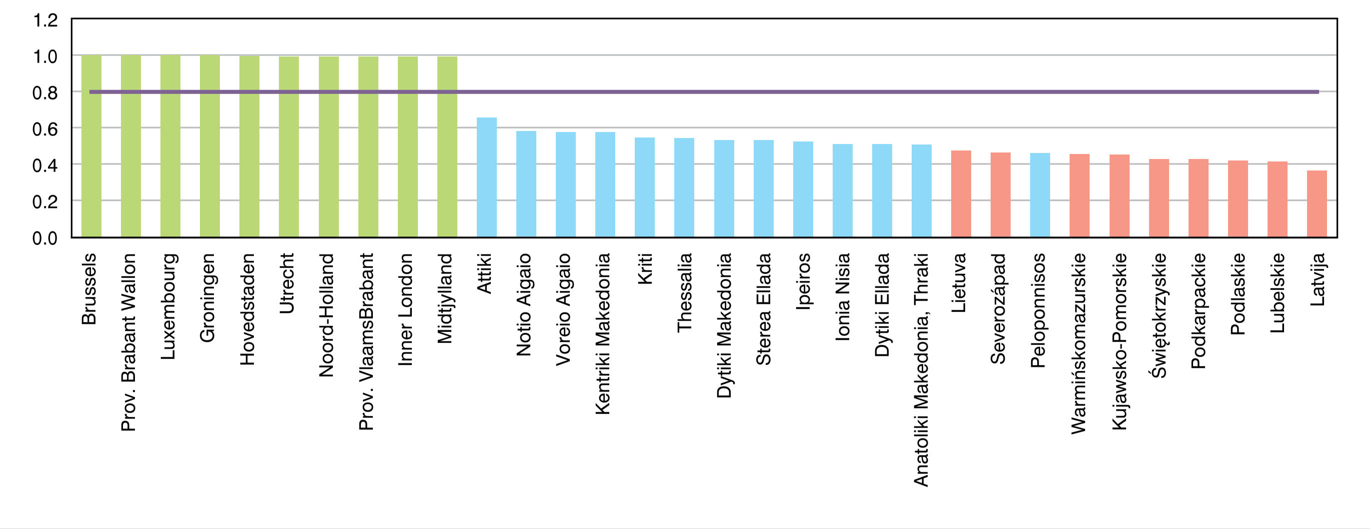
5.1. Technical efficiency estimates of EU regions

Technical efficiency scores for all regions, as derived from the maximum likelihood estimation of the regional production function (equation 3.1), along with the inefficiency equation (3.2), are presented in detail in Table A.1 of the Appendix and are geographically illustrated in Map 5.1. Two main patterns are identified after a careful inspection of regional efficiency scores across the EU. First, the regions of northern and central-western Europe, with average efficiency scores above 90%, outperform the other regions of the EU. Specifically, regions in some of the most developed countries, such as Belgium, the Netherlands, Denmark and Germany, are very efficient compared to other areas of Europe. On the contrary, regions located in eastern and southern Europe lag significantly in terms of efficiency performance. Figure 5.1 shows that the average level of regional technical efficiency in the EU has basically remained the same (with only a slight decrease from 80% to 79%) during the period 2010–2016. All Greek regions fall considerably behind the EU average, with an average level of technical efficiency approximately equal to 54% during this period.

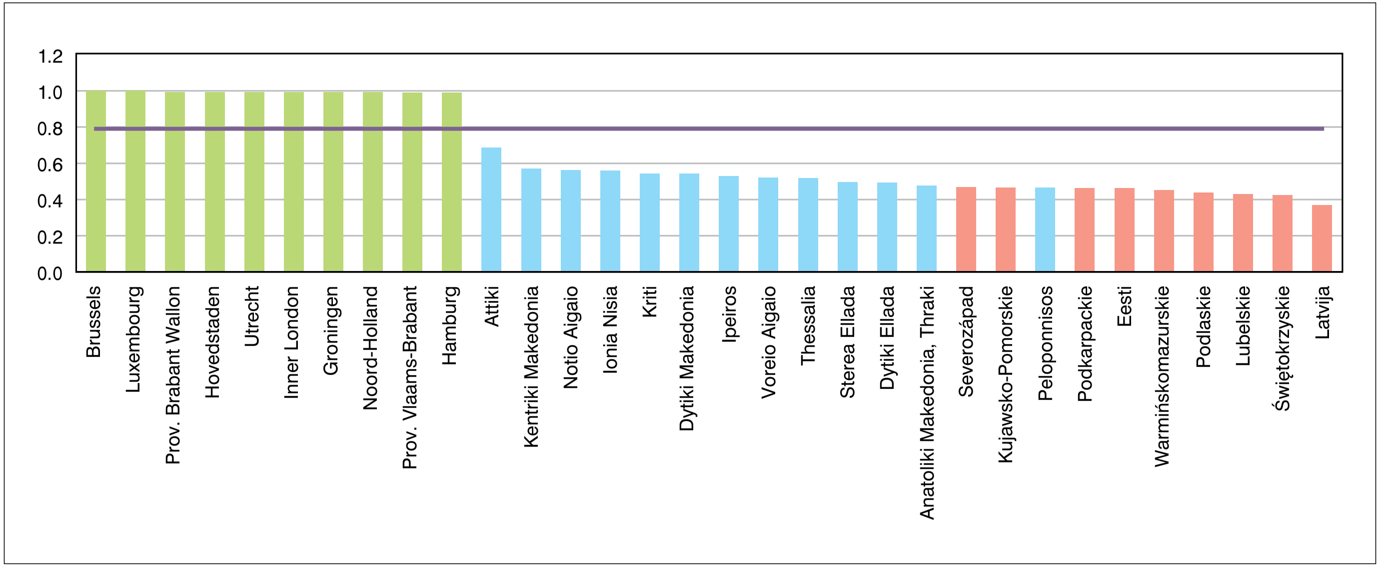
Second, there are considerable disparities within selected countries, in terms of the efficiency performance of their constituent regions (these interregional differences are also evident in Map 5.1). For instance, in 2016, the efficiency score (96%) of Outer London, which was the best performing region of the UK, was more than 30 percentage points higher than that of the lowest performing region of the same country, which was Cornwall and the Isles of Scilly (63%). Also, in 2016, the efficiency score (66%) of the best performing region of Greece, Attiki, was more than 20 percentage points higher than the efficiency score (44%) of the lowest performing region, i.e., Peloponnisos, which is the 8th least efficient region of the EU (Figure 5.1). The second most urbanised region, Kentriki Makedonia (where the second largest city, Thessaloniki, is located) and the island regions of Notio Aigaio,

FIGURE 5.1
Technical efficiency of Greek regions and the 10 best- and worst-performing EU regions in years (a) 2010 and (b) 2016

(a)

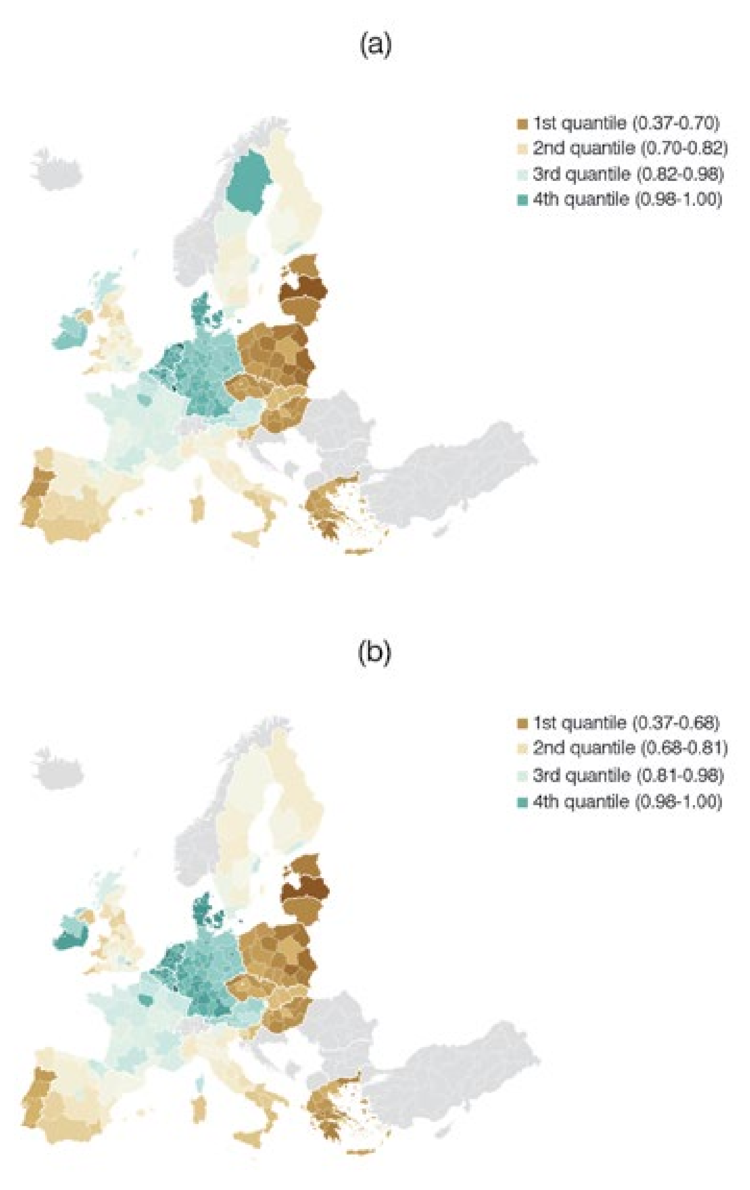


(b)



Note: The straight black line denotes the EU average level of technical efficiency.

MAP 5.1
Geographical distribution of technical efficiency across EU regions in (a) 2010 and (b) 2016



Kriti, Voreio Aigaio (in 2010) and Ionia Nisia (in 2016) have efficiency scores above the country's average (54%). In 2016, Attiki also reduced its distance from the average EU efficiency level by 3.8%.

Similar magnitudes of interregional disparities in efficiency are observed in other countries, such as Spain, i.e., 88% in the Basque Autonomous Community (País Vasco) vs. 68% in the region of Murcia, and Italy, i.e., 83% in the Autonomous Province of Trento vs. 63% in the region of Calabria, in 2016. These results possibly suggest that there exist important inequalities in the way that the productive resources are allocated within some EU countries. However, they may also imply that some regions are better able to exploit their own advantages and/or efficiently manage local agglomeration economies. The following subsection presents in detail the results concerning the determinants of EU regional efficiency.

5.2. Baseline econometric estimates and robustness analysis

5.2.1. Results of the baseline model

Table 5.1 reports maximum likelihood coefficient estimates when regressing regional inefficiency on the explanatory variables of equation (3.2). We first run regressions which include one explanatory variable at a time (Columns 1–7 of Table 5.1). We do this because the inclusion of a fairly large set of covariates limits degrees of freedom, whereas coefficients could be unstable even in cases of mild collinearity. The estimated production function includes the inputs of labour and physical capital, and a time trend t, which proxies for technological progress (equation 3.1). The inefficiency equation is estimated along with the regional production function. The initial econometric results of Table 5.1 show that the coefficient of developed land per capita has the expected positive and statistically significant estimate, while its squared term enters with a significantly negative coefficient estimate (Column 1). By contrast, the coefficient estimate of land-use mix is positive, but not statistically significant (Column 2). Regarding the rest of the estimates, the variable of employment

TABLE 5.1
Baseline econometric estimates

	1	2	3	4	5	6	7	8
Production function, Dependent variable: ln(Output)								
Constant	2.875*** (0.090)	2.840*** (0.118)	2.456** (0.996)	2.458** (0.997)	2.448*** (0.154)	2.599*** (0.958)	3.208*** (0.107)	3.101*** (0.093)
ln(Hours worked)	0.988*** (0.014)	0.990*** (0.019)	0.872 (0.564)	0.867 (0.819)	0.945*** (0.024)	0.924*** (0.109)	0.978** (0.017)	1.008*** (0.017)
ln(Physical capital)	0.071*** (0.012)	0.072*** (0.018)	0.180 (0.319)	0.171 (0.448)	0.129*** (0.023)	0.133 (0.116)	0.054*** (0.015)	0.043*** (0.014)
Time trend	0.030*** (0.007)	0.046*** (0.008)	-0.031 (0.249)	0.024 (0.262)	0.033*** (0.011)	0.003 (0.183)	0.098*** (0.013)	0.049*** (0.007)
Inefficiency model, Dependent variable: technical inefficiency								
Constant	0.263*** (0.033)	0.237*** (0.030)	0.019 (0.973)	0.043 (0.943)	0.122 (0.073)	0.042 (0.940)	0.840*** (0.050)	0.534*** (0.045)
devlandpc	0.001** (0.001)							0.0001 (0.0004)
$\mathit{devlandpc}^2$	-0.002*** (0.0004)							-0.0004*** (0.0002)
landmix		0.026 (0.987)						0.138*** (0.040)
empdens			-0.0001*** (0.00001)					-0.00002 (0.00001)

empdens^2			0.000002*** (0.000001)					0.000002*** (0.0000002)
mpi				-0.682 (0.989)				-0.669*** (0.090)
spec					-0.263 (0.197)			0.696*** (0.127)
div						-0.005 (0.338)		0.037*** (0.015)
tert							-0.014*** (0.001)	-0.008*** (0.001)
Time effects	included	included	included	included	included	included	included	included
Country effects	included	included	included	included	included	included	included	included
σ^2 (p-value)	0.022*** (0.002)	0.024*** (0.001)	0.079 (0.977)	0.099 (0.567)	0.039*** (0.004)	0.067 (0.113)	0.016*** (0.001)	0.014*** (0.001)
γ (p-value)	0.372*** (0.020)	0.382*** (0.046)	0.694 (0.992)	0.695 (0.992)	0.614*** (0.022)	0.755** (0.371)	0.018 (0.011)	0.099*** (0.012)
Log likelihood	423.858	408.388	117.929	131.250	325.727	194.619	473.495	546.261
Observations	735	735	735	735	735	735	735	735

Notes:

a. Standard errors are included in parentheses.

b. ***, ** and * denote statistical significance at 1%, 5% and 10% levels, respectively.

c. Coefficients of all explanatory variables in the baseline econometric model of Column 8 are estimated jointly within the two-stage estimation procedure.

density enters the regression with a significantly negative coefficient estimate, while its squared term (*empdens*^{2}) has a significantly positive coefficient estimate (Column 3). Finally, the variable of human capital, as measured by the share of hours worked by highly skilled workers, has the expected negative coefficient estimate (Column 7). The majority of the coefficient estimates of Table 5.1 are in favour of a significantly positive effect of labour and physical capital inputs on regional output. The same also holds for the coefficient of time trend, which exerts a positive effect on regional output.

The last column (Column 8) of Table 5.1 presents estimates in which all explanatory variables of the inefficiency equation (3.2) enter as regressors. In order to determine whether deviations from the estimated production frontier are due to inefficiency effects, the null hypothesis that $\gamma = 0$ is tested, against the alternative hypothesis that $\gamma > 0$. It is evident that the parameter γ is significantly different from zero, suggesting that inefficiency effects are present and that we should proceed with the estimation of parameters explaining the sources of inefficiency.

The econometric estimates of the baseline model (Column 8 of Table 5.1) suggest that all explanatory variables —except for the linear terms of employment density and of developed land per capita— exert a statistically significant impact on regional efficiency. These results denote that the model specification takes into account the varying impact of scale economies on regional efficiency. Specifically, the negative, but statistically insignificant, first-order (linear) effect of urbanisation economies, as measured by employment density, can be attributed to the fact that the urban structure of the EU regions is quite heterogeneous. Metropolitisation may take place across different scales and in various forms, which can have either a positive or negative impact on regional efficiency. Hence, the significant efficiency-enhancing impact of urbanisation economies in some metropolitan regions is likely to be cancelled out by the less significant or negative impact of urbanisation in other regions which include smaller-size or very large metropolitan regions. In this latter case, detrimental impacts of congestion and other (e.g., environmental) negative externalities may arise, as reflected by the significantly positive second-order (nonlinear) effect of employment density on regional inefficiency. According to McCann (2019), some countries in Europe have almost zero productivity-scale relationships and many cities or urban regions display no or even a negative productivity premium and are not productivity growth drivers (see, also, Bettencourt and Lobo (2016) and OECD (2020)).

Similarly, the developed land per capita is found to exert a positive, but statistically insignificant, impact on inefficiency, suggesting that the effect of intensity of land uses could be quite heterogeneous, as it varies with the scale and type of developed land. Hence, the net impact on technical efficiency of the developed land per capita is negative, but not significant, at the regional level, compared to the significant effects found in the literature at the urban level (see subsection 2.1).

However, the nonlinear impact of developed land per capita on inefficiency is negative and statistically significant. The latter outcome possibly denotes the existence of positive economies of scale in production and the more efficient organisation of space (e.g., polycentric form of development and decentralised activity clusters) when the total land allocated to socio-economic activities exceeds a specific threshold. Given the high degree of spatial and sectoral heterogeneity, the threshold effects may greatly vary by country and could be conditional upon the effect of other regional determinants on technical inefficiency (see below). Hence, a more disaggregate analysis at the country level could be useful to identify these threshold effects on inefficiency; see, for instance, the specific analysis for the case of Greece in subsection 5.3.2.

The efficiency-enhancing impact of growth in sprawled development verifies relevant findings of theoretical economic models (Anas, 2020) and can be related to positive interaction effects among developers who tend to push new land development patterns away from areas with existing dense urban development and pull new development towards areas with yet undeveloped land (Irwin and Bockstael, 2004). In turn, this growing sprawl process leads to the formation and development of activity clusters across the regions (Krugman, 1996).

As far as the variable of land-use mix is concerned, its impact on inefficiency is positive and statistically significant. Hence, the increased concentration or reduced evenness of land resources in favour of a single type (or two types) of land use positively affect regional efficiency. This outcome can be regarded as consistent with those of Lucas and Rossi-Hansberg (2002) and Rossi-Hansberg (2004), who found a positive association between mixed land uses and efficiency loss in terms of increased commuting costs in an urban area. The latter association was attributed to efficiency gains originating from increased specialisation and production externalities when firms locate near producers (in production centres), away from residential areas. Regarding the remaining estimates of Column 8 of Table 5.1, the coefficient estimate of market potential is statistically significant and has the expected negative sign. This estimate verifies that the increased connectivity among the EU regions and spatial spillover effects across them can diminish sources of inefficiency. As expected, market access, as expressed by the market potential index, does significantly improve the technical efficiency of the EU regions.

Both increased specialisation and increased sectoral diversity are found to exert a statistically significant positive impact on regional inefficiency. These outcomes can be considered as confirming or not contradicting other findings in the related literature (Marrocu et al., 2013). Particularly, regions tend to enhance their efficiency through adjusting their production pattern so as to reduce its divergence from that of the rest of the EU, and through concentrating their labour resources on a single activity (or a closely connected set of productive activities), that they regard as possessing comparative advantages.

These findings verify that the economies of geographical and sectoral concentration have a different impact on efficiency and depend on the spatial (local vs. EU-wide) context of reference. On the one side, sectoral concentration works efficiently at the level of the regional economy. Specifically, EU regions having a less uniform (or more skewed) distribution of market shares across sectors tend to be more efficient, compared to those having a more uniform distribution (or more diversified employment shares). On the other side, regions having an employment distribution across sectors that is more uniform (or less distant) with respect to that of the whole EU are more likely to perform better than those having a less uniform or more specialised pattern of employment. These results can be considered as consistent with the observed trends of decreasing specialisation (or de-specialisation) in the overall economy of many countries across the EU, despite the significant differences pertaining to the technology and knowledge intensity of their economic structure (Cutrini, 2010).

Additionally, this link of regional efficiency with reduced specialisation and high market concentration can be generally attributed to the reliance of the EU economy on medium-technology sectors and its failure to move into new and higher technology sectors, which would imply more localisation externalities, knowledge diffusion and potential for innovation-led growth (Vegeulers, 2017). Furthermore, the negative association found between specialisation and efficiency can be explained by the gradual process of convergence of the industrial structure of regions and the increasing importance of the functional or task specialisation (within sectors) than sectoral specialisation per se. This fact is due to the changing role of the globalised value added and supply chains, which widen differences between firms within industries rather than among entire sectors (Martin et al., 2019). Thus, there is a need to reinforce both vertical and horizontal integration in the EU through the pursuit of value-added industrial linkages across and within regions.

Finally, the results verify the significantly negative influence of human capital, as measured by the share of hours worked by persons with tertiary education, on regional inefficiency. In turn, they support the findings of the related literature (subsection 2.2.5) about the decisive role of human capital —through investment in education and training— in enhancing the efficiency of regions and countries.

Table A.2 of the Appendix shows the estimates of country and time dummies for the baseline model specification (Column 8 of Table 5.1). The results indicate that all time-specific effects are statistically significant and have a positive sign, suggesting that the specific years (2013 and 2016) following the economic crisis in the EU exerted a positive influence on regional inefficiency. The country-specific coefficients, including that of Greece, are statistically significant (except those of the Slovak Republic, Slovenia and Portugal) and have a negative sign, except for some countries of the eastern EU, i.e., the Czech Republic, Estonia, Hungary, Lithuania, Latvia and Poland, implying the existence of unobserved country heterogeneity which should be accounted for in our model.

5.2.2. Analysis of robustness

In this subsection, several alternative model specifications are examined to check the robustness of the baseline model estimates. Table A.3 of the Appendix reports inefficiency estimates of equation 3.2 based on a more flexible translog production function of the following form:

$$\begin{aligned}\ln(Y_{it}) = \alpha_0 + \beta_1 \ln(L_{it-1}) + \beta_2 \ln(K_{it-1}) + \beta_3 t + 0.5 \times \gamma_1 \{\ln(L_{it-1})\}^2 + \\ + 0.5 \times \gamma_2 \{\ln(K_{it-1})\}^2 + 0.5 \times \gamma_3 t^2 + \delta_1 \ln(L_{it-1}) \times \ln(K_{it-1}) + \\ + \delta_2 \ln(L_{it-1}) \times t + \delta_3 \ln(K_{it-1}) \times t + U_{it} + V_{it}. \qquad (5.1)\end{aligned}$$

It is shown that, by and large, the estimates of the model relying on a translog production function do not significantly differentiate from those of the baseline model, which relies on the use of a Cobb-Douglas production function. It seems that the use of a more general and flexible production function does not substantially alter the sign or the significance of the driving factors of inefficiency at the regional EU level.

Next, a set of alternative model specifications and data samples are employed to examine the robustness of the effect of urbanisation on regional efficiency. We first estimate the baseline model without including in equation (3.2) the effect of employment density, in order to test whether, under this circumstance, the efficiency impact of developed land per capita departs from that established in the baseline model. However, the results of the first column of Table 5.2 do not substantially differentiate as regards the sign and significance of the coefficient estimate of developed land per capita as well as of most of the remaining coefficients.

In the model specification of the second column, the employment density effects are replaced by a dummy proxying for the existence of a metropolitan region (*metro region*), which receives ones if a region includes at least one functional urban area (FUA)[8] whose population exceeds one million inhabitants (OECD, 2013). Likewise, this specification does not substantially affect the direction or the significance of the impact of either developed land per capita or most of the other explanatory variables on regional efficiency, except for the variables of land-use mix, whose coefficient estimate becomes statistically insignificant, and diversification, which

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[8] The functional urban areas (FUA) constitute a new definition of urban areas, based on their economic functioning, rather than their administrative boundaries, thus allowing for better comparisons of economic performance across countries and regions. Specifically, each FUA corresponds to a spatial economic entity characterised by a densely inhabited urban core and hinterlands, namely, working catchment areas of urban labour markets, which are highly integrated with the urban core.

turns to negative. The latter outcome arguably entails that the representation of urbanisation with a single dummy variable indicating for the existence of a metropolitan area cannot adequately account for the importance of heterogeneity underlying the urban structure of EU regions and disentangle the efficiency effects of urbanisation from those of diversification economies at the regional level. This efficiency-enhancing impact of the metropolitisation of regions is consistent with the empirical literature (Ahrend et al., 2017), from the viewpoint that the doubling of the population in large metropolitan areas within the OECD is associated with a total increase (12%) in average labour productivity, originating from both selection and agglomeration effects.

In order to account for the existence of outliers in the size of the population of EU regions and, hence, disentangle the impact of large metropolitan areas on regional efficiency, the econometric model of the first column of Table 5.2 is estimated across three different sample sizes. These subsamples arise after successively removing from the original sample: (i) very large (mega) metropolitan regions, which contain FUA>3 million inhabitants, corresponding to 5.3% of the total sample (third column); (ii) large metropolitan regions, which contain FUA>2 million inhabitants, corresponding to 11.4% of the total sample (fourth column); and (iii) metropolitan regions having FUA>1 million inhabitants, corresponding to 23.7% of the total sample (fifth column). Econometric estimates with respect to efficiency determinants in all three cases are basically the same as those obtained from the baseline model. Namely, the exclusion of EU regions with metropolitan areas of varying size does not considerably change, on average, the impact that various agglomeration economies exert on inefficiency. Nevertheless, it should be noted that the level of significance of the quadratic effects of the development sprawl variable on inefficiency varies with the size of the metropolitan regions included in the sample. This outcome verifies that the relationship between development sprawl and technical efficiency is nonlinear and conditional upon the scale of urbanisation in each region.

Furthermore, when employing different geographical centrality indices (Table A.4 of the Appendix), instead of the initial market potential index, the results of the baseline model are robust to: (i) the use of the generalised transport cost, instead of the network distance, in the market potential

TABLE 5.2
Robustness analysis of the efficiency impact of urbanisation

	Exclude employment density	Include a dummy that indicates the existence of at least one FUA within a region	Exclude regions with FUA>3 million inhabitants	Exclude regions with FUA>2 million inhabitants	Exclude regions with FUA>1 million inhabitants
Production function, Dependent variable: ln(Output)					
Constant	3.122*** (0.130)	3.347*** (0.123)	3.309*** (0.094)	3.164*** (0.106)	3.381*** (0.094)
ln(Hours worked)	0.975*** (0.018)	0.958*** (0.018)	0.999*** (0.015)	0.979*** (0.018)	0.990*** (0.016)
ln(Physical capital)	0.060*** (0.017)	0.057** (0.016)	0.028* (0.015)	0.052*** (0.015)	0.026** (0.013)
Time trend	0.036*** (0.011)	-0.002 (0.011)	0.040*** (0.002)	0.027*** (0.009)	0.035*** (0.006)
Inefficiency model, Dependent variable: technical inefficiency					
Constant	0.751*** (0.090)	0.782*** (0.055)	0.576*** (0.064)	0.115 (0.118)	0.363*** (0.064)
devlandpc	0.0001 (0.001)	0.00004 (0.001)	-0.0001 (0.001)	0.0002 (0.0004)	-0.0004 (0.0004)
devlandpc^2	-0.001*** (0.0003)	-0.001*** (0.0002)	-0.001*** (0.0001)	-0.001* (0.0003)	-0.0004** (0.0001)
landmix	0.030 (0.073)	0.028 (0.032)	0.148*** (0.039)	0.241*** (0.062)	0.164*** (0.030)

metro region		-0.050*** (0.011)			
mpi	-0.655*** (0.078)	-0.591*** (0.042)	-1.035*** (0.051)	-0.634*** (0.129)	-0.793*** (0.086)
spec	0.539*** (0.149)	0.731*** (0.127)	0.525*** (0.105)	0.797*** (0.167)	0.635*** (0.140)
div	0.004 (0.02)	-0.040*** (0.008)	0.049*** (0.012)	0.078** (0.032)	0.050*** (0.013)
tert	-0.011*** (0.001)	-0.007*** (0.001)	-0.011*** (0.001)	-0.009*** (0.002)	-0.009*** (0.001)
Time effects	included	included	included	included	included
Country effects	included	included	included	included	included
σ^2 (p-value)	0.017*** (0.001)	0.014*** (0.001)	0.014*** (0.001)	0.013*** (0.001)	0.011*** (0.001)
γ (p-value)	0.107*** (0.016)	0.043*** (0.012)	0.088*** (0.015)	0.141 (0.096)	0.143*** (0.017)
Log likelihood	509.45	543.595	531.85	502.36	497.43
Observations	735	735	696	651	561

Notes:

a. Standard errors are included in parentheses.

b. ***, ** and * denote statistical significance at 1%, 5% and 10% levels, respectively.

c. Following the definition of the OECD (2013), the dummy “metro region” takes the value 1 if the region includes at least one functional urban area whose population exceeds 1 million, and 0 otherwise.

function, (ii) the use of the gravity index, and (iii) the use of the population potential index. These findings suggest that all these indices may well represent the average impact of changes in geographical centrality on regional efficiency.

Finally, Table A.5 of the Appendix shows the estimates of the baseline econometric model after alternatively excluding from equation (3.2) the variables of regional specialisation and sectoral diversification. Coefficient estimates of both variables retain their positive sign. However, the effect of sectoral diversification on inefficiency becomes statistically insignificant when excluding the variable of regional specialisation. The obtained results denote the importance of considering both types of agglomeration variables, as the interplay between them may influence the way that regional determinants related to concentration/diversification economies impact technical inefficiency. It is also stressed that this outcome does not contradict with the results of Marrocu et al. (2013) for the EU regions and corroborates the long-established finding in the literature (Malizia and Ke, 1993; Wagner and Deller, 1998) that there is no contradiction among decreasing specialisation and industrial diversity, as the latter may reflect the presence of multiple specialisations. Specifically, for the EU countries, the association between reducing industrial diversity and decreasing geographical concentration has been attributed to the de-concentration effect of the reduced transport costs (Aiginger and Davies, 2004).

5.3. Determinants of inefficiency on laggard regions of the EU

In this subsection, we extend the baseline model to investigate whether the inefficiency effect of spatial determinants differs substantially across laggard regions of the EU. Consequently, the baseline model is first augmented with interactions of all main covariates with a dummy that indicates whether a region belongs to the eastern European countries or not (Table 5.3). Such interaction terms can capture effects related to the fact that eastern European countries joined the EU at a later stage and have different historical paths and economic characteristics, pertaining to lower levels of income and development, as they were part of the Communist bloc before the fall of the Soviet Union. They also have different intrinsic features with regard to their institutions and planning policies, which may bias the results. These countries/regions refer to the Czech Republic, Estonia, Hungary, Lithuania, Latvia, Poland, Slovenia and the Slovak Republic. Similarly, interaction terms of each main covariate with a dummy of Greek regions are introduced in the baseline model in order to identify possible differences in the effect of explanatory variables in Greece (Table 5.4).

5.3.1. Distinct effects of explanatory variables across eastern EU regions

Regression estimates of Table 5.3 reveal that the inefficiency effect of several agglomeration-related determinants differentiates across regions of eastern Europe, compared to the average impact estimated across the entire sample of EU regions (Table 5.2). More specifically, the coefficient estimate of the variable *eastern Europe* × *devlandpc* is positive (Column 1 of Table 5.3), suggesting that the inefficiency effect of developed land per capita is systematically higher in regions of eastern Europe. Thus, there are significant efficiency-enhancing advantages related to decreasing the total developed land per capita in the eastern EU regions, in contrast with the central-western and southern EU regions, where these effects are not significant. This outcome can be considered as complementary to that of Brülhart and Mathys (2008), who found that the inclusion of eastern European regions systematically raises the estimated density coefficient for the whole EU. It entails that the effect of compactness of land uses is stronger in the regions of the eastern EU and can be possibly attributed to the increased levels of development and concentration of the most productive activities and investments in the capital regions of these countries, as a legacy of their central planning processes (Brülhart and Koenig, 2006; Psycharis et al., 2020).

Another possible explanation of this positive association between less sprawled development and regional efficiency in the eastern EU regions possibly relates to the lower availability and quality of transport and other services and the higher uncertainty associated with new land developments in those areas (Fallah et al., 2012), which typically pertains to less advanced economies, compared to the more advanced economies of

TABLE 5.3
Estimates with interactions of explanatory variables with a dummy of eastern EU regions

	1	2	3	4	5	6	7
Production function, Dependent variable: ln(Output)							
Constant	2.922*** (0.108)	3.249*** (0.099)	3.310*** (0.092)	3.237*** (0.090)	3.244*** (0.142)	3.310*** (0.080)	2.982*** (0.118)
ln(Hours worked)	1.000*** (0.018)	1.003*** (0.015)	1.009*** (0.013)	1.052*** (0.015)	1.036*** (0.026)	1.007*** (0.012)	1.005*** (0.020)
ln(Physical capital)	0.061*** (0.016)	0.035*** (0.014)	0.030*** (0.012)	0.006 (0.013)	0.017 (0.021)	0.029*** (0.010)	0.054*** (0.018)
Time trend	0.032*** (0.009)	0.027*** (0.007)	0.032*** (0.008)	0.031*** (0.007)	0.021 (0.014)	0.015** (0.007)	0.029*** (0.010)
Inefficiency model, Dependent variable: technical inefficiency							
δ_0	0.420*** (0.101)	0.731*** (0.067)	0.815*** (0.064)	0.416*** (0.042)	0.480*** (0.131)	0.633*** (0.035)	0.264** (0.127)
Dummy Eastern Europe	-0.043 (0.342)	0.460 (0.362)	0.138 (0.335)	0.313 (0.339)	0.084 (0.341)	0.309 (0.347)	0.447 (0.358)
devlandpc	0.0002 (0.001)	0.0001 (0.0003)	-0.00001 (0.0004)	0.001*** (0.0001)	-0.001 (0.001)	0.001* (0.0003)	0.001 (0.001)
devlandpc^2	-0.001*** (0.0002)	-0.001*** (0.0001)	-0.001*** (0.0002)	-0.0001** (0.0001)	-0.001** (0.0003)	-0.001*** (0.0001)	-0.001*** (0.0004)
Eastern Europe × *devlandpc*	0.013*** (0.005)						

landmix	0.330*** (0.099)	-0.020 (0.075)	-0.074 (0.050)	0.294*** (0.038)	0.390*** (0.117)	0.098*** (0.020)	0.307** (0.120)
Eastern Europe × *landmix*		-0.514*** (0.216)					
empdens	-0.00003 (0.00002)	0.00001 (0.00001)	-0.00002 (0.00002)	-0.00003* (0.00001)	-0.0001* (0.00004)	0.00001 (0.00001)	0.00001 (0.00003)
empdens^2	0.000002 (0.00001)	0.000001 (0.000001)	0.000001* (0.000001)	0.000001*** (0.000002)	0.000001*** (0.000001)	0.000002*** (0.0000002)	-0.001*** (0.0004)
Eastern Europe × *empdens*			-0.0001 (0.0001)				
mpi	-0.632*** (0.152)	-0.643*** (0.072)	-0.750*** (0.120)	-0.594*** (0.102)	-0.737*** (0.260)	-0.828*** (0.040)	-0.667*** (0.198)
Eastern Europe × *mpi*				-1.363*** (0.327)			
spec	0.665*** (0.169)	0.498*** (0.149)	0.535*** (0.133)	0.729*** (0.155)	0.550 (0.441)	0.552*** (0.099)	0.653*** (0.193)
Eastern Europe × *spec*					0.990 (0.784)		
div	0.038* (0.020)	0.031* (0.017)	0.027* (0.014)	0.038** (0.018)	0.029 (0.034)	0.043*** (0.007)	0.066** (0.031)
Eastern Europe × *div*						-0.076** (0.033)	

TABLE 5.3 (continued)

	1	2	3	4	5	6	7
Inefficiency model, Dependent variable: technical inefficiency (continued)							
tert	-0.010*** (0.002)	-0.011*** (0.001)	-0.009*** (0.001)	-0.008*** (0.001)	-0.009*** (0.003)	-0.010*** (0.001)	-0.007*** (0.002)
Eastern Europe × *tert*							-0.012** (0.005)
Time effects	included	included	included	included	included	included	included
Country effects	included	included	included	included	included	included	included
σ^2 (p-value)	0.015*** (0.001)	0.014*** (0.001)	0.014*** (0.001)	0.016*** (0.001)	0.023*** (0.003)	0.012*** (0.001)	0.017*** (0.002)
γ (p-value)	0.260*** (0.034)	0.045*** (0.008)	0.115*** (0.014)	0.130*** (0.014)	0.457*** (0.042)	0.018*** (0.005)	0.323*** (0.027)
Log likelihood	543.986	547.161	543.617	502.843	447.604	547.174	525.309
Observations	735	735	735	735	735	735	735

Notes:

a. Standard errors are included in parentheses.

b. ***, ** and * denote statistical significance at 1%, 5% and 10% levels, respectively.

the central-western EU. The results of Table 5.3 also show that the coefficient estimate of the variable *eastern Europe* × *landmix* is significantly negative (Column 2 of Table 5.3), suggesting the adverse effect of the land-use mix on the inefficiency of eastern European regions, in contrast with its average positive impact on the inefficiency of central-western and southern EU regions. Therefore, a balanced or more even allocation of different types of land uses in the eastern European regions is strongly linked with higher technical efficiency.

Similarly, a higher degree of diversification across sectors of eastern EU regions is significantly connected with higher technical efficiency (Column 6 of Table 5.3). These findings possibly denote the existence of external industrial spillovers or knowledge transfers between dissimilar industries as well as increasing returns in production in more densely and (economic and land-use) diversified areas in the eastern EU regions, compared to the central-western and southern EU regions. Finally, the effects of market potential and human capital on the technical efficiency of eastern EU regions are found to be significantly negative and stronger than the EU average (see Columns 4 and 7 of Table 5.3, respectively). These outcomes arguably depict the increased importance for the regions of the eastern EU of making investments to enhance connectivity with large European markets and to raise human capital stock accumulation in order to expedite their catching-up process.

5.3.2. Distinct effects of explanatory variables across Greek regions

Next, we investigate whether the effects that were estimated in the baseline model differentiate across the regions of Greece. In doing so, we augment the econometric specification by including interaction terms of Greek regions (i.e., a dummy that receives ones across the thirteen Greek regions) with all explanatory variables that enter the specification of the baseline model. The coefficient estimate of the interaction term between the variable of developed land per capita and the dummy for Greek regions is negative and statistically significant (Column 1 of Table 5.4). This outcome suggests that the technical efficiency of Greek territories is favourably affected by land-intensive developments and that, on average, more

TABLE 5.4

Estimates with interactions of explanatory variables with a dummy of Greek regions

	1	2	3	4	5	6	7
Production function, Dependent variable: ln(Output)							
Constant	2.990*** (0.128)	3.211*** (0.098)	3.160*** (0.112)	3.159*** (0.104)	2.284** (0.892)	3.176*** (0.086)	3.279*** (0.109)
ln(Hours worked)	1.009*** (0.021)	0.980*** (0.014)	0.980*** (0.017)	1.014*** (0.015)	0.790*** (0.115)	1.002*** (0.020)	1.003*** (0.016)
ln(Physical capital)	0.051*** (0.019)	0.053*** (0.013)	0.048*** (0.015)	0.035** (0.014)	0.249** (0.103)	0.041*** (0.014)	0.035** (0.015)
Time trend	0.033*** (0.011)	0.020** (0.009)	0.046*** (0.007)	0.030** (0.011)	-0.072 (0.061)	0.031*** (0.005)	0.040*** (0.009)
Inefficiency model, Dependent variable: technical inefficiency							
Constant	0.424*** (0.087)	0.788*** (0.066)	0.501*** (0.041)	0.758*** (0.079)	0.462 (0.775)	0.813*** (0.043)	0.786*** (0.063)
Dummy Greece	-0.019 (2.07)	0.089 (0.719)	-0.069 (0.708)	-0.045 (0.708)	0.021 (0.738)	-0.110 (0.710)	-0.093 (0.710)
devlandpc	0.0004 (0.001)	0.0002 (0.001)	0.001*** (0.0004)	-0.0001 (0.001)	0.001 (0.003)	-0.0004 (0.0006)	0.0001 (2.07)
devlandpc^2	-0.001* (0.0003)	-0.001*** (0.0001)	-0.001*** (0.0002)	-0.001*** (0.0003)	-0.004* (0.002)	-0.0008*** (0.00003)	-0.001** (0.0002)

Greece × devlandpc	-0.012** (0.006)						
landmix	0.266*** (0.095)	-0.020 (0.060)	0.328*** (0.045)	0.042 (0.082)	-0.129 (0.760)	-0.068 (0.101)	-0.087 (0.069)
Greece × landmix		-0.376 (0.323)					
empdens	-0.0001** (0.00003)	0.000003 (0.00001)	-0.00002** (0.00001)	-0.000004 (0.00001)	0.00002 (0.0002)	-0.00001 (0.00001)	-0.00003** (0.00001)
empdens^2	0.000001** (0.000001)	0.000004*** (0.000001)	0.000001*** (0.0000002)	0.000001 (0.0000003)	0.000002 (0.000004)	0.000001*** (0.000002)	0.000001** (0.0000003)
Greece × empdens			-0.001** (0.0003)				
mpi	-0.588*** (0.144)	-0.758*** (0.067)	-0.995*** (0.076)	-0.697*** (0.082)	-1.440* (0.778)	-0.794*** (0.024)	-0.654*** (0.084)
Greece × mpi				-1.359 (1.002)			
spec	0.909*** (0.163)	0.597*** (0.155)	0.751*** (0.168)	0.635*** (0.203)	1.025 (0.912)	0.566*** (0.162)	0.611*** (0.148)
Greece × spec					-0.087 (0.981)		
div	0.065** (0.029)	0.007 (0.018)	-0.014 (0.017)	0.013 (0.018)	0.268 (0.168)	0.016 (0.019)	0.023 (0.017)
Greece × div						0.037 (0.053)	

TABLE 5.4 (continued)

	1	2	3	4	5	6	7
Inefficiency model, Dependent variable: technical inefficiency (continued)							
tert	-0.011*** (0.002)	-0.009*** (0.001)	-0.007*** (0.001)	-0.011*** (0.001)	-0.026 (0.018)	-0.010*** (0.001)	-0.009*** (0.001)
Greece × *tert*							0.005 (0.005)
Time effects	included	included	included	included	included	included	included
Country effects	included	included	included	included	included	included	included
σ^2 (p-value)	0.015*** (0.001)	0.014*** (0.001)	0.015*** (0.001)	0.015*** (0.001)	0.062*** (0.014)	0.015*** (0.001)	0.014*** (0.001)
γ (p-value)	0.260*** (0.030)	0.099*** (0.012)	0.067*** (0.010)	0.144*** (0.027)	0.376*** (0.124)	0.161*** (0.012)	0.078*** (0.012)
Log likelihood	547.712	535.482	506.382	516.026	146.659	532.688	547.462
Observations	735	735	735	735	735	735	735

Notes:

a. Standard errors are included in parentheses.

b. ***, ** and * denote statistical significance at 1%, 5% and 10% levels, respectively.

sprawled development patterns are associated with higher levels of efficiency across regions of Greece, in comparison to the entire sample of EU regions. The efficiency of Greek regions is also subject to significant positive economies of scale as reflected by the nonlinear (threshold) effects of developed land per capita.

Nonetheless, there could be an important degree of heterogeneity across Greek regions with respect to the effect of development sprawl. In order to quantify these threshold effects, we first differentiate equation (3.2) with respect to the variable of $devlandpc_i$. We then use the estimated coefficients of the first column of Table 5.4 to derive the following expression that represents the marginal effect of developed land per capita on regional inefficiency:

$$\partial(\mu_i)/\partial(devlandpc_i) = \delta_1 + 2 \times \delta_2 \times devlandpc_i, \tag{5.2}$$

where δ_1 and δ_2 are estimated parameters. The above relationship implies that the threshold size of development sprawl relating to negative effects on regional inefficiency is 11.515 km^2 per inhabitant. In 2015, 6 out of 13 regions of the country had developed land per capita that was below the threshold level of sprawl required to produce efficiency gains.

More specifically, the capital region of Attiki had by far the lowest level of sprawl (0.609 km^2 per inhabitant). Given the significant impact of the capital region for the development of the whole country,[9] this source of inefficiency can be regarded as reducing the aggregate productivity of the Greek economy. Among others, this outcome can possibly be attributed to the overconcentration of developed land uses, especially those for services and residential purposes, as well as the misallocation of developed land uses within the region of Attiki. It may also suggest the need for decentralisation of some economic activities towards other, peripheral, regions of the country, particularly towards those regions whose level of development sprawl is beyond the threshold level. The regions of the country that fall below the minimum threshold of development sprawl refer ei-

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[9] In the case of Greece, it is estimated that the recovery period (to return to the pre-crisis level of GDP) would be 15 years, given a national growth rate of around 2%, while it would be reduced to half (around 8 years), if growth would be restored in Attica to 3% (OECD, 2020).

ther to regions containing very large urban areas, i.e., Kentriki Makedonia (7.746 km^2 per inhabitant) and Dytiki Ellada (10.589 km^2 per inhabitant), or island regions, i.e., Ionia Nisia (5.882 km^2 per inhabitant), Notio Aigaio (7.696 km^2 per inhabitant) and Kriti (8.887 km^2 per inhabitant), which also includes large urban areas, such as Heraklion.

The regression results indicate that the negative effect of employment density on inefficiency is systematically higher on average among Greek regions, compared to the other EU regions (Column 3 of Table 5.4). This outcome is consistent with previous studies that analysed the determinants of the technical inefficiency of Greek regions (Papaioannou et al., 2017), as well as with studies pointing to the positive productivity effects of urbanisation economies (Louri, 1988), although urban agglomeration diseconomies may well be in place (Vagionis and Spence, 1994).

The above finding can be possibly attributed to intrinsic weaknesses and peculiarities pertaining to the Greek spatial planning system. Specifically, its loose and reactive character has led to several amendments, exemptions and special (by-passing) laws, which encouraged the built-up development in peri-urban areas, coastal zones and along road axes (Getimis and Giannakourou, 2014; Tsilimigkas et al., 2016). It is argued that Greece may be facing the most problematic situation in terms of accommodating urban growth and managing urban development sprawl (Couch et al., 2007). The OECD (2020) provides a recent overview of such land-use governance and spatial planning problems in Greece and reports the significant lags that exist in the transition to the new planning system.

Particularly in the leading metropolitan areas of Athens (region of Attiki) and Thessaloniki (region of Kentriki Makedonia), a combination of investment incentives and environmental restrictions, lower land rents and enhanced accessibility to amenities contributed to the build-up of industrial areas within them and across neighboring regions and, in turn, the unplanned extension of urban fabric and housing-job patterns (Petrakos and Psycharis, 2004; Petrakos et al., 2012; Tsekeris, 2019). Other factors influencing the linkages between developed land per capita and efficiency may concern the spatial allocation of energy-producing activities in a few regions (particularly, in Dytiki Makedonia and —to a lesser extent— in Peloponnisos), as well as the allocation of production factors in remote/

insular areas, especially in island regions, to fulfill specific (social, security, defense) needs and territorial cohesion requirements.

Human capital, market access and other agglomeration-related determinants are not found to exert a systematically different impact on the technical efficiency of Greek regions, compared to the rest of the EU. The direction of the influence of these determinants is largely in line with estimates provided at the regional level for the Greek economy as a whole (Papaioannou et al., 2017), except for the variable of regional specialisation. The latter outcome could signify that the effect of increased specialisation on regional technical efficiency depends on the spatial context of reference: at the national level, this effect is positive, while at the EU level, the effect is negative, providing evidence of the catching-up process confined within the borders of the national economy.

5.4. The efficiency impact of different land-use types

In this subsection, we investigate the efficiency impact of different types of developed land. For this purpose, the baseline model is estimated separately for the four main categories, which are agriculture, forestry, heavy environmental impact, and housing and services (Table 5.5). The results demonstrate that there are significant (nonlinear) negative effects on inefficiency of space-intensive (sprawled) development in the land-use categories of agriculture, forestry, and housing and services (see Table 5.5). The latter outcome possibly denotes the existence of positive scale economies followed by the expansive development of urban land per inhabitant, for instance, through more efficient patterns of polycentric development and decentralised activity clusters. This outcome also verifies existing ones resulting from theoretical economic models (Anas, 2020) and suggests that the sprawled development of businesses and housing reduces deadweight losses, because more people and freight are moving with free-flow speed, makes land rents cheaper and lowers wages, due to the substitution of land for labour, thus making each labour unit more productive. Moreover, policies that restrict the amount of urban land for services and residential purposes tend to decrease the number of stores and the space for stores, thus reducing output and productivity, as output

TABLE 5.5
Econometric estimates for different types of developed land uses

	Agriculture	Forestry	Heavy environmental impact activities	Services and residential purposes
Production function, Dependent variable: ln(Output)				
Constant	3.169*** (0.093)	3.296*** (0.114)	2.975*** (0.115)	2.975*** (0.130)
ln(Hours worked)	0.978*** (0.016)	1.011*** (0.015)	1.009*** (0.017)	1.004*** (0.018)
ln(Physical capital)	0.052*** (0.014)	0.029** (0.015)	0.053*** (0.016)	0.056*** (0.018)
Time trend	0.030*** (0.007)	0.031*** (0.010)	0.043*** (0.008)	0.027*** (0.010)
Inefficiency model, Dependent variable: technical inefficiency				
Constant	0.676*** (0.049)	0.823*** (0.081)	0.521*** (0.102)	0.387*** (0.056)
devlandpc	0.003 (0.002)	0.0003 (0.001)	0.015 (0.023)	0.006 (0.004)
$devlandpc^2$	-0.001** (0.001)	-0.011*** (0.003)	-0.310 (0.243)	-0.002*** (0.0003)
landmix	0.214*** (0.038)	-0.101 (0.062)	0.228*** (0.074)	0.407*** (0.073)
empdens	0.0001*** (0.00001)	-0.00002 (0.00002)	-0.00002 (0.00002)	-0.00002 (0.00003)
$empdens^2$	0.000002 (0.000003)	0.0000001 (0.0000001)	0.0000001 (0.0000001)	0.0000003 (0.000001)
mpi	-0.716*** (0.057)	-0.726*** (0.115)	-0.682*** (0.141)	-0.622*** (0.123)
spec	0.470*** (0.112)	0.551*** (0.164)	0.668*** (0.166)	0.823*** (0.157)
div	-0.002 (0.008)	0.027 (0.022)	0.046** (0.020)	0.039** (0.019)
tert	-0.012*** (0.001)	-0.009*** (0.001)	-0.010*** (0.002)	-0.010*** (0.002)
Time effects	included	included	included	included
Country effects	included	included	included	included

TABLE 5.5 (continued)

	Agriculture	Forestry	Heavy environmental impact activities	Services and residential purposes
σ^2 (p-value)	0.012*** (0.001)	0.014*** (0.001)	0.014*** (0.001)	0.015*** (0.001)
γ (p-value)	0.066*** (0.009)	0.124*** (0.026)	0.226*** (0.035)	0.224*** (0.032)
Log likelihood	569.438	558.194	540.568	542.263
Observations	735	735	735	735

Notes:
a. Standard errors are included in parentheses.
b. ***, ** and * denote statistical significance at 1%, 5% and 10% levels, respectively.

rises with store size, if all else is equal (Cheshire et al., 2015). In fact, Cheshire and Sheppard (2002) found that the net costs of restrictions on the amount of land available for residential development can be significant (as much as 3.9% of annual household incomes in many cities in southern England).

The situation of efficiency-enhancing growth in sprawled development can also be relevant for agricultural and forestry activities, which are natural-resource intensive and exploit scale economies (Manjunatha et al., 2013). The non-significant effects of growth in the sprawl of heavy environmental impact activities may entail that its linkage with technical efficiency is sensitive to and varies by the type of industries in each region. However, particularly in relation to the manufacturing industry, more developed land per capita is linked with a larger average plant size, which can be translated into increasing economies of scale in production and the attraction of relatively large producers, which are associated with efficiency gains from the increased productivity, compared to lower average plant size and smaller producers (Wheeler, 2006; Monkkonen et al., 2020).

The use of more detailed data, such as those originating from satellite-based remote sensing imagery (see section 2.1), for different subcategories of heavy environmental impact activities, including manufacturing, construction, energy, and transport and storage facilities, could possibly offer more insights into how those land uses affect technical efficiency at the regional level. The same also holds for different subcategories of other land-use types, such as arable land, permanent crops and grassland in agriculture, and commerce, finance and business, housing, and recreation, leisure and sports in services and residential purposes.

5.5. Regional analysis of TFP, technology gaps and their determinants

5.5.1. TFP growth and regional convergence

This subsection describes the estimates of TFP, its growth rate, its convergence and the corresponding technology gaps among EU regions, based on the models presented in section 4.1. Specifically, Table A.6 of the Appendix presents the average TFP growth rates during the study period and Table A.7 shows estimates of technology gaps among EU regions for 2016. Furthermore, for geographical illustration purposes, Map A.2 of the Appendix depicts the TFP estimates across EU regions in 2010 and 2016. By and large, it can be easily observed that the spatial variations of TFP follow a core-periphery pattern, as Brussels is the frontier EU region and the highest-TFP regions are mostly situated in the central-western EU countries; regions in a few other countries, such as Ireland and Denmark, also present increased TFP levels.

These estimates verify that the laggard EU regions are those situated in the eastern and southern countries of Europe. It is indicatively mentioned that all regions of Greece remain below the average EU level of TFP during the whole study period. However, spatial variations are considerable not only among the EU countries, but also across regions of the same country. Specifically, important interregional disparities in TFP are observed between London and the rest of the UK and —to a lesser extent– among Attiki and the remaining regions of Greece, and Île de France and the remaining regions of France.

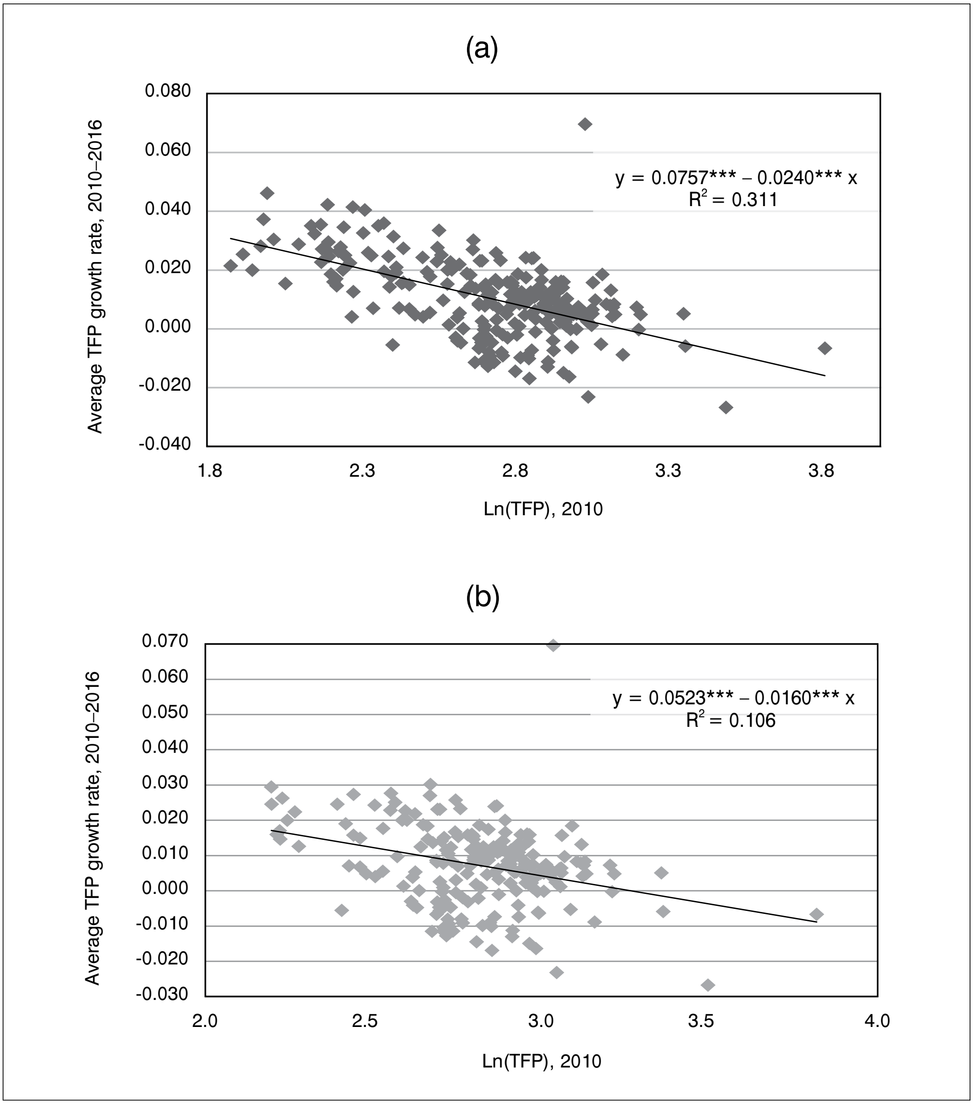
The spatial pattern of the average TFP growth rate is classified in Map A.3, signifying the existence of distinct clusters of productivity development across EU regions during the study period. The best performing regions, with average TFP growth rates above 10%, are mainly those from the ex-communist, eastern EU countries, such as Poland, Hungary and the Czech Republic, implying that a process of convergence is under way after their transition to the market economy. Several regions of southern Europe (in Greece, Spain and Portugal) and Ireland belong to the cluster achieving TFP growth rates above the average (3.9%). These outcomes are largely consistent with those of other studies in the literature (Männasoo et al., 2018; Kijek and Matras-Bolibok, 2020), in the sense that the productivity in (catching-up) regions with low levels of TFP grew faster than in those with high levels of TFP.

On the contrary, the TFP growth for most regions of central-western and northern Europe and Italy is around or below the EU average. A cluster of regions in the UK, Sweden, Finland and a few other regions in central-western Europe present the worst performance, with negative TFP growth rates. Nonetheless, considerable disparities in TFP growth are also evident among regions of the same country, like in Greece, where the regions of Thessalia and Dytiki Makedonia belong to the best-performing cluster, with growth rates equal to 10.9% and 10.5%, respectively, while the region of Voreio Aigaio belongs to the worst-performing cluster, with a negative growth rate (-1.9%). Other islands regions, such as Notio Aigaio and Ionia Nisia, also underperform, with TFP growth rates below the EU average (1.9% and 2.9%, respectively). The above-detected patterns of TFP growth manifest the existence of important interregional inequalities and signify a multi-speed catching-up or convergence process among EU regions.

Based on regression results that are illustrated in Figure 5.2(a), there is a clear trend of interregional convergence across the entire sample of EU regions over the study period, as the β coefficient in equation (4.4) has the expected (positive) and statistically significant sign ($\beta=0.024$). In turn, the speed of convergence is positive over the study period and equal to $\beta_s=0.022$. These results imply that it should take $t_{0.5}=31$ years to reduce the interregional technology gap in the whole EU by half.

When excluding from the sample the regions of eastern EU countries (Figure 5.2(b)), the convergence hypothesis is also accepted. However, this convergence process is evidently weaker, as reflects the lower value

FIGURE 5.2
Diagrammatic representation of beta (β) convergence of TFP
(a) for the entire sample of EU regions and
(b) when excluding eastern EU regions



Note: (***) (**) (*) denote statistical significance above 99%, 95% and 90% level of confidence, respectively. The hypothesis that $\beta = 0$ is not rejected at all levels of significance for both sample cases.

of the β coefficient ($\beta = 0.016$) and, consequently, the slower speed of convergence ($\beta_s = 0.015$) and the longer period required ($t_{0.5} = 46$ years) in order for the interregional technology gap to be reduced by half. This outcome verifies previous empirical evidence (OECD, 2018c) that most of the growth dynamics in the so called 'Old Europe' are concentrated at the frontier regions, whose steady-state growth path stays ahead of the lagging regions, with limited effects from the catching-up process.

5.5.2. Regional determinants of TFP and technology gaps

This subsection presents the estimates of the influencing factors of TFP and technology gaps across EU regions (whose method of estimation was described in subsection 4.1). In particular, Table 5.6 provides us with estimates regarding the regional determinants of TFP and technology gaps, as these are derived endogenously within the two-stage model of equations (3.1) and (3.2). Moreover, Table 5.7 shows the estimates which rely on TFP and technology gaps that were calculated on the basis of the observed national labour shares[10] originating from the Penn World Database (Feenstra et al., 2015). These shares are provided at the country level and vary over time (for more details, see Table A.8 of the Appendix).[11] The latter estimates indicate that the determinants of TFP and technology gaps are not substantially different when using either the two-stage estimation process (Table 5.6) or the observed national labour shares (Table 5.7). Namely, the results of both estimation methods show that the explanatory variables that positively influence regional efficiency largely coincide with those that favourably affect regional TFP and negatively impact technology gaps. Therefore, policies that can be regarded as successfully promoting regional efficiency might well be considered to increase TFP and reduce the TFP inequalities among EU regions.

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[10] This method is referred to as the Solow index number approach and is often used to provide (regional) TFP estimates; for instance, see Beugelsdijk et al. (2018) for TFP estimates in the EU regional context. Kohli (1990) provides an analytical discussion of the differences between the index number approach and the econometric estimation of income share parameters for the derivation of TFP.

[11] The income share of capital is measured as 1 minus the income share of labour.

TABLE 5.6
Impact of regional determinants on TFP and technology gaps (endogenously derived from the two-stage model)

Dependent variable	TFP	Technology gap
Constant	8.873*** (1.146)	4.211*** (0.149)
devlandpc	-0.006 (0.005)	0.0001 (0.0008)
devlandpc^2	0.010*** (0.001)	-0.001*** (0.0003)
landmix	-4.366** (2.164)	0.100 (0.197)
empdens	0.001 (0.001)	-0.00002 (0.00006)
empdens^2	-0.00004* (0.00002)	3.00e^{-06}* (1.71e^{-06})
mpi	10.812*** (1.488)	-1.986*** (0.223)
spec	-1.587 (1.615)	2.761*** (0.549)
div	-0.153 (0.349)	0.102** (0.046)
tert	0.185*** (0.026)	-0.031*** (0.003)
Time effects	included	included
Country effects	included	included
R^2	0.775	0.848
F test (33, 701)	481.73***	197.02***
Root Mean Square Error	2.252	0.364
Observations	735	735

Notes:
a. Heteroscedasticity-robust standard errors are included in parentheses.
b. ***, ** and * denote statistical significance at 1%, 5% and 10% levels, respectively.

TABLE 5.7
Impact of regional determinants on TFP and technology gaps (based on observed national labour shares)

Dependent variable	TFP	Technology gap
Constant	2.777*** (0.363)	1.288*** (0.084)
devlandpc	-0.004* (0.002)	0.001 (0.001)
devlandpc^2	0.002** (0.001)	-0.001** (0.0004)
landmix	-1.013** (0.514)	0.245** (0.109)
empdens	0.0003 (0.0002)	-0.00001 (0.00003)
empdens^2	-0.00001*** (0.000002)	0.00001** (0.000004)
mpi	2.555*** (0.482)	-0.679*** (0.108)
spec	0.122 (0.508)	0.323** (0.166)
div	0.024 (0.095)	0.017 (0.023)
tert	0.041*** (0.007)	-0.013*** (0.002)
Time effects	included	included
Country effects	included	included
R^2	0.837	0.865
F test (33, 689)	200.43***	202.94***
Root Mean Square Error	0.655	0.191
Observations	735	735

Notes:
a. Heteroscedasticity-robust standard errors are included in parentheses.
b. ***, ** and * denote statistical significance at 1%, 5% and 10% levels, respectively.

Specifically, the growth of developed land per capita and employment density are found to exert a significantly positive and negative effect, respectively, on the measures of regional TFP. Conversely, the nonlinear increase of developed land per capita and employment density have a negative and positive effect, respectively, on interregional technology gaps. The latter outcome is consistent with the findings of Cheshire and Sheppard (2002), who argued that restrictions of land development in the form of open space —when it is generally accessible to the public— generate significant costs and tend to increase inequality, while limitations on industrial land use also raise inequality. Moreover, the diversity of land uses, as expressed by the land-use entropy index, has a significantly adverse influence on TFP and a significantly positive impact on technology gaps among EU regions.

Regarding the remaining explanatory variables, specialisation and sectoral diversification are not significantly associated with changes in regional TFP, but they both have a positive impact on technology gaps among EU regions, based on the endogenous estimation within the two-stage model (Table 5.6). As expected, the enhancement of market access is significantly associated with higher TFP and lower technology gaps. Finally, the results verify the significantly positive influence of human capital on promoting TFP and diminishing TFP inequalities among EU regions.

CHAPTER 6

CONCLUSIONS

Based on a theoretically solid, two-stage econometric framework involving a regional production function and an inefficiency equation, the present study estimated the technical efficiency scores of EU regions and identified its key determinants. The results are supported by a range of regressions encompassing different specifications to the baseline model, which include alternative explanatory variables, interaction effects and other productivity-related dependent variables, such as TFP and technology gaps among EU regions. The results stress the existence of considerable spatial inequalities, since regions of northern and central-western Europe, which have efficiency scores above 90%, significantly outperform the regions located in the eastern and southern Europe.

At the same time, there exist persistent substantial disparities within specific countries, as the efficiency performance of their constituent regions greatly varies. The largest within-country inequalities are detected in the UK (where Inner and Outer London outperform the other regions), Greece (where the capital region of Attiki outperforms the other regions), Italy (between the northern and southern regions) and Spain. There are also considerable differences in the dynamism among regions, which can be largely regarded as the result of a) the productivity slowdown observed in most developed countries/regions, b) the economic crisis (particularly for the case of Greece) and c) the catching-up process of the eastern EU regions. The outcomes imply the existence of a multi-speed convergence process within the EU and, hence, the need for more regionally targeted growth and cohesion policies.

The findings signify the complexity underlying the linkage among various agglomeration economies and technical efficiency at the regional level. It can be argued that the agglomeration-productivity nexus is context-specific, as it depends on various factors, including: (i) the growth (above a threshold) in employment density and land-development sprawl, which essentially determine how metropolitan regions drive productivity change, (ii) the geographical and sectoral concentration of economic activities across multiple (European and local) spatial contexts, (iii) the composition of land uses, and (iv) the spatial spillovers. In addition, human capital and country-specific characteristics related to macroeconomic/planning policies and the level/stage of development significantly influence regional efficiency.

It could be that policy measures that are space-blind or aspatial may induce considerable inefficiencies and inequalities across countries as well as across regions at the national and the EU level. The sustainable and fair development and cohesion among the EU regions require the efficient allocation of productive resources as well as their management through harnessing agglomeration economies and human capital. In this respect, the present study underscores another major challenge for policy makers in the EU and national authorities, particularly in relation to the weaker regions: to adopt policy objectives and investment criteria which mirror the socio-economic conditions on the ground, beyond the traditional consideration of raising economic output and income (GDP per capita) levels, and accelerate GDP or income convergence. Particularly, raising the level of productivity and efficiency is not only essential for the long-term economic prosperity of (weaker) regions, but also for ensuring sustainable job creation, wage growth, better living standards and various other dimensions of well-being. Given the binding public budget constraints and financing limitations, efficiency considerations are crucial for the optimal use of existing resources and the shift of economic activity and employment to more productive uses. For this purpose, regional development strategies and the allocation of funds should focus on productivity-enhancing activities. This strategic orientation would harness the competitive advantage of each region in order to shift towards more dynamic and innovative activities that have higher added value and that can compete in the EU and international markets.

The novel contribution of the study concerning the measurement of regional economic performance, in terms of both technical efficiency and TFP, instead of other traditional economic measures, at the scale of the whole EU, can help to identify frontier regions or technology leaders, and most laggard regions. In addition to the issue of raising the levels of productivity and efficiency, the reduction of productivity gaps and relevant equity issues are also emphasised and addressed here, beyond traditional measures to tackle growth or income disparities. Specifically, the study contributes by classifying distinct groups of regions according to their efficiency improvement and TFP convergence, thus allowing distinction between catching-up regions and slow converging or diverging regions. The present study further contributes by identifying some new, land-use-related factors, which, hitherto, have not been properly considered in the literature, such as development sprawl (by land-use category) and land-use mix, in conjunction with other agglomeration economies to raise productivity and diminish efficiency losses. These factors should be jointly examined to support the selection of appropriate investments and reforms to treat sources of inefficiency linked with the inherent needs and problems of each region.

In this line, the formulation and implementation of investment programmes and regional plans should involve a bundle of policy measures to work in synergy to foster local productivity and to diminish regional inequalities, particularly in situations where the effects of multiple factors on regional economic performance is heterogeneous and nonlinear (Tsvetkova et al., 2020). A central role should be played by the synchronisation and complementarity of regional development policies in order to enhance each other. Such bundles of policy interventions, which must be considered in association with each other, and their possible implications for the regional development and cohesion in the EU over the programming period 2021–2027 and in the light of the COVID-19 pandemic, are described in the following paragraphs.

1. Technological progress, accumulation of physical capital and improvement of labour input

Given the significant role of the physical capital and labour inputs and technological progress on regional productivity, there is a need for improvement, better interaction and creation of synergies among them. For instance, emphasis should be given to investments and incentives to businesses to accelerate the adoption of information and communication technologies (ICT) and to reduce the technological gap between more and less developed regions across Europe. Investment programmes should also add capacity and focus on upgrading and maintaining existing (transport, ICT, energy and environment-protecting) infrastructure.

Additionally, policy measures must address population aging, reduce unemployment and create new and sustainable job positions in the most productive sectors of the economy of each region. Especially for countries pertaining to large interregional disparities, like Greece, the increased gaps in efficiency (or TFP) can be largely attributed to both the reduction or slowdown of the productive performance of the whole country and the poor performance of the laggard regions. Provided that regional convergence processes may significantly vary not only at the EU, but also at the national level, there is a need in the new programming period 2021–2027 for targeting policies that can address the issue of ‘double convergence’, i.e., the regional convergence at both the EU and the national level.

2. Land-use management to promote efficiency

The results concerning the significant influence of growth in job density and developed land per capita on efficiency —although they cannot be generalised into other types of benefits and costs— underline the importance of strengthening spatial planning institutions and policies for the optimal allocation of productive resources. Related land-use planning policies may include the increase of the developed land per capita, compared to the vacant/abandoned land, e.g., through greenfield projects or urban area regeneration programmes and further land development for agricultural and forestry purposes. However, projects associated with the increase of urban sprawl (typically involving more developed land for services and residential uses) should be balanced and accompanied by appropriate measures for combatting congestion externalities to diminish possible inefficiencies. Planning regulation/zoning strategies can be possibly deployed to address congestion in highly urbanised areas of metro regions and protect agricultural uses from adverse urban sprawling effects.

The favourable influence of the concentration of specific (closely connected to each other) land uses points to enhancing localisation economies, e.g., through establishing special planning frameworks for productive sectors, such as agriculture, industrial uses, and services, which are associated with the comparative advantages of each region. The results can have further important implications for the assessment of public policies, such as investment in large-scale transport projects to increase intra- and inter-regional connectivity. Such assessment processes, in practice, commonly fail to consider decreasing returns of transport infrastructure investment due to congestion as well as land-use changes, with respect to either the compactness or, inversely, the sprawling of land development. In this respect, land-use planning strategies may have an important complementary role and must sometimes be prioritised in formulating productivity-enhancing regional policies, compared to additional massive investment programmes.

3. Harnessing other agglomeration economies

Regarding other agglomeration economies, the de-agglomeration or dispersion of specialisation can enhance efficiency, compared to the increased specialisation in a single sector. The latter pattern is often related to the limited production base or the weak production structure of a region, particularly in the case that this region cannot exploit other types of agglomeration economies, such as those of urbanisation (which typically take place in densely populated/metro regions). Hence, priority should be given to policies involving the broadening of the production base and specialisation patterns, in order to increase multiplier effects and regional integration into the national and EU/global value chains. Such policies may include the development of integrated value chain networks, which have mostly horizontal effects (extensive backward and forward linkages) across the whole economy, such as those encompassing digital technologies and agriculture, food, tourism, transport and logistics.

As far as the concentration economies are concerned, it was found that the concentration of employment and land resources to a single sector or a related set of activities (where a region possesses a relative comparative advantage) enhances efficiency. Nevertheless, this outcome raises questions about the sustainability of regional economies, in terms of their long-standing performance and resilience. This is because the damage of a sector-specific shock is anticipated to be more dangerous for the whole region, as the absence of variety cannot spread risks among sectors. Furthermore, the risks associated with the lack of competition and hysteresis in the adoption of technologies required to promote innovation and diffuse spillover effects across other sectors of the regional economy should be properly considered and addressed.

4. Reinforcement of regional market access

The significant efficiency-enhancing impact of market potential stresses the need to allocate resources for increasing connectivity between and within regions, in order to promote spatial spillovers of local development and spread the extent of positive agglomeration economies within each region and into other (neighbouring) regions. In particular, investment in transport infrastructure should be prioritised to enhance accessibility to other (regional, national and international) networks, through upgrading the speed of connection (e.g., by introducing innovative technologies and administrative reforms at border crossing points), without compromising resource-efficient and environmentally sustainable development. For instance, the expansion of high-speed train connections can foster accessibility and reduce the transport costs of more distant (southern and eastern European) regions to large markets, thus diminishing their productivity gaps with the most efficient regions of central-western Europe. The improvement of the connectivity between mainland and island regions, especially in Greece, can be regarded as important for both increasing technical efficiency and TFP and reducing the corresponding productivity gaps.

5. Human capital enhancement

Given the efficiency-enhancing impact of human capital, a range of education and training programmes and policies should be deployed to ensure the quality of the labour force and its relevance with labour market challenges. Such programmes and policies may include vocational education and training, and the development of specific skills that are lacking and are indispensable to local employers. The active collaboration between higher education/research institutions, local firms, policy-makers and other stakeholders is also required to exploit available human capital and design place-based policies, according to the industrial structure, the comparative advantages and other characteristics of regions.

In this context, specific targets should be set to reduce skills mismatch and promote technology diffusion, innovation and the attraction of skills-intensive, outward-oriented and higher value-added industries at the regional level (OECD, 2015; Vandeplas and Thum-Thysen, 2019). Additionally, targets should be defined to raise the regional expenditure on research and development, for instance, at 2-3% of regional GDP, to stimulate patenting intensity, and to increase the share of the population with tertiary education in all regions to at least 20% (Charlot et al., 2015). Finally, in order to support the orientation/reallocation of the labour force and the creation of jobs in the most-productive industries, appropriate structural reforms should take place, involving the reduction of barriers to firm entry and exit.

6. Effects specific to laggard countries/regions

The findings underline the necessity to adjust economic policies to the particular characteristics, the stage/level of development and the historical-institutional factors pertaining to groups or blocs of regions across the EU.

Regarding the eastern EU regions, spatial (land-use) planning institutions should be strengthened, in addition to investing in physical and human capital, in order to facilitate the catching-up process. Compact development through confining the total developed land per capita to harness urbanisation economies, the diversification of land uses and the broadening of the production base across industries can lead to significant increases in the efficiency of the eastern EU regions. In turn, investments in areas with increased diversity in their socio-economic activities are expected to bring about higher returns, due to external industrial spillovers and/or knowledge transfers between dissimilar industries. Furthermore, improvement in regional connectivity with large central EU markets would reduce transport/trade costs and raise efficiency gains.

In relation to the Greek regions, the management of urbanisation, land uses and space-intensive developments must be thoroughly taken into consideration at the regional level in order to prevent efficiency losses. The completion of the cadastral system, the decentralisation and comprehensive planning of large urban areas at the metropolitan level, especially for Athens and Thessaloniki, along with the development of an integrated spatial planning framework, could enhance efficiency and reduce interregional productivity gaps. This framework would coordinate regional and sectoral growth plans, special planning frameworks for main economic activities (fisheries, mining, renewable energy, manufacturing, tourism, logistics) and special planning regulations for realising 'fast-track' infrastructure investments.

The coordination of regional and sectoral policies should aim to strengthen and broaden the functional specialisation and clustering of local economic activities, according to the structural characteristics and production challenges of each area. At the same time, it would help Greek regions to decrease the divergence of their economic structure from the average (of higher technology and knowledge intensity) economic structure of the EU regions through enhancing the adoption and diffusion of new technologies that expedite the catching-up process. The efficiency and technology gaps of the Greek regions with the most productive regions of Europe would be further improved through enhancing their market access to the central EU markets, which is still considerably low, and taking local actions —such as those described before— to promote the development of human capital.

7. Implications for the EU cohesion policy over the period 2021–2027

The findings stress the failure of EU cohesion policies to effectively address the significant and persistent productivity gaps among regions both across and within member countries. Hence, they underline the need to formulate a more holistic package of suitable policies adapted to the productivity challenges and capabilities of each region (or group of regions) in the EU, based on the increased heterogeneity in efficiency performance. This package should offer to each region the opportunity to synthesise a mixture of place-sensitive and efficiency-enhancing policy options. Consequently, a more flexible financial framework for productive resource allocation and performance evaluation is required in the new programming period 2021–2027, instead of strict and uniform policy directives.

Furthermore, a comprehensive regional development policy is needed to align and coordinate strategic and detailed spatial and sectoral growth plans with land uses, avoiding possible conflicts between planning objectives and criteria for financing private and public projects (e.g., due to non-permissible or undesirable land uses) and, hence, costly and inefficient outcomes. Land-use planning and regulation policies can be regarded as priority measures in the newly launched EU Cohesion Policy (EC, 2018), given its strong focus on the sustainable urban development and a greener, carbon-free Europe, in order to successfully respond to local needs and tackle regional inequalities.

As an extension, fiscal instruments and taxation policies (for instance, development property taxes, brownfield redevelopment incentives, rehabilitation tax credits, development rights transfers and land value capture schemes) could be included in regionally targeted (or place-based) growth policies to affect investment plans towards more desirable (efficient) land-use patterns and diminish the amount of vacant and unused land. The formulation and tailoring of such policies are particularly important for countries like Greece, where a considerable number of vacant and unused properties have resulted from the period of economic crisis, especially in core or the outskirts of highly urbanised/metropolitan regions.

8. Regional productivity and policy implications in light of the COVID-19 pandemic

The COVID-19 pandemic crisis has affected both the demand (consumption, investment, exports) and the supply (lockdowns, factory closures, firm liquidity) conditions of regional economies, increasing unemployment and exacerbating social hardship and inequalities. The negative impacts on the productivity of EU regions are expected to span over the short and long term, i.e., from temporary disruptions of regional integration in global value chains up to changes in capital accumulation-deepening and TFP. However, some adjustments and responses to the pandemic crisis may positively affect productivity. These developments concern the increased ICT adoption and digitisation of work, education, business and public administration, which could upgrade skills and foster innovation and the role of rural or semi-urban areas as work hubs.

Specifically, the pandemic and the relevant containment measures have had some considerable implications on the way socio-economic activities are organised in space, however, there are still no definite conclusions on whether the sprawling or compactness of urban settlements affect COVID-19 infection/fatality rates (Carozzi et al., 2020; Hamidi et al., 2020; Rodriguez-Pose and Burlina, 2020). First, the precautionary measures to prevent or control the spread of and increase the resilience to infectious diseases, like COVID-19, are closely associated with the re-spacing or out-spacing of urban areas in favour of cycling and walking, through physically spaced sidewalks, and the expansion of public transport capacity and open spaces (ITF, 2020). At the same time, the pressures imposed by the increased demand for private car travel should be properly treated, for instance, by implementing congestion management measures or re-directing traffic and part of the socio-economic activities to the city outskirts.

Second, the additional urban space and the increasing returns to scale associated with the expansion of urban land uses (especially those for services and residential purposes) as well as the reshoring of some value chains, would have a strong impact on the regional productivity and aggregate growth of national economies. Nonetheless, the current findings also underline the importance of the deployment of comprehensive regional growth plans, accounting for the coordinated and selective sprawling of land uses of different types, rather than in isolation with each other, in association with comparative advantages of each area.

Therefore, there is a need for linking the re-allocation or re-use of urban spaces with a long-term regional development strategy. This strategy, on the one hand, should reduce the contagion of infectious diseases and enhance efficiency, without compromising, on the other hand, safety requirements, environmental protection and the effective and equitable accessibility to jobs and essential services across regions. Such a balanced spatial development pattern can arguably be achieved through a polycentric type of urbanisation of regions (Arbabi et al., 2020), where productivity gains due to the development sprawl are in tandem with intra-city mobility improvements, increased inter-city transport connectivity (favourably, by high-quality, demand-responsive, fixed-route transport systems) and possibly other agglomeration-related benefits.

APPENDIX

TABLE A.1
Technical efficiency scores (0-100%) by country/region, 2010-2016

NUTS-Code	Country	Region name	2010	2013	2016
AT11	Austria	Burgenland (AT)	87.55%	85.31%	92.30%
AT12	Austria	Niederösterreich	91.60%	89.80%	95.46%
AT13	Austria	Wien	98.84%	98.73%	99.21%
AT21	Austria	Kärnten	89.81%	87.69%	91.82%
AT22	Austria	Steiermark	88.51%	87.25%	90.21%
AT31	Austria	Oberösterreich	90.70%	89.52%	93.43%
AT32	Austria	Salzburg	94.11%	92.76%	96.05%
AT33	Austria	Tirol	94.19%	93.65%	95.19%
AT34	Austria	Vorarlberg	94.42%	93.63%	95.68%
BE10	Belgium	Région de Bruxelles-Capitale / Brussels	100.00%	100.00%	100.00%
BE21	Belgium	Prov. Antwerpen	99.51%	99.50%	99.48%
BE22	Belgium	Prov. Limburg (BE)	99.36%	99.34%	99.30%
BE23	Belgium	Prov. Oost-Vlaanderen	99.50%	99.47%	99.45%
BE24	Belgium	Prov. Vlaams-Brabant	100.00%	100.00%	99.58%
BE25	Belgium	Prov. West-Vlaanderen	99.42%	99.42%	99.34%
BE31	Belgium	Prov. Brabant Wallon	100.00%	100.00%	100.00%
BE32	Belgium	Prov. Hainaut	99.25%	99.26%	99.14%
BE33	Belgium	Prov. Liège	99.35%	99.33%	99.29%
BE34	Belgium	Prov. Luxembourg (BE)	99.25%	99.21%	99.18%
BE35	Belgium	Prov. Namur	99.40%	99.38%	99.34%
CZ01	Czech Republic	Praha	64.33%	65.51%	67.90%
CZ02	Czech Republic	Střední Čechy	55.52%	56.70%	57.63%

TABLE A.1 (continued)

NUTS-Code	Country	Region name	2010	2013	2016
CZ03	Czech Republic	Jihozápad	53.76%	53.26%	52.94%
CZ04	Czech Republic	Severozápad	50.42%	50.83%	50.37%
CZ05	Czech Republic	Severovýchod	51.97%	51.61%	51.78%
CZ06	Czech Republic	Jihovýchod	54.24%	54.99%	54.88%
CZ07	Czech Republic	Střední Morava	51.00%	51.27%	51.18%
CZ08	Czech Republic	Moravskoslezsko	52.67%	52.05%	52.02%
DE11	Germany	Stuttgart	97.13%	97.00%	96.14%
DE12	Germany	Karlsruhe	96.66%	96.62%	95.73%
DE13	Germany	Freiburg	94.93%	93.87%	90.40%
DE14	Germany	Tübingen	96.13%	96.45%	93.60%
DE21	Germany	Oberbayern	95.33%	95.85%	95.17%
DE22	Germany	Niederbayern	89.46%	88.56%	84.68%
DE23	Germany	Oberpfalz	91.34%	92.74%	88.81%
DE24	Germany	Oberfranken	93.12%	91.94%	87.72%
DE25	Germany	Mittelfranken	95.25%	95.59%	92.67%
DE26	Germany	Unterfranken	96.07%	95.93%	93.20%
DE27	Germany	Schwaben	93.37%	92.06%	90.17%
DE30	Germany	Berlin	98.58%	98.59%	98.17%
DE40	Germany	Brandenburg	92.45%	89.65%	86.67%
DE50	Germany	Bremen	94.49%	94.10%	90.91%
DE60	Germany	Hamburg	98.51%	98.47%	98.46%
DE71	Germany	Darmstadt	97.28%	97.85%	97.26%
DE72	Germany	Giessen	96.99%	97.41%	95.94%
DE73	Germany	Kassel	95.50%	94.49%	91.46%
DE80	Germany	Mecklenburg-Vorpommern	86.95%	85.07%	82.70%
DE91	Germany	Braunschweig	93.15%	93.37%	91.09%
DE92	Germany	Hannover	94.92%	94.54%	91.99%
DE93	Germany	Lüneburg	89.81%	90.15%	87.77%

TABLE A.1 (continued)

NUTS-Code	Country	Region name	2010	2013	2016
DE94	Germany	Weser-Ems	92.13%	90.95%	87.34%
DEA1	Germany	Düsseldorf	97.94%	97.89%	97.16%
DEA2	Germany	Köln	98.14%	98.06%	97.48%
DEA3	Germany	Münster	97.19%	97.21%	95.87%
DEA4	Germany	Detmold	94.52%	94.77%	91.95%
DEA5	Germany	Arnsberg	95.22%	94.61%	93.42%
DEB1	Germany	Koblenz	94.60%	95.50%	92.97%
DEB2	Germany	Trier	96.81%	96.47%	93.82%
DEB3	Germany	Rheinhessen-Pfalz	96.69%	97.14%	96.04%
DEC0	Germany	Saarland	92.65%	93.36%	89.56%
DED2	Germany	Dresden	92.90%	90.90%	88.12%
DED4	Germany	Chemnitz	92.75%	88.67%	86.47%
DED5	Germany	Leipzig	95.19%	94.44%	89.95%
DEE0	Germany	Sachsen-Anhalt	90.39%	88.80%	85.70%
DEF0	Germany	Schleswig-Holstein	90.48%	89.80%	86.76%
DEG0	Germany	Thüringen	92.48%	92.22%	87.75%
DK01	Denmark	Hovedstaden	99.52%	99.52%	99.50%
DK02	Denmark	Sjælland	99.42%	99.37%	99.32%
DK03	Denmark	Syddanmark	99.38%	99.39%	99.31%
DK04	Denmark	Midtjylland	99.43%	99.35%	99.32%
DK05	Denmark	Nordjylland	99.38%	99.26%	99.10%
EE00	Estonia	Eesti	48.82%	47.41%	45.53%
EL11	Greece	Anatoliki Makedonia, Thraki	49.99%	46.39%	45.84%
EL12	Greece	Kentriki Makedonia	58.40%	57.49%	56.12%
EL13	Greece	Dytiki Makedonia	52.09%	52.26%	51.57%
EL14	Greece	Thessalia	54.47%	49.94%	49.83%
EL21	Greece	Ipeiros	52.97%	52.11%	52.28%
EL22	Greece	Ionia Nisia	50.29%	50.76%	55.35%

TABLE A.1 (continued)

NUTS-Code	Country	Region name	2010	2013	2016
EL23	Greece	Dytiki Ellada	51.74%	48.77%	48.50%
EL24	Greece	Sterea Ellada	52.80%	51.97%	47.12%
EL25	Greece	Peloponnisos	45.38%	45.22%	44.02%
EL30	Greece	Attiki	64.51%	65.71%	65.59%
EL41	Greece	Voreio Aigaio	57.47%	55.60%	51.50%
EL42	Greece	Notio Aigaio	57.53%	57.06%	55.28%
EL43	Greece	Kriti	54.83%	51.46%	53.21%
ES11	Spain	Galicia	73.11%	72.98%	73.56%
ES12	Spain	Principado de Asturias	78.97%	79.21%	78.97%
ES13	Spain	Cantabria	80.91%	81.37%	81.01%
ES21	Spain	País Vasco	88.69%	88.81%	88.36%
ES22	Spain	Comunidad Foral de Navarra	84.66%	86.20%	85.30%
ES23	Spain	La Rioja	83.06%	79.08%	81.01%
ES24	Spain	Aragón	79.97%	80.91%	78.94%
ES30	Spain	Comunidad de Madrid	84.73%	85.77%	84.97%
ES41	Spain	Castilla y León	79.06%	78.77%	76.77%
ES42	Spain	Castilla-La Mancha	73.74%	73.34%	73.01%
ES43	Spain	Extremadura	72.18%	70.46%	69.12%
ES51	Spain	Cataluña	79.28%	79.43%	79.95%
ES52	Spain	Comunidad Valenciana	74.77%	75.95%	75.56%
ES53	Spain	Illes Balears	72.77%	72.25%	71.51%
ES61	Spain	Andalucía	71.81%	71.04%	69.48%
ES62	Spain	Región de Murcia	71.03%	68.67%	67.95%
FI19	Finland	Länsi-Suomi	84.04%	81.35%	81.20%
FI1B	Finland	Helsinki-Uusimaa	90.60%	89.38%	86.11%
FI1C	Finland	Etelä-Suomi	83.15%	81.99%	80.30%
FI1D	Finland	Pohjois- ja Itä-Suomi	80.04%	78.78%	77.37%
FI20	Finland	Åland	83.93%	82.09%	78.05%

TABLE A.1 (continued)

NUTS-Code	Country	Region name	2010	2013	2016
FR10	France	Île de France	99.28%	99.23%	99.35%
FR21	France	Champagne-Ardenne	89.68%	91.54%	90.49%
FR22	France	Picardie	95.31%	93.62%	94.33%
FR23	France	Haute-Normandie	91.61%	94.96%	92.43%
FR24	France	Centre	91.13%	90.63%	89.70%
FR25	France	Basse-Normandie	90.22%	88.62%	87.46%
FR26	France	Bourgogne	90.83%	88.22%	86.20%
FR30	France	Nord - Pas-de-Calais	97.90%	97.58%	97.26%
FR41	France	Lorraine	91.64%	93.18%	94.14%
FR42	France	Alsace	95.27%	93.57%	93.51%
FR43	France	Franche-Comté	89.42%	87.36%	86.61%
FR51	France	Pays de la Loire	89.26%	87.36%	88.58%
FR52	France	Bretagne	88.22%	88.14%	86.39%
FR53	France	Poitou-Charentes	84.15%	83.12%	83.59%
FR61	France	Aquitaine	85.03%	83.27%	84.35%
FR62	France	Midi-Pyrénées	89.20%	89.28%	89.37%
FR63	France	Limousin	87.64%	87.11%	85.97%
FR71	France	Rhône-Alpes	89.57%	89.73%	91.36%
FR72	France	Auvergne	89.05%	85.38%	86.17%
FR81	France	Languedoc-Roussillon	83.09%	82.27%	82.68%
FR82	France	Provence-Alpes-Côte d’Azur	85.06%	85.72%	86.41%
FR83	France	Corse	75.72%	83.54%	85.16%
HU10	Hungary	Közép-Magyarország	58.78%	59.25%	58.92%
HU21	Hungary	Közép-Dunántúl	51.08%	51.53%	50.30%
HU22	Hungary	Nyugat-Dunántúl	52.55%	52.07%	51.61%
HU23	Hungary	Dél-Dunántúl	49.39%	50.18%	48.10%
HU31	Hungary	Észak-Magyarország	49.73%	49.17%	48.44%
HU32	Hungary	Észak-Alföld	50.18%	49.90%	47.73%

TABLE A.1 (continued)

NUTS-Code	Country	Region name	2010	2013	2016
HU33	Hungary	Dél-Alföld	50.17%	49.66%	47.98%
IE01	Ireland	Border, Midland and Western	99.31%	99.21%	99.21%
IE02	Ireland	Southern and Eastern	99.50%	99.50%	99.54%
ITC1	Italy	Piemonte	79.38%	77.52%	75.71%
ITC2	Italy	Valle d'Aosta/Vallée d'Aoste	82.05%	81.34%	80.24%
ITC3	Italy	Liguria	82.34%	79.74%	77.26%
ITC4	Italy	Lombardia	81.17%	79.27%	78.54%
ITF1	Italy	Abruzzo	76.67%	74.33%	70.94%
ITF2	Italy	Molise	76.64%	73.77%	73.29%
ITF3	Italy	Campania	73.00%	71.08%	68.96%
ITF4	Italy	Puglia	72.06%	69.17%	67.52%
ITF5	Italy	Basilicata	70.95%	70.00%	67.60%
ITF6	Italy	Calabria	68.16%	65.28%	63.32%
ITG1	Italy	Sicilia	70.65%	67.50%	64.73%
ITG2	Italy	Sardegna	70.16%	69.39%	66.58%
ITH1	Italy	Provincia Autonoma di Bolzano/Bozen	83.31%	82.11%	81.64%
ITH2	Italy	Provincia Autonoma di Trento	85.61%	84.59%	82.59%
ITH3	Italy	Veneto	78.83%	76.72%	75.73%
ITH4	Italy	Friuli-Venezia Giulia	77.63%	78.09%	75.95%
ITH5	Italy	Emilia-Romagna	81.04%	79.21%	78.39%
ITI1	Italy	Toscana	77.35%	76.36%	75.28%
ITI2	Italy	Umbria	77.40%	75.72%	73.04%
ITI3	Italy	Marche	76.01%	74.91%	73.13%
ITI4	Italy	Lazio	76.93%	74.38%	72.85%
LT00	Lithuania	Lietuva	46.69%	47.06%	46.49%
LU00	Luxemburg	Luxemburg	100.00%	100.00%	100.00%

TABLE A.1 (continued)

NUTS-Code	Country	Region name	2010	2013	2016
LV00	Latvia	Latvija	37.18%	36.87%	36.43%
NL11	Netherlands	Groningen	100.00%	100.00%	99.57%
NL12	Netherlands	Friesland (NL)	99.36%	99.31%	99.14%
NL13	Netherlands	Drenthe	99.25%	99.17%	99.12%
NL21	Netherlands	Overijssel	99.49%	99.48%	99.44%
NL22	Netherlands	Gelderland	99.55%	99.52%	99.50%
NL23	Netherlands	Flevoland	99.55%	99.51%	99.51%
NL31	Netherlands	Utrecht	100.00%	100.00%	100.00%
NL32	Netherlands	Noord-Holland	99.58%	99.55%	99.54%
NL33	Netherlands	Zuid-Holland	99.51%	99.49%	99.44%
NL34	Netherlands	Zeeland	99.46%	99.33%	99.28%
NL41	Netherlands	Noord-Brabant	99.53%	99.52%	99.49%
NL42	Netherlands	Limburg (NL)	99.49%	99.45%	99.44%
PL11	Poland	Łódzkie	46.27%	46.67%	46.43%
PL12	Poland	Mazowieckie	50.43%	51.31%	50.28%
PL21	Poland	Małopolskie	45.35%	46.42%	46.45%
PL22	Poland	Śląskie	50.04%	49.90%	49.70%
PL31	Poland	Lubelskie	38.99%	38.68%	39.95%
PL32	Poland	Podkarpackie	40.90%	41.58%	42.73%
PL33	Poland	Świętokrzyskie	41.19%	39.73%	39.68%
PL34	Poland	Podlaskie	38.85%	39.97%	39.69%
PL41	Poland	Wielkopolskie	44.65%	46.70%	47.14%
PL42	Poland	Zachodniopomorskie	49.31%	49.02%	48.94%
PL43	Poland	Lubuskie	48.29%	48.46%	49.02%
PL51	Poland	Dolnośląskie	50.45%	51.47%	51.53%
PL52	Poland	Opolskie	46.72%	47.14%	48.00%
PL61	Poland	Kujawsko-Pomorskie	43.22%	43.59%	43.56%
PL62	Poland	Warmińsko-mazurskie	44.08%	43.56%	42.65%

TABLE A.1 (continued)

NUTS-Code	Country	Region name	2010	2013	2016
PL63	Poland	Pomorskie	48.74%	48.95%	48.14%
PT11	Portugal	Norte	52.89%	53.24%	53.50%
PT15	Portugal	Algarve	54.88%	55.56%	54.12%
PT16	Portugal	Centro (PT)	50.89%	53.35%	55.39%
PT17	Portugal	Lisboa	63.02%	62.18%	63.05%
PT18	Portugal	Alentejo	55.55%	55.01%	55.50%
SE11	Sweden	Stockholm	87.12%	85.16%	86.46%
SE12	Sweden	Östra Mellansverige	84.13%	82.16%	82.67%
SE21	Sweden	Småland med öarna	81.99%	79.92%	81.21%
SE22	Sweden	Sydsverige	89.87%	86.67%	87.76%
SE23	Sweden	Västsverige	85.85%	84.56%	85.32%
SE31	Sweden	Norra Mellansverige	81.13%	78.40%	78.55%
SE32	Sweden	Mellersta Norrland	83.47%	77.92%	77.36%
SE33	Sweden	Övre Norrland	96.68%	88.96%	79.19%
SI03	Slovenia	Vzhodna Slovenija	59.64%	59.53%	60.03%
SI04	Slovenia	Zahodna Slovenija	66.99%	66.83%	66.69%
SK01	Slovak Republic	Bratislavský kraj	74.78%	74.25%	74.76%
SK02	Slovak Republic	Západné Slovensko	62.29%	61.62%	60.81%
SK03	Slovak Republic	Stredné Slovensko	61.66%	61.18%	60.83%
SK04	Slovak Republic	Východné Slovensko	59.30%	59.26%	60.09%
UKC1	United Kingdom	Tees Valley and Durham	69.84%	67.35%	67.49%
UKC2	United Kingdom	Northumberland and Tyne and Wear	68.80%	68.21%	67.03%
UKD1	United Kingdom	Cumbria	69.19%	67.20%	65.87%
UKD3	United Kingdom	Greater Manchester	75.57%	74.72%	72.42%
UKD4	United Kingdom	Lancashire	74.06%	72.54%	69.39%
UKD6	United Kingdom	Cheshire	78.22%	78.09%	76.39%
UKD7	United Kingdom	Merseyside	73.01%	70.04%	69.76%

TABLE A.1 (continued)

NUTS-Code	Country	Region name	2010	2013	2016
UKE1	United Kingdom	East Yorkshire and Northern Lincolnshire	72.41%	70.11%	69.54%
UKE2	United Kingdom	North Yorkshire	78.36%	77.24%	73.37%
UKE3	United Kingdom	South Yorkshire	71.49%	70.42%	69.00%
UKE4	United Kingdom	West Yorkshire	72.74%	71.51%	69.57%
UKF1	United Kingdom	Derbyshire and Nottinghamshire	78.06%	75.99%	74.55%
UKF2	United Kingdom	Leicestershire, Rutland and Northamptonshire	78.63%	76.02%	73.76%
UKF3	United Kingdom	Lincolnshire	75.00%	73.09%	71.16%
UKG1	United Kingdom	Herefordshire, Worcestershire and Warwickshire	76.55%	77.65%	77.51%
UKG2	United Kingdom	Shropshire and Staffordshire	74.41%	72.56%	72.73%
UKG3	United Kingdom	West Midlands	75.27%	74.94%	72.47%
UKH1	United Kingdom	East Anglia	77.25%	77.16%	74.02%
UKH2	United Kingdom	Bedfordshire and Hertfordshire	78.83%	82.70%	79.08%
UKH3	United Kingdom	Essex	75.99%	76.62%	74.07%
UKI1	United Kingdom	Inner London	97.37%	99.58%	94.04%
UKI2	United Kingdom	Outer London	96.40%	97.16%	95.92%
UKJ1	United Kingdom	Berkshire, Buckinghamshire and Oxfordshire	83.03%	84.15%	84.12%
UKJ2	United Kingdom	Surrey, East and West Sussex	81.82%	81.51%	79.08%
UKJ3	United Kingdom	Hampshire and Isle of Wight	78.52%	78.94%	75.65%
UKJ4	United Kingdom	Kent	79.46%	79.05%	75.94%
UKK1	United Kingdom	Gloucestershire, Wiltshire and Bristol/Bath area	78.19%	78.72%	76.88%
UKK2	United Kingdom	Dorset and Somerset	74.99%	74.53%	73.39%
UKK3	United Kingdom	Cornwall and Isles of Scilly	66.60%	67.14%	62.64%
UKK4	United Kingdom	Devon	72.55%	72.36%	70.14%
UKL1	United Kingdom	West Wales and The Valleys	70.37%	68.13%	67.59%

TABLE A.1 (continued)

NUTS-Code	Country	Region name	2010	2013	2016
UKL2	United Kingdom	East Wales	76.61%	73.64%	72.68%
UKM2	United Kingdom	Eastern Scotland	70.77%	71.55%	71.35%
UKM3	United Kingdom	South Western Scotland	68.74%	68.65%	68.01%
UKM5	United Kingdom	North Eastern Scotland	70.35%	68.80%	70.88%
UKM6	United Kingdom	Highlands and Islands	76.74%	67.17%	71.81%
UKN0	United Kingdom	Northern Ireland	65.97%	65.80%	63.68%

TABLE A.2
Estimates of country and time dummies (baseline model)

	Coefficient estimate	Standard deviation	t-statistic value
Year 2013	0.034	0.009	3.796
Year 2016	0.073	0.010	7.179
Country-Austria	-0.387	0.048	-8.017
Country-Belgium	-0.427	0.031	-13.580
Country-Czech Republic	0.123	0.047	2.628
Country-Germany	-0.280	0.026	-10.863
Country-Denmark	-0.606	0.031	-19.425
Country-Estonia	0.257	0.093	2.750
Country-Greece	-0.116	0.049	-2.347
Country-Spain	-0.230	0.043	-5.388
Country-Finland	-0.284	0.054	-5.277
Country-France	-0.271	0.035	-7.701
Country-Hungary	0.128	0.049	2.591
Country-Ireland	-0.637	0.045	-14.203
Country-Italy	-0.278	0.044	-6.284
Country-Lithuania	0.269	0.088	3.063
Country-Luxemburg	-0.701	0.037	-18.857
Country-Latvia	0.441	0.096	4.584
Country-Netherlands	-0.494	0.030	-16.268
Country-Poland	0.197	0.038	5.205
Country-Portugal	-0.061	0.054	-1.126
Country-Sweden	-0.274	0.052	-5.239
Country-Slovenia	-0.012	0.079	-0.147
Country-Slovak Republic	-0.076	0.053	-1.450

Note: Excluded year dummy: 2010; excluded country dummy: United Kingdom.

TABLE A.3
Econometric model estimates based on a translog production function

Production function, Dependent variable: ln(Output)	
Constant	1.979** (0.875)
ln(Hours worked)	0.111 (0.160)
ln(Physical capital)	0.704*** (0.182)
Time trend	-0.103 (0.113)
$\{\ln(\text{Hours worked})\}^2$	-0.020 (0.036)
$\{\ln(\text{Physical capital})\}^2$	-0.093*** (0.022)
$(\text{Time trend})^2$	0.014 (0.018)
ln(Hours worked) × ln(Physical capital)	0.079*** (0.024)
ln(Hours worked) × Time trend	-0.005 (0.016)
ln(Physical capital) × Time trend	0.010 (0.012)
Inefficiency model, Dependent variable: technical inefficiency	
Constant	0.444*** (0.079)
devlandpc	0.0004 (0.0004)
$devlandpc^2$	-0.0001 (0.0002)
landmix	0.171** (0.074)
empdens	-0.00003 (0.00003)
$empdens^2$	0.000001** (0.0000005)
mpi	-0.652*** (0.140)

TABLE A.3 (continued)

Inefficiency model, Dependent variable: technical inefficiency (continued)	
spec	0.534*** (0.160)
div	0.035 (0.023)
tert	-0.008*** (0.001)
Time effects	included
Country effects	included
σ^2 (p-value)	0.014*** (0.001)
γ (p-value)	0.283*** (0.029)
Log likelihood	561.08
Observations	735

Notes:
a. Standard errors are included in parentheses.
b. ***, ** and * denote statistical significance at 1%, 5% and 10% levels, respectively.

TABLE A.4

Estimates for alternative variables of geographical centrality (baseline model)

	GTC-based mpi	Gravity index	Population potential index
Production function, Dependent variable: ln(Output)			
Constant	3.123*** (0.106)	3.113*** (0.106)	3.428*** (0.110)
ln(Hours worked)	1.017*** (0.014)	1.017*** (0.014)	0.944*** (0.014)
ln(Physical capital)	0.033** (0.014)	0.033* (0.014)	0.051*** (0.012)
Time trend	0.041*** (0.008)	0.041*** (0.008)	0.024*** (0.008)
Inefficiency model, Dependent variable: technical inefficiency			
Constant	0.430*** (0.039)	0.620*** (0.129)	0.714*** (0.045)
devlandpc	0.0002 (0.001)	-0.001 (0.001)	0.0004 (0.0003)
devlandpc^{2}	-0.001*** (0.00002)	-0.001* (0.0004)	-0.0003** (0.0001)
landmix	0.436*** (0.038)	0.173 (0.108)	0.012 (0.040)
empdens	-0.0001*** (0.0004)	-0.0001*** (0.00001)	-0.00009*** (0.000007)
empdens^{2}	0.0000003 (0.00000002)	-0.000001*** (0.0000003)	0.000001*** (0.0000001)
gmpi	-0.515*** (0.052)		
gi		-0.278*** (0.097)	
ppi			-0.351*** (0.027)
spec	0.714*** (0.133)	0.762*** (0.172)	0.570*** (0.127)
div	0.034** (0.014)	0.018 (0.024)	0.027*** (0.010)

TABLE A.4 (continued)

	GTC-based mpi	Gravity index	Population potential index
Inefficiency model, Dependent variable: technical inefficiency (continued)			
tert	-0.010*** (0.001)	-0.011*** (0.002)	-0.011*** (0.001)
Time effects	included	included	included
Country effects	included	included	included
σ^2 (p-value)	0.016*** (0.001)	0.017*** (0.001)	0.013*** (0.001)
γ (p-value)	0.138*** (0.018)	0.227*** (0.023)	0.023*** (0.004)
Log likelihood	525.45	503.17	551.96
Observations	735	735	735

Notes:
a. Standard errors are included in parentheses.
b. ***, ** and * denote statistical significance at 1%, 5% and 10% levels, respectively.

TABLE A.5
Estimates after alternatively excluding regional specialisation and sectoral diversification (baseline model)

	Exclude regional specialisation	Exclude sectoral diversification
Production function, Dependent variable: ln(Output)		
Constant	3.232*** (0.090)	3.296*** (0.077)
ln(Hours worked)	0.981*** (0.014)	0.994*** (0.014)
ln(Physical capital)	0.051** (0.012)	0.037*** (0.013)
Time trend	0.024*** (0.007)	0.029*** (0.008)
Inefficiency model, Dependent variable: technical inefficiency		
Constant	0.915*** (0.061)	0.853*** (0.044)
devlandpc	-0.00003 (0.0004)	-0.0001 (0.0002)
devlandpc^2	-0.001*** (0.0001)	-0.001*** (0.0001)
landmix	-0.098 (0.038)	-0.123*** (0.044)
empdens	0.00004 (0.00001)	0.000 (0.000)
empdens^2	0.0000005*** (0.0000001)	0.0000005*** (0.0000001)
mpi	-0.768*** (0.067)	-0.774*** (0.078)
spec		0.574*** (0.129)
div	0.008 (0.016)	
tert	-0.011*** (0.001)	-0.008*** (0.001)
Time effects	included	included
Country effects	included	included

TABLE A.5 (continued)

	Exclude regional specialisation	Exclude sectoral diversification
σ^2 (p-value)	0.015*** (0.001)	0.013*** (0.001)
γ (p-value)	0.099*** (0.016)	0.064*** (0.009)
Log likelihood	511.87	564.93
Observations	735	735

Notes:
a. Standard errors are included in parentheses.
b. ***, ** and * denote statistical significance at 1%, 5% and 10% levels, respectively.

TABLE A.6
TFP growth of EU regions (average of years 2010, 2013, 2016)

NUTS-Code	Country	Description	Average TFP growth
IE02	Ireland	Southern and Eastern	27.907%
PL32	Poland	Podkarpackie	17.737%
PL21	Poland	Małopolskie	15.932%
PL42	Poland	Zachodniopomorskie	15.584%
CZ02	Czech Republic	Střední Čechy	15.192%
PL11	Poland	Łódzkie	14.069%
PL41	Poland	Wielkopolskie	13.610%
HU31	Hungary	Észak-Magyarország	13.365%
PL43	Poland	Lubuskie	13.208%
HU22	Hungary	Nyugat-Dunántúl	13.100%
HU21	Hungary	Közép-Dunántúl	13.015%
CZ01	Czech Republic	Praha	12.603%
HU33	Hungary	Dél-Alföld	12.400%
PL22	Poland	Śląskie	12.309%
PL62	Poland	Warmińsko-mazurskie	11.743%
PL51	Poland	Dolnośląskie	11.686%
ES53	Spain	Illes Balears	11.144%
HU23	Hungary	Dél-Dunántúl	11.018%
EL14	Greece	Thessalia	10.894%
PL61	Poland	Kujawsko-Pomorskie	10.777%
PL34	Poland	Podlaskie	10.614%
EL13	Greece	Dytiki Makedonia	10.537%
CZ03	Czech Republic	Jihozápad	10.278%
ES11	Spain	Galicia	10.190%
ES51	Spain	Cataluña	9.933%
CZ05	Czech Republic	Severovýchod	9.833%
EL25	Greece	Peloponnisos	9.645%

TABLE A.6 (continued)

NUTS-Code	Country	Description	Average TFP growth
FR63	France	Limousin	9.528%
CZ06	Czech Republic	Jihovýchod	9.494%
PL52	Poland	Opolskie	9.371%
LV00	Latvia	Latvija	9.301%
CZ08	Czech Republic	Moravskoslezsko	9.236%
ES52	Spain	Comunidad Valenciana	9.182%
CZ07	Czech Republic	Střední Morava	9.149%
EL21	Greece	Ipeiros	9.106%
PT15	Portugal	Algarve	9.015%
ES21	Spain	País Vasco	8.887%
ES61	Spain	Andalucía	8.879%
SK01	Slovak Republic	Bratislavský kraj	8.868%
ES22	Spain	Comunidad Foral de Navarra	8.782%
ES30	Spain	Comunidad de Madrid	8.504%
LT00	Lithuania	Lietuva	8.472%
ES13	Spain	Cantabria	8.450%
ES24	Spain	Aragón	8.429%
ES62	Spain	Región de Murcia	8.354%
ES42	Spain	Castilla-La Mancha	8.297%
EL12	Greece	Kentriki Makedonia	8.169%
PL31	Poland	Lubelskie	8.043%
ES41	Spain	Castilla y León	8.006%
SK04	Slovak Republic	Východné Slovensko	7.716%
HU10	Hungary	Közép-Magyarország	7.383%
DK02	Denmark	Sjælland	7.298%
EL30	Greece	Attiki	7.266%

TABLE A.6 (continued)

NUTS-Code	Country	Description	Average TFP growth
ES43	Spain	Extremadura	7.263%
PT16	Portugal	Centro (PT)	7.258%
PL12	Poland	Mazowieckie	7.246%
PL33	Poland	Świętokrzyskie	7.246%
HU32	Hungary	Észak-Alföld	7.223%
SI03	Slovenia	Vzhodna Slovenija	7.117%
EL24	Greece	Sterea Ellada	6.896%
DEG0	Germany	Thüringen	6.839%
FR72	France	Auvergne	6.782%
ES12	Spain	Principado de Asturias	6.709%
NL32	Netherlands	Noord-Holland	6.698%
ITF5	Italy	Basilicata	6.485%
FR62	France	Midi-Pyrénées	6.302%
EL43	Greece	Kriti	6.190%
ITH5	Italy	Emilia-Romagna	6.067%
AT33	Austria	Tirol	5.978%
FR41	France	Lorraine	5.838%
DK03	Denmark	Syddanmark	5.810%
ITF3	Italy	Campania	5.781%
EL23	Greece	Dytiki Ellada	5.771%
NL41	Netherlands	Noord-Brabant	5.765%
ITH1	Italy	Provincia Autonoma di Bolzano/ Bozen	5.740%
FR52	France	Bretagne	5.735%
AT34	Austria	Vorarlberg	5.668%
ES23	Spain	La Rioja	5.616%
SK02	Slovak Republic	Západné Slovensko	5.597%

TABLE A.6 (continued)

NUTS-Code	Country	Description	Average TFP growth
DE40	Germany	Brandenburg	5.550%
CZ04	Czech Republic	Severozápad	5.527%
DED2	Germany	Dresden	5.514%
SI04	Slovenia	Zahodna Slovenija	5.485%
PT18	Portugal	Alentejo	5.391%
PT11	Portugal	Norte	5.280%
DE80	Germany	Mecklenburg-Vorpommern	5.274%
DED5	Germany	Leipzig	5.252%
SK03	Slovak Republic	Stredné Slovensko	5.177%
IE01	Ireland	Border, Midland and Western	5.123%
NL42	Netherlands	Limburg (NL)	5.100%
AT32	Austria	Salzburg	5.047%
DED4	Germany	Chemnitz	5.001%
DEB2	Germany	Trier	4.980%
DK04	Denmark	Midtjylland	4.763%
NL33	Netherlands	Zuid-Holland	4.728%
DK01	Denmark	Hovedstaden	4.712%
EL11	Greece	Anatoliki Makedonia, Thraki	4.572%
FR43	France	Franche-Comté	4.532%
ITH4	Italy	Friuli-Venezia Giulia	4.515%
NL21	Netherlands	Overijssel	4.503%
ITI3	Italy	Marche	4.502%
AT21	Austria	Kärnten	4.497%
NL22	Netherlands	Gelderland	4.496%
FR51	France	Pays de la Loire	4.477%
AT22	Austria	Steiermark	4.185%
FR23	France	Haute-Normandie	4.159%

TABLE A.6 (continued)

NUTS-Code	Country	Description	Average TFP growth
NL13	Netherlands	Drenthe	4.142%
DEE0	Germany	Sachsen-Anhalt	4.142%
FR22	France	Picardie	4.028%
BE22	Belgium	Prov. Limburg (BE)	3.908%
DK05	Denmark	Nordjylland	3.897%
FR61	France	Aquitaine	3.891%
FR24	France	Centre	3.819%
ITI1	Italy	Toscana	3.800%
NL23	Netherlands	Flevoland	3.782%
AT11	Austria	Burgenland (AT)	3.764%
AT31	Austria	Oberösterreich	3.691%
BE23	Belgium	Prov. Oost-Vlaanderen	3.677%
AT12	Austria	Niederösterreich	3.661%
ITG2	Italy	Sardegna	3.514%
NL31	Netherlands	Utrecht	3.476%
FR26	France	Bourgogne	3.395%
FR25	France	Basse-Normandie	3.286%
ITC3	Italy	Liguria	3.274%
SE23	Sweden	Västsverige	3.182%
ITC4	Italy	Lombardia	3.119%
FR30	France	Nord - Pas-de-Calais	3.115%
ITF1	Italy	Abruzzo	3.100%
FR42	France	Alsace	3.094%
ITH3	Italy	Veneto	3.048%
DEB1	Germany	Koblenz	3.045%
DE93	Germany	Lüneburg	3.026%
FR53	France	Poitou-Charentes	3.010%

TABLE A.6 (continued)

NUTS-Code	Country	Description	Average TFP growth
DE21	Germany	Oberbayern	2.997%
DE11	Germany	Stuttgart	2.983%
ITC1	Italy	Piemonte	2.934%
EL22	Greece	Ionia Nisia	2.925%
UKM6	United Kingdom	Highlands and Islands	2.903%
FI1C	Finland	Etelä-Suomi	2.835%
BE24	Belgium	Prov. Vlaams-Brabant	2.804%
NL34	Netherlands	Zeeland	2.737%
FR71	France	Rhône-Alpes	2.711%
BE25	Belgium	Prov. West-Vlaanderen	2.674%
DE27	Germany	Schwaben	2.647%
DE50	Germany	Bremen	2.603%
FR10	France	Île de France	2.598%
DEF0	Germany	Schleswig-Holstein	2.573%
PL63	Poland	Pomorskie	2.549%
ITF6	Italy	Calabria	2.421%
DEA4	Germany	Detmold	2.407%
SE21	Sweden	Småland med öarna	2.381%
FR83	France	Corse	2.351%
DE26	Germany	Unterfranken	2.350%
DE30	Germany	Berlin	2.339%
ITH2	Italy	Provincia Autonoma di Trento	2.329%
DE24	Germany	Oberfranken	2.298%
DEB3	Germany	Rheinhessen-Pfalz	2.237%
NL12	Netherlands	Friesland (NL)	2.188%
DE23	Germany	Oberpfalz	2.140%
SE11	Sweden	Stockholm	1.968%

TABLE A.6 (continued)

NUTS-Code	Country	Description	Average TFP growth
ITG1	Italy	Sicilia	1.966%
BE33	Belgium	Prov. Liège	1.955%
DE14	Germany	Tübingen	1.949%
EL42	Greece	Notio Aigaio	1.894%
FR82	France	Provence-Alpes-Côte d'Azur	1.850%
LU00	Luxembourg	Luxembourg	1.846%
DEC0	Germany	Saarland	1.835%
DEA2	Germany	Köln	1.828%
FR81	France	Languedoc-Roussillon	1.825%
DE22	Germany	Niederbayern	1.794%
BE21	Belgium	Prov. Antwerpen	1.752%
UKM2	United Kingdom	Eastern Scotland	1.742%
DE25	Germany	Mittelfranken	1.734%
DE71	Germany	Darmstadt	1.720%
FR21	France	Champagne-Ardenne	1.670%
AT13	Austria	Wien	1.580%
ITF4	Italy	Puglia	1.520%
EE00	Estonia	Eesti	1.441%
DE13	Germany	Freiburg	1.406%
PT17	Portugal	Lisboa	1.359%
DE73	Germany	Kassel	1.296%
BE32	Belgium	Prov. Hainaut	1.262%
UKG1	United Kingdom	Herefordshire, Worcestershire and Warwickshire	1.142%
DE72	Germany	Giessen	1.123%
BE35	Belgium	Prov. Namur	0.985%
ITC2	Italy	Valle d'Aosta/Vallée d'Aoste	0.952%

TABLE A.6 (continued)

NUTS-Code	Country	Description	Average TFP growth
UKM3	United Kingdom	South Western Scotland	0.931%
DEA1	Germany	Düsseldorf	0.870%
DEA5	Germany	Arnsberg	0.806%
SE12	Sweden	Östra Mellansverige	0.732%
ITI4	Italy	Lazio	0.710%
UKN0	United Kingdom	Northern Ireland	0.507%
SE31	Sweden	Norra Mellansverige	0.496%
DE12	Germany	Karlsruhe	0.445%
FI1D	Finland	Pohjois- ja Itä-Suomi	0.379%
UKI2	United Kingdom	Outer London	0.337%
SE22	Sweden	Sydsverige	0.149%
ITI2	Italy	Umbria	0.130%
ITF2	Italy	Molise	0.121%
DE94	Germany	Weser-Ems	0.023%
DE92	Germany	Hannover	-0.041%
DEA3	Germany	Münster	-0.053%
DE60	Germany	Hamburg	-0.083%
BE34	Belgium	Prov. Luxembourg (BE)	-0.554%
FI19	Finland	Länsi-Suomi	-0.582%
UKL2	United Kingdom	East Wales	-0.830%
UKK3	United Kingdom	Cornwall and Isles of Scilly	-1.007%
UKD1	United Kingdom	Cumbria	-1.061%
UKC2	United Kingdom	Northumberland and Tyne and Wear	-1.068%
UKL1	United Kingdom	West Wales and The Valleys	-1.353%
FI20	Finland	Åland	-1.358%
UKF3	United Kingdom	Lincolnshire	-1.508%
BE31	Belgium	Prov. Brabant Wallon	-1.530%

TABLE A.6 (continued)

NUTS-Code	Country	Description	Average TFP growth
UKH1	United Kingdom	East Anglia	-1.590%
UKD4	United Kingdom	Lancashire	-1.612%
DE91	Germany	Braunschweig	-1.791%
EL41	Greece	Voreio Aigaio	-1.855%
UKE4	United Kingdom	West Yorkshire	-1.935%
FI1B	Finland	Helsinki-Uusimaa	-2.035%
UKJ1	United Kingdom	Berkshire, Buckinghamshire and Oxfordshire	-2.080%
UKG2	United Kingdom	Shropshire and Staffordshire	-2.286%
BE10	Belgium	Région de Bruxelles-Capitale / Brussels	-2.287%
UKH2	United Kingdom	Bedfordshire and Hertfordshire	-2.511%
UKJ2	United Kingdom	Surrey, East and West Sussex	-2.529%
UKD3	United Kingdom	Greater Manchester	-2.748%
UKF2	United Kingdom	Leicestershire, Rutland and Northamptonshire	-2.754%
UKI1	United Kingdom	Inner London	-3.007%
UKK1	United Kingdom	Gloucestershire, Wiltshire and Bristol/Bath area	-3.089%
UKC1	United Kingdom	Tees Valley and Durham	-3.125%
UKH3	United Kingdom	Essex	-3.147%
SE32	Sweden	Mellersta Norrland	-3.207%
UKK2	United Kingdom	Dorset and Somerset	-3.209%
UKJ4	United Kingdom	Kent	-3.460%
UKG3	United Kingdom	West Midlands	-3.571%
UKK4	United Kingdom	Devon	-3.871%
UKF1	United Kingdom	Derbyshire and Nottinghamshire	-3.905%
UKE3	United Kingdom	South Yorkshire	-3.920%
UKE2	United Kingdom	North Yorkshire	-4.336%

TABLE A.6 (continued)

NUTS-Code	Country	Description	Average TFP growth
UKJ3	United Kingdom	Hampshire and Isle of Wight	-4.439%
UKE1	United Kingdom	East Yorkshire and Northern Lincolnshire	-4.817%
SE33	Sweden	Övre Norrland	-4.963%
UKD6	United Kingdom	Cheshire	-5.039%
UKD7	United Kingdom	Merseyside	-5.619%
NL11	Netherlands	Groningen	-5.661%
UKM5	United Kingdom	North Eastern Scotland	-7.524%

TABLE A.7
Technology gaps of EU regions in 2016

NUTS Code	Country	Region	Technology gap
BE10	Belgium	Région de Bruxelles-Capitale / Brussels	1.000
IE02	Ireland	Southern and Eastern	1.284
LU00	Luxembourg	Luxembourg	1.462
BE31	Belgium	Prov. Brabant Wallon	1.570
NL11	Netherlands	Groningen	1.590
FR10	France	Île de France	1.677
BE21	Belgium	Prov. Antwerpen	1.685
NL32	Netherlands	Noord-Holland	1.735
DK01	Denmark	Hovedstaden	1.752
DE60	Germany	Hamburg	1.757
DE21	Germany	Oberbayern	1.793
DE50	Germany	Bremen	1.814
BE24	Belgium	Prov. Vlaams-Brabant	1.822
AT34	Austria	Vorarlberg	1.825
DE71	Germany	Darmstadt	1.831
DE11	Germany	Stuttgart	1.837
SE11	Sweden	Stockholm	1.858
NL31	Netherlands	Utrecht	1.887
FR83	France	Corse	1.950
DEB3	Germany	Rheinhessen-Pfalz	1.962
UKI1	United Kingdom	Inner London	1.964
DEA2	Germany	Köln	1.968
NL41	Netherlands	Noord-Brabant	2.006
DE14	Germany	Tübingen	2.014
DK03	Denmark	Syddanmark	2.018
BE25	Belgium	Prov. West-Vlaanderen	2.027

TABLE A.7 (continued)

NUTS Code	Country	Region	Technology gap
DE12	Germany	Karlsruhe	2.029
DE23	Germany	Oberpfalz	2.034
DEA1	Germany	Düsseldorf	2.038
AT32	Austria	Salzburg	2.038
AT13	Austria	Wien	2.045
DE26	Germany	Unterfranken	2.050
ITH1	Italy	Provincia Autonoma di Bolzano/Bozen	2.058
DE91	Germany	Braunschweig	2.059
NL23	Netherlands	Flevoland	2.064
NL33	Netherlands	Zuid-Holland	2.074
DE22	Germany	Niederbayern	2.074
ES21	Spain	País Vasco	2.088
DK02	Denmark	Sjælland	2.096
DE25	Germany	Mittelfranken	2.097
DEC0	Germany	Saarland	2.103
ES22	Spain	Comunidad Foral de Navarra	2.103
DE27	Germany	Schwaben	2.108
DK04	Denmark	Midtjylland	2.114
DEA4	Germany	Detmold	2.128
SK01	Slovak Republic	Bratislavský kraj	2.143
DEB1	Germany	Koblenz	2.145
AT33	Austria	Tirol	2.145
DK05	Denmark	Nordjylland	2.146
DE92	Germany	Hannover	2.152
NL34	Netherlands	Zeeland	2.155
BE23	Belgium	Prov. Oost-Vlaanderen	2.166
DE72	Germany	Giessen	2.177

TABLE A.7 (continued)

NUTS Code	Country	Region	Technology gap
FR23	France	Haute-Normandie	2.183
DE30	Germany	Berlin	2.185
DE24	Germany	Oberfranken	2.187
DE73	Germany	Kassel	2.190
DEA3	Germany	Münster	2.193
ITC2	Italy	Valle d’Aosta/Vallée d’Aoste	2.194
NL42	Netherlands	Limburg (NL)	2.196
DE13	Germany	Freiburg	2.202
UKI2	United Kingdom	Outer London	2.207
DEB2	Germany	Trier	2.213
AT31	Austria	Oberösterreich	2.219
FR42	France	Alsace	2.231
DEA5	Germany	Arnsberg	2.233
NL21	Netherlands	Overijssel	2.237
FR62	France	Midi-Pyrénées	2.243
BE33	Belgium	Prov. Liège	2.246
FR71	France	Rhône-Alpes	2.251
DE93	Germany	Lüneburg	2.255
FR82	France	Provence-Alpes-Côte d’Azur	2.261
FR22	France	Picardie	2.263
ITH2	Italy	Provincia Autonoma di Trento	2.265
UKJ1	United Kingdom	Berkshire, Buckinghamshire and Oxfordshire	2.280
FI1B	Finland	Helsinki-Uusimaa	2.280
FR72	France	Auvergne	2.284
DEF0	Germany	Schleswig-Holstein	2.285
BE22	Belgium	Prov. Limburg (BE)	2.286

TABLE A.7 (continued)

NUTS Code	Country	Region	Technology gap
NL22	Netherlands	Gelderland	2.286
FR61	France	Aquitaine	2.318
DE94	Germany	Weser-Ems	2.331
FR63	France	Limousin	2.333
BE35	Belgium	Prov. Namur	2.337
ES30	Spain	Comunidad de Madrid	2.340
FR51	France	Pays de la Loire	2.356
NL12	Netherlands	Friesland (NL)	2.357
AT12	Austria	Niederösterreich	2.359
NL13	Netherlands	Drenthe	2.366
ES23	Spain	La Rioja	2.377
FR41	France	Lorraine	2.379
FR30	France	Nord - Pas-de-Calais	2.382
FI20	Finland	Åland	2.386
DED5	Germany	Leipzig	2.392
ITC4	Italy	Lombardia	2.398
FR81	France	Languedoc-Roussillon	2.399
BE32	Belgium	Prov. Hainaut	2.401
AT21	Austria	Kärnten	2.402
FR24	France	Centre	2.403
AT11	Austria	Burgenland (AT)	2.406
FR52	France	Bretagne	2.411
FR43	France	Franche-Comté	2.414
UKM5	United Kingdom	North Eastern Scotland	2.433
ES53	Spain	Illes Balears	2.437
UKJ2	United Kingdom	Surrey, East and West Sussex	2.439
FR53	France	Poitou-Charentes	2.440

TABLE A.7 (continued)

NUTS Code	Country	Region	Technology gap
FR25	France	Basse-Normandie	2.455
AT22	Austria	Steiermark	2.457
FR21	France	Champagne-Ardenne	2.464
SE33	Sweden	Övre Norrland	2.467
FR26	France	Bourgogne	2.474
SE22	Sweden	Sydsverige	2.476
DE40	Germany	Brandenburg	2.489
ITC3	Italy	Liguria	2.489
ES24	Spain	Aragón	2.489
UKD6	United Kingdom	Cheshire	2.489
ITH5	Italy	Emilia-Romagna	2.490
ES51	Spain	Cataluña	2.496
ES13	Spain	Cantabria	2.507
SE23	Sweden	Västsverige	2.543
SE32	Sweden	Mellersta Norrland	2.550
SE12	Sweden	Östra Mellansverige	2.575
UKJ3	United Kingdom	Hampshire and Isle of Wight	2.587
ITI4	Italy	Lazio	2.595
ITH4	Italy	Friuli-Venezia Giulia	2.598
DED2	Germany	Dresden	2.601
UKM2	United Kingdom	Eastern Scotland	2.608
UKH2	United Kingdom	Bedfordshire and Hertfordshire	2.618
IE01	Ireland	Border, Midland and Western	2.638
UKM6	United Kingdom	Highlands and Islands	2.640
DEE0	Germany	Sachsen-Anhalt	2.649
BE34	Belgium	Prov. Luxembourg (BE)	2.649
ITI1	Italy	Toscana	2.651

TABLE A.7 (continued)

NUTS Code	Country	Region	Technology gap
CZ01	Czech Republic	Praha	2.665
ITH3	Italy	Veneto	2.665
ES12	Spain	Principado de Asturias	2.673
UKK1	United Kingdom	Gloucestershire, Wiltshire and Bristol/ Bath area	2.687
UKJ4	United Kingdom	Kent	2.695
DEG0	Germany	Thüringen	2.697
ES41	Spain	Castilla y León	2.704
DED4	Germany	Chemnitz	2.717
UKG1	United Kingdom	Herefordshire, Worcestershire and Warwickshire	2.732
DE80	Germany	Mecklenburg-Vorpommern	2.739
FI1C	Finland	Etelä-Suomi	2.744
UKD1	United Kingdom	Cumbria	2.751
UKH3	United Kingdom	Essex	2.762
ES42	Spain	Castilla-La Mancha	2.765
FI19	Finland	Länsi-Suomi	2.774
ITF1	Italy	Abruzzo	2.784
ES11	Spain	Galicia	2.789
ITC1	Italy	Piemonte	2.792
ITF2	Italy	Molise	2.801
ES52	Spain	Comunidad Valenciana	2.805
EL30	Greece	Attiki	2.808
UKD7	United Kingdom	Merseyside	2.822
ITI3	Italy	Marche	2.839
ES43	Spain	Extremadura	2.847
UKM3	United Kingdom	South Western Scotland	2.874
FI1D	Finland	Pohjois- ja Itä-Suomi	2.880

TABLE A.7 (continued)

NUTS Code	Country	Region	Technology gap
ES62	Spain	Región de Murcia	2.889
UKD3	United Kingdom	Greater Manchester	2.904
UKE1	United Kingdom	East Yorkshire and Northern Lincolnshire	2.905
SE31	Sweden	Norra Mellansverige	2.913
UKC1	United Kingdom	Tees Valley and Durham	2.915
UKH1	United Kingdom	East Anglia	2.928
UKL2	United Kingdom	East Wales	2.939
SI04	Slovenia	Zahodna Slovenija	2.946
ES61	Spain	Andalucía	2.998
UKC2	United Kingdom	Northumberland and Tyne and Wear	3.017
UKF2	United Kingdom	Leicestershire, Rutland and Northamptonshire	3.024
UKD4	United Kingdom	Lancashire	3.029
SE21	Sweden	Småland med öarna	3.032
UKK2	United Kingdom	Dorset and Somerset	3.043
UKE4	United Kingdom	West Yorkshire	3.045
UKF1	United Kingdom	Derbyshire and Nottinghamshire	3.049
PL12	Poland	Mazowieckie	3.058
ITF5	Italy	Basilicata	3.062
PT17	Portugal	Lisboa	3.090
UKG2	United Kingdom	Shropshire and Staffordshire	3.098
ITG2	Italy	Sardegna	3.105
ITI2	Italy	Umbria	3.111
UKG3	United Kingdom	West Midlands	3.113
EL13	Greece	Dytiki Makedonia	3.125
PL41	Poland	Wielkopolskie	3.137
UKE2	United Kingdom	North Yorkshire	3.137

TABLE A.7 (continued)

NUTS Code	Country	Region	Technology gap
PL51	Poland	Dolnośląskie	3.137
UKK4	United Kingdom	Devon	3.140
HU22	Hungary	Nyugat-Dunántúl	3.212
UKN0	United Kingdom	Northern Ireland	3.231
CZ02	Czech Republic	Střední Čechy	3.235
UKF3	United Kingdom	Lincolnshire	3.240
UKE3	United Kingdom	South Yorkshire	3.245
UKK3	United Kingdom	Cornwall and Isles of Scilly	3.255
UKL1	United Kingdom	West Wales and The Valleys	3.261
ITG1	Italy	Sicilia	3.337
PL42	Poland	Zachodniopomorskie	3.341
PT18	Portugal	Alentejo	3.342
SK04	Slovak Republic	Východné Slovensko	3.344
PT15	Portugal	Algarve	3.344
ITF3	Italy	Campania	3.390
EL24	Greece	Sterea Ellada	3.391
SK02	Slovak Republic	Západné Slovensko	3.413
PL22	Poland	Śląskie	3.436
ITF4	Italy	Puglia	3.448
HU10	Hungary	Közép-Magyarország	3.474
SI03	Slovenia	Vzhodna Slovenija	3.514
EL42	Greece	Notio Aigaio	3.522
CZ08	Czech Republic	Moravskoslezsko	3.529
ITF6	Italy	Calabria	3.541
CZ06	Czech Republic	Jihovýchod	3.541
SK03	Slovak Republic	Stredné Slovensko	3.584
PL21	Poland	Małopolskie	3.607

TABLE A.7 (continued)

NUTS Code	Country	Region	Technology gap
HU21	Hungary	Közép-Dunántúl	3.612
EL22	Greece	Ionia Nisia	3.650
CZ03	Czech Republic	Jihozápad	3.825
PL52	Poland	Opolskie	3.843
EL12	Greece	Kentriki Makedonia	3.853
CZ07	Czech Republic	Střední Morava	3.854
PL43	Poland	Lubuskie	3.868
EL25	Greece	Peloponnisos	3.892
EL14	Greece	Thessalia	3.933
PL63	Poland	Pomorskie	3.977
HU31	Hungary	Észak-Magyarország	4.002
PT16	Portugal	Centro (PT)	4.007
CZ05	Czech Republic	Severovýchod	4.026
HU33	Hungary	Dél-Alföld	4.036
EL21	Greece	Ipeiros	4.066
EL41	Greece	Voreio Aigaio	4.073
EL11	Greece	Anatoliki Makedonia, Thraki	4.078
HU23	Hungary	Dél-Dunántúl	4.082
EL43	Greece	Kriti	4.184
HU32	Hungary	Észak-Alföld	4.208
LT00	Lithuania	Lietuva	4.222
PT11	Portugal	Norte	4.248
EL23	Greece	Dytiki Ellada	4.252
PL32	Poland	Podkarpackie	4.278
EE00	Estonia	Eesti	4.354
PL61	Poland	Kujawsko-Pomorskie	4.356
PL11	Poland	Łódzkie	4.606

TABLE A.7 (continued)

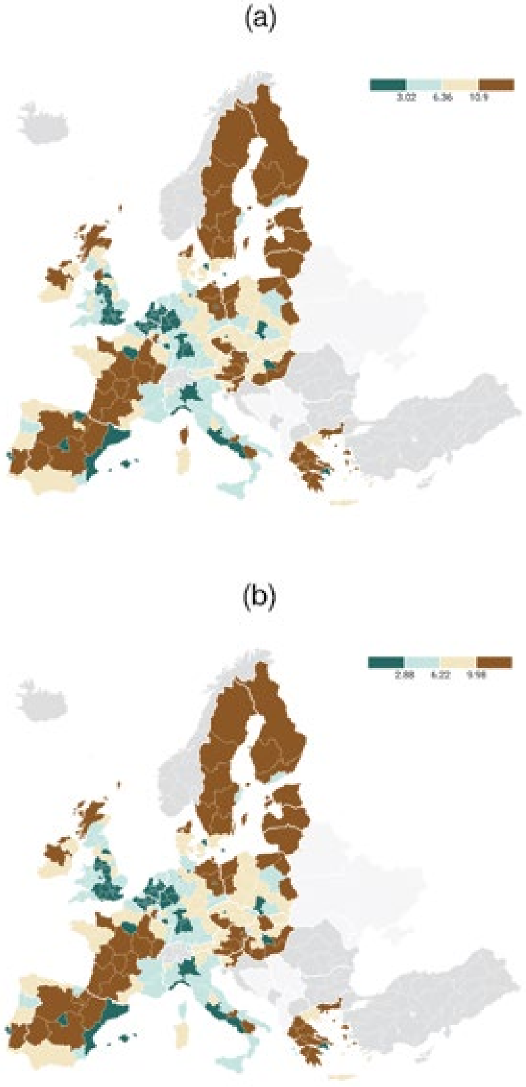
NUTS Code	Country	Region	Technology gap
PL62	Poland	Warmińsko-mazurskie	4.675
PL34	Poland	Podlaskie	4.955
CZ04	Czech Republic	Severozápad	4.997
LV00	Latvia	Latvija	5.350
PL33	Poland	Świętokrzyskie	5.390
PL31	Poland	Lubelskie	5.727

TABLE A.8
National shares of labour, 2009–2016

Country	2009	2010	2011	2012	2013	2014	2015	2016
Austria	0.581	0.577	0.571	0.579	0.583	0.578	0.574	0.576
Belgium	0.636	0.620	0.622	0.631	0.636	0.632	0.620	0.611
Czech Republic	0.506	0.511	0.512	0.522	0.524	0.510	0.506	0.517
Germany	0.621	0.609	0.610	0.620	0.621	0.619	0.617	0.615
Denmark	0.661	0.633	0.629	0.622	0.621	0.614	0.612	0.613
Estonia	0.649	0.601	0.569	0.578	0.579	0.585	0.602	0.610
Greece	0.549	0.552	0.534	0.508	0.486	0.493	0.489	0.499
Spain	0.608	0.606	0.601	0.582	0.577	0.576	0.580	0.577
Finland	0.613	0.603	0.606	0.620	0.616	0.609	0.601	0.595
France	0.628	0.628	0.627	0.632	0.632	0.633	0.628	0.630
Hungary	0.596	0.586	0.590	0.604	0.601	0.593	0.577	0.598
Ireland	0.513	0.486	0.466	0.455	0.453	0.432	0.331	0.339
Italy	0.530	0.527	0.525	0.530	0.525	0.522	0.522	0.521
Lithuania	0.532	0.495	0.472	0.465	0.468	0.475	0.501	0.522
Luxemburg	0.396	0.375	0.365	0.375	0.370	0.367	0.364	0.365
Latvia	0.584	0.560	0.507	0.513	0.530	0.545	0.567	0.588
Netherlands	0.597	0.585	0.587	0.591	0.588	0.588	0.577	0.583
Poland	0.571	0.573	0.562	0.562	0.561	0.558	0.548	0.560
Portugal	0.624	0.617	0.607	0.588	0.583	0.579	0.573	0.576
Sweden	0.561	0.542	0.548	0.564	0.566	0.562	0.548	0.550
Slovenia	0.664	0.671	0.659	0.661	0.648	0.638	0.635	0.642
Slovak Republic	0.565	0.546	0.540	0.538	0.542	0.550	0.559	0.568
United Kingdom	0.605	0.607	0.600	0.598	0.599	0.586	0.589	0.589

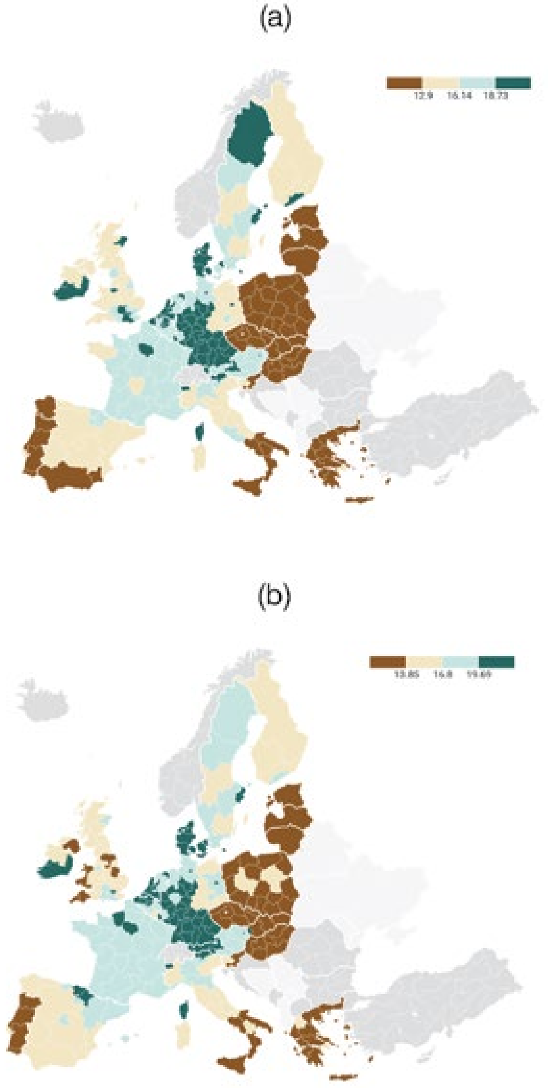
Source: Penn World Tables Database 9.1.

MAP A.1
Total developed land use per capita across EU regions in (a) 2009 and (b) 2015



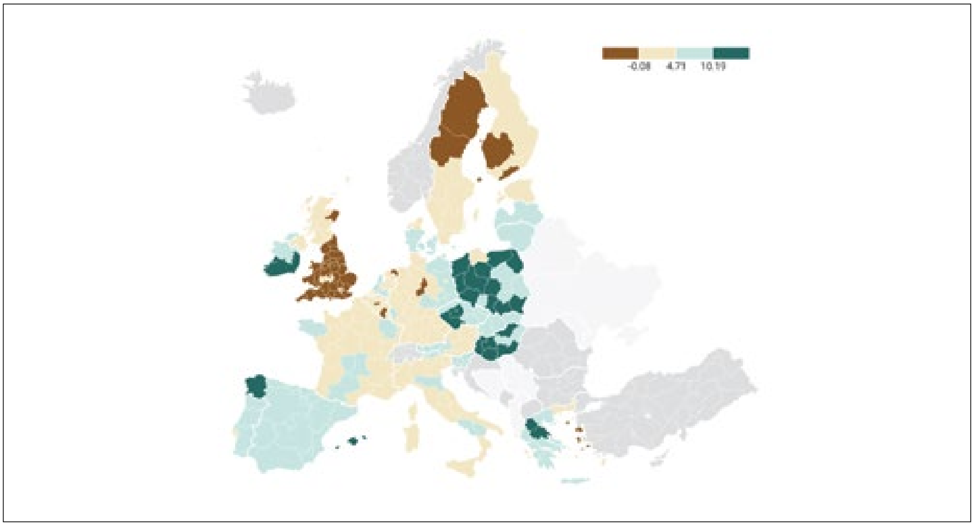
Note: Bin ranges correspond to the quartiles of the developed land per capita of EU regions in 2009 and 2015.

MAP A.2
TFP across EU regions in (a) 2010 and (b) 2016



Note: Bin ranges correspond to the quartiles of the distribution of regional TFP in 2010 and 2016.

MAP A.3
Average growth rates of TFP during the period 2010-2016



Note: The bin ranges are expressed here as ‘natural breaks’ according to the Jenks optimisation method (Jenks, 1967), which is a data clustering method designed to determine the best arrangement of values into different classes. This method minimises the average deviation of each class from the class mean, while it maximises the deviation of each class from the means of the other groups; hence, it reduces the variance within classes and maximises the variance between classes.

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