WIFO

ÖSTERREICHISCHES INSTITUT
FÜR WIRTSCHAFTSFORSCHUNG

WORKING PAPERS

# The EU 2020 Innovation Indicator

## A Step Forward in Measuring Innovation Outputs and Outcomes?

Jürgen Janger, Torben Schubert, Petra Andries, Christian Rammer, Machteld Hoskens

529/2016

WIFO

ÖSTERREICHISCHES INSTITUT FÜR WIRTSCHAFTSFORSCHUNG
AUSTRIAN INSTITUTE OF ECONOMIC RESEARCH

# The EU 2020 Innovation Indicator

## A Step Forward in Measuring Innovation Outputs and Outcomes?


### Jürgen Janger, Torben Schubert, Petra Andries, Christian Rammer, Machteld Hoskens



WIFO Working Papers, No. 529

October 2016



### Abstract

In October 2013, the European Commission presented a new indicator intended to capture innovation outputs and outcomes and thereby "support policy-makers in establishing new or reinforced actions to remove bottlenecks that prevent innovators from translating ideas into products and services that can be successful on the market". This paper aims to evaluate the usefulness of the new indicator against the background of the difficulties in measuring innovation outputs and outcomes. We develop a unique conceptual framework for measuring innovation outcomes that distinguishes structural change and structural upgrading as two key dimensions in both manufacturing and services. We conclude that the new indicator is biased towards a somewhat narrowly defined "high-tech" understanding of innovation outcomes. We illustrate our framework proposing a broader set of outcome indicators capturing also structural upgrading. We find that the results for the modified indicator differ substantially for a number of countries, with potentially wide-ranging consequences for innovation and industrial policies.



E-mail address: Juergen.Janger@wifo.ac.at


2016/327/W/0




Medieninhaber (Verleger), Hersteller: Österreichisches Institut für Wirtschaftsforschung • 1030 Wien, Arsenal, Objekt 20 • Tel. (43 1) 798 26 01-0 • Fax (43 1) 798 93 86 • http://www.wifo.ac.at/ • Verlags- und Herstellungsort: Wien

# The EU 2020 Innovation Indicator: A Step Forward in Measuring Innovation Outputs and Outcomes?

Jürgen Janger[c*], Torben Schubert[e,f], Petra Andries[a,b], Christian Rammer[d], Machteld Hoskens[b]

October 2016

*A slightly shorter version of this paper is soon to be published in **Research Policy**.*

**Abstract**

In October 2013, the European Commission presented a new indicator intended to capture innovation outputs and outcomes and thereby "support policy-makers in establishing new or reinforced actions to remove bottlenecks that prevent innovators from translating ideas into products and services that can be successful on the market". This article aims to evaluate the usefulness of the new indicator against the background of the difficulties in measuring innovation outputs and outcomes. We develop a unique conceptual framework for measuring innovation outcomes that distinguishes structural change and structural upgrading as two key dimensions in both manufacturing and services. We conclude that the new indicator is biased towards a somewhat narrowly defined "high-tech" understanding of innovation outcomes. We illustrate our framework proposing a broader set of outcome indicators capturing also structural upgrading. We find that the results for the modified indicator differ substantially for a number of countries, with potentially wide-ranging consequences for innovation and industrial policies.

**Keywords:** Innovation Output, Innovation Outcome, Innovation Measurement, Structural Change, Structural Upgrading, EU 2020 Strategy, Innovation Policy

**JEL-Classification:** O25; O31; O38; O52

[a] Ghent University, Dept. of Innovation, Entrepreneurship and Service Management, Ghent, Belgium
[b] KU Leuven, Centre for R&D Monitoring, Leuven, Belgium
[c] Austrian Institute of Economic Research (WIFO), Vienna, Austria
[d] Centre for European Economic Research (ZEW), Mannheim, Germany
[e] University of Lund, CIRCLE, Lund, Sweden
[f] Fraunhofer-Institute for System and Innovation Research (ISI), Karlsruhe, Germany

* Corresponding author: Jürgen Janger, WIFO, Arsenal 20, A-1030 Vienna, E-Mail: juergen.janger@wifo.ac.at

# 1 Introduction

In October 2013, the European Commission (EC) launched a new indicator (henceforth the EU 2020 Innovation Indicator) for measuring the EU's progress in meeting the goals of the Europe 2020 Strategy and its Innovation Union flagship initiative (European Commission, 2013). The EU 2020 Innovation Indicator is intended to measure innovation outputs and outcomes, complementing the headline R&D intensity indicator (R&D expenditures as a share of GDP) used so far for policy coordination. During the 2000s, this R&D intensity indicator strongly influenced research and innovation policy in Europe as the heads of state and government of EU member states agreed on a 3% target for this indicator at their Barcelona summit in 2002 (European Commission, 2002). Over time, both policy makers and researchers recognised that the R&D intensity indicator had certain limitations in order to serve as the main indicator to monitor improvements of the EU in becoming the most competitive knowledge-intensive society. On the one hand, industry structure strongly determines R&D intensity (Mathieu and van Pottelsberghe de la Potterie, 2010; Reinstaller and Unterlass, 2012), favouring countries with R&D-intensive industries. On the other hand, relying only on input indicators might result in overrating unproductive R&D investment (Edquist and Zabala-Itturiagagoitia, 2015).

The European Council tried to solve these problems and asked the EC to develop "*a new indicator measuring the share of fast-growing innovative companies in the economy*"[1] to add an output and outcome dimension to the input dimension already provided by the R&D intensity indicator. In the following two years, the Commission services experimented with different approaches to develop and measure such an indicator, consulting also with a "High Level Panel on the Measurement of Innovation" (2013) and finally presented the EU 2020 Innovation Indicator. It combines four individual indicators intended to measure innovation outputs and outcomes into a single composite indicator: (1) patent applications, (2) economic significance of knowledge-intensive sectors, (3) trade performance of knowledge-intensive

[1] Conclusion of 4/2/2011 (Council doc. EUCO 2/1/11 REV1).

goods and services and (4) significance of fast-growing firms in innovative sectors. The four individual indicators are also part of the Innovation Union Scoreboard (IUS, from 2016 on: European Innovation Scoreboard).

Since tools such as the EU 2020 Innovation Indicator are not only used as a purely informational basis but also feed into evidence-based policy advice, e.g. country specific recommendations within the Europe 2020 strategy or smart specialisation initiatives, the adequacy of the information provided becomes crucial. It is therefore critical to know whether the EU 2020 Innovation Indicator measures innovation outputs and outcomes without bias. This paper attempts to evaluate the EU 2020 Innovation Indicator against this policy background. We develop a conceptual framework of innovation outcomes at the sector level that distinguishes two types of innovation outcomes: (1) structural change towards knowledge-intensive sectors, and (2) structural upgrading, i.e. moving closer to the frontier[2] within existing sectors.

An illustrative empirical analysis using novel indicators for structural upgrading reveals that the EU 2020 Innovation Indicator is reasonably well reflecting processes of structural change while it does not appropriately address structural upgrading. The indicator therefore overrates countries specialised in knowledge-intensive sectors far from the frontier. With the same reasoning it underrates countries specialised in less-knowledge intensive sectors close to the frontier. In this respect, the EU 2020 Innovation Indicator solves only one of the two problems associated with the R&D intensity indicator. While it complements the input perspective with an outcome perspective, it also strongly focuses on the share of sectors classified as knowledge-intensive in the economy and tends to ignore actual innovation outcomes.

The paper is organised as follows: Section 2 develops a conceptual framework of innovation outcome measurement. Based on this framework, section 3 analyses the strengths and weaknesses of the new EU 2020 Innovation Indicator and compares the results of this

[2] We use the term “frontier” broadly in this paper, indicating the highest level of the concept of interest, such as knowledge intensity, quality, etc., referring to the performance of both manufacturing and services.

indicator with a more comprehensive outcome indicator that includes structural upgrading. In Section 4 we discuss the policy relevance of our findings and suggest ways for improving the measurement of innovation outcomes at the country level.

# 2 Measuring Innovation Outputs and Outcomes at the Country Level

## 2.1 Innovation Outputs vs. Outcomes

Traditionally, most attempts to measure innovation focused on innovation inputs, in particular R&D (see the Frascati Manual; OECD, 2015) and human resources for innovation (see the Canberra Manual; OECD and Eurostat, 1995). While these approaches have been by and large successful in terms of delivering comparable international data on the input side, comparable and reliable indicators on innovation outputs and outcomes at the country-level are still largely missing in spite of the efforts by the Oslo Manual (OECD and Eurostat, 2005) to harmonise measurement of innovation output and outcomes (see Godin, 2003, 2007; Freeman and Soete, 2009).

A starting point to derive country-level indicators of innovation outputs and outcomes is the literature on the innovation production function (e.g., Pakes and Griliches, 1984; Bernstein and Singh, 2006; Godin, 2007; Roper et al., 2008; Chen and Guan, 2011). In addition, stage process models from the evaluation literature (e.g., the logic chain model) try to identify critical areas of innovation performance measurement, including wider impacts of innovation on society and the economy (e.g. McLaughlin and Jordan, 1999).

Following this literature and the terminology of the Oslo Manual, firms can transform innovation inputs (e.g. R&D, human resources, research infrastructures and the stock of existing knowledge) in a first stage into intermediate outputs, such as patents, often referred to as throughputs (Grupp, 1997; Frietsch and Schmoch, 2006) and potentially[3], in a second stage, into innovation *outputs*. They refer to the direct results of innovative efforts of economic actors. This is typically the introduction of an innovation on the market (product

[3] Not all patents are used for the introduction of innovations (section 3.1).

innovation, marketing innovation) or in the economic actor's operation (process innovation, organisational innovation). Typical measures of innovation output are counts of product and process innovations (see Geroski, 1994) or the share of firms that have introduced innovations.

Innovation *outcomes* are the consequences of the introduction of innovations, among them the economic effects of innovation outputs on the firms introducing them. Introducing an innovation and even less so applying for a patent does not automatically have economic effects. A product innovation, for example, needs to be sold to users, and a process innovation must lead to significant changes in cost or other production related inputs in order to generate economic effects. Linked to these potential firm-level outcomes are economy-wide outcomes, also called impacts, resulting from the diffusion of an innovation from the firm and sector where the innovation originated onto other industries and finally the economy as a whole (see the seminal work by Rogers, 2003, on the diffusion of innovations). These outcomes also include non-economic ones, e.g. health benefits of new medical equipment. In the present paper, we refer to the economic consequences of all four types of innovation output identified by the Oslo Manual (product, process, marketing, organisational), in line with the scope of the EU Innovation Indicator. Figure A1 in the Appendix provides a graphical presentation of this input-output framework.

While the EU 2020 Innovation Indicator is a systematic attempt to provide internationally comparable data on the output and outcome dimension of innovation, it has important limitations. First, while the EU 2020 Innovation Indicator tries to address innovation outputs, it does so only based on patent data which reflect the output of R&D processes but should, for several reasons discussed below, not be equated with innovation output. Second, we will argue that the EU 2020 Innovation Indicator adopts a "high-tech" view on innovation because the three indicators relating to innovation outcomes (significance of knowledge-intensive sectors, the competitiveness of knowledge-intensive goods and services, and the significance of fast-growing firms in innovative sectors) mainly attempt to measure structural change of economic activity towards predefined sectors with high knowledge intensity. The sole focus on such sectors, however, neglects innovation outcomes of firms in less-knowledge-intensive sectors that may lead to an upgrading of such sectors and may improve economy-wide performance substantially. It also neglects actual innovation outcomes in knowledge-intensive sectors as we don't know, e.g., whether fast-growing firms in these sectors achieved their growth because of innovation.

## 2.2 Innovation outcomes: structural change vs. upgrading

Economic effects of innovation have often been related to the degree of novelty of innovations, with scholars distinguishing between "radical" innovations, describing completely new goods and services or production processes, and "incremental" innovations, relating to performance improvements of existing goods and services or production processes which do not fundamentally alter their characteristics (e.g., Dosi, 1982; Freeman and Soete, 1997). More radical innovation may lead to higher productivity and growth effects as a higher degree of novelty can potentially allow for a more substantial change in production methods or performance characteristics of new goods and services. Radical innovation may also mobilise new demand by offering entirely new applications. If radical innovations indeed generated superior economic effects, the measurement of innovation outcomes would need to focus on capturing the degree of novelty of innovations which is difficult. Quantifying the radicalness of innovation —or its degree of novelty— remains a substantial challenge for empirical research.[4]

Interestingly, Saviotti and Metcalfe (1984) argued that radical technical changes do not necessarily lead to radical innovations in terms of how product features change. For example, the change from propeller to jet aircraft technology provided only incremental service improvements in terms of faster travel times while incremental technical changes can lead to radical innovations in terms of the services they provide to users, such as the Smartphone

[4] Efforts include (a) "the objective approach", technometrics or literature-based measures of novelty, which are based on information from technical and trade journals (Grupp, 1994; Kleinknecht and Reijnen, 1993; Coombs et al., 1996), and (b) "the subjective approach", surveying firms about novelty as outlined in the Oslo Manual and applied in the Community Innovation Surveys. The Oslo Manual sets a threshold level for a change to count as an innovation by referring to the concept of "significant improvement". Beyond that, it distinguishes between innovations which are "new to the firm", "new to the market" and "new to the world". While the first approach is cumbersome and barely works for services, the second is a subjective assessment which has been shown to vary with the level of development of countries or markets (see Knell and Srholec, 2009).

(Vogelstein, 2013)[5]. In terms of innovation outcomes, incremental innovations may hence be as important as radical ones. A large variety of literature provides support for this view. While the focus of the early innovation literature was clearly devoted to radical innovations (Schumpeter, 1961; compare also Smith, 2005), the importance and frequent occurrence of incremental innovations has inter alia been outlined by Kline and Rosenberg (1986) and Lundvall (2010), not least because they mirror trends in both competition strategy and growing complexity of knowledge bases.

First, in countries close to the frontier, innovation is the dominant business strategy for many firms, and innovation processes become routine elements of firm activities (Hölzl and Janger, 2014). Increasing competitive pressure by low-cost firms may lead to upgrading of existing products and processes (Bloom et al., 2016). In many mature industries, radical innovation by incumbents could endanger their return on large sunk investments, with successful innovations mainly replacing the incumbent's old profit position (Arrow, 1962, Reinganum 1983), so that moving forward by small steps may be the rational competitive strategy.

Second, the growing complexity of knowledge leads to an increasing specialisation of firms on core competencies, in turn contributing to increased path-dependency of technological progress at the firm level. Firms usually learn along their cumulative knowledge bases, guided by firm-specific routines (see Dosi and Nelson, 2010, for a recent survey), and this results rather in incremental than radical innovation (Pavitt, 2005).[6]

A focus on the measurement of the economic effects of radical vs. incremental innovations may hence be of limited relevance. Therefore, we conclude that capturing innovation outcomes at the firm level according to novelty should not be a main requirement for

[5] Radical and incremental changes can also be intertwined. The accumulation of incremental improvements over time may eventually constitute a radical (technological) innovation (e.g. as in the case of spark generators, the weight of which was reduced from 118kg to 2kg over a span of 30 years), while subsequent incremental (technical) innovations may be necessary for a preceding radical (technical) innovation to create radical new service characteristics (e.g., as in the case of Teflon; see Kline and Rosenberg, 1986).

[6] "It is precisely the paradigmatic cumulative nature of technological knowledge that accounts for the relatively ordered nature of the observed patterns of technological change… [ ] technological search processes in each firm are cumulative processes too. What the firm can hope to do technologically in the future is narrowly constrained by what it has been capable of doing in the past" (Dosi, 1988, p. 1129f.).

indicators measuring such outcomes. Instead, we see more potential for identifying and measuring innovation outcomes at the industry level. Dosi (1988) calls the economic effect of innovations an asymmetry-creating effect which will improve the competitive position of a firm, e.g. through lower prices or better goods and services. Dosi (1988) notes as a result that industrial structure is endogenous to innovative activity, i.e. that outcomes of innovation are reflected in changes of industry structure. From a measurement perspective, we propose that there are two possible ways for innovation outputs to show up in outcomes at the sector level of both manufacturing and services, i.e. as economic benefits of innovation. The first, which we call **structural change**, reflects a differential growth of value added across industries, away from industries with lower levels of knowledge intensity to industries with higher intensity. By such a change, the share of output in knowledge-intensive industries in an economy's total output will increase.

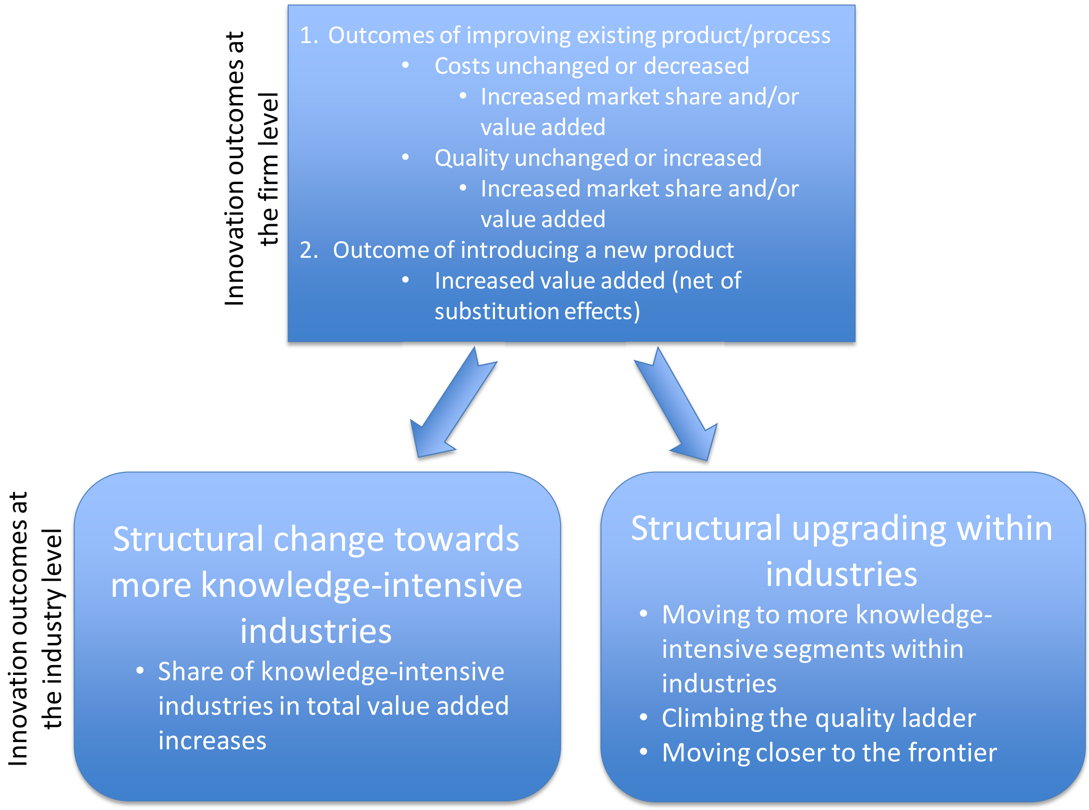
The second, which we call **structural upgrading**, features differential performance of firms within industries without necessarily changing the overall composition of economic activities. This differential performance may be reflected in moving to more knowledge-intensive activities within a sector, thereby preserving or reinforcing existing competitive advantages. Dosi (1988) has conceptualised this intra-sectoral movement of firms through innovation in terms of changing distances to the frontier at the firm level. Such upgrading may not necessarily be reflected in differential value added growth at the firm level. Instead, its economic benefit may consist in increasing the quality of goods and services to be able to hold market shares and prices constant when confronted with low-cost competition or in keeping costs down to stay competitive in spite of higher wages paid to a firm's workforce.

A simple conceptual model can illustrate both channels (see Figure 1, a more formal version is presented in the Appendix, Figure A2). The model starts with innovation outcomes at the firm level, which result from the characteristics of innovation outputs.[7] On the one hand, changes to existing processes can decrease a firm's production costs. This either allows to reduce costs relative to competing firms or to keep them constant relative to competitors that

[7] For brevity, we only mention product and process innovation, but the model works equally for marketing and organisational innovation.

are also trying to reduce costs. Depending on the amount of relative cost reduction and the ensuing price setting, value added and market shares generated by a firm's goods and services may remain unchanged or may increase.[8] On the other hand, innovations can also change existing product quality, keep product quality unchanged relative to competitors or increase it, with impacts on value added or market shares as a function of corresponding price setting. In addition, a new successful product can increase value added (net of any substitution effects with the older product).

**Figure 1: Innovation outcomes at the firm and the industry level: a conceptual model**



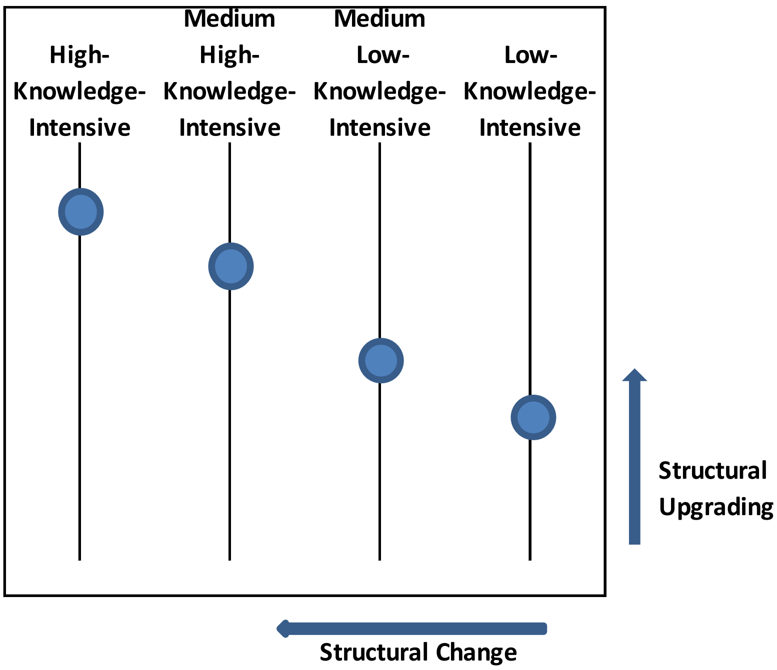

Source: Authors' own presentation.

[8] "Whenever at any time a given quantity of output costs less to produce than the same or a smaller quantity did cost or would have cost before, we may be sure, if prices of factors have not fallen, that there has been innovation somewhere" (Schumpeter, 1939, p. 89, as cited by Godin, 2007, p. 1390).

These outcomes of innovations at the firm level translate either into economic effects of innovation changing the sector composition of activities (structural change through higher value added growth of industries characterised by high knowledge intensity relative to industries showing lower knowledge intensities) or change the intra-sector composition of activities by moving towards segments of higher knowledge intensity within the same industry (structural upgrading).

Both outcomes, structural change and upgrading, are shown schematically in Figure 2. Industries from either manufacturing or services are roughly classified in four broad groups by knowledge intensity. The circle for each group represents its average knowledge intensity, going from low intensity, on the right, to high intensity, on the left. Within each of the groupings, firms can be more or less knowledge-intensive, or display varying distances to the frontier in each grouping, sliding up or down the vertical axis. Structural upgrading (SU) then occurs when firms (and consequently industries composed of those firms in a country) move upward on the vertical axis. Structural change (SC) occurs when there is a horizontal move, from industries with lower levels of knowledge intensity, towards industries with higher knowledge intensity.

**Figure 2: Schematic display of structural change and upgrading**




Source: Authors' own presentation.

While radical innovations may be more likely than incremental innovations to trigger structural change, Figure 1 and 2 show that structural change can well be the result of incrementally improving products and processes, e.g. when the firm is already active in a very knowledge-intensive industry (e.g. iterations of the latest Smartphone). On the other hand, a radically new product in a less knowledge-intensive sector may merely prevent the decline of the industry (see, e.g. the development of breathable and waterproof textiles). Put differently, developments along a technological trajectory may not only lead to structural upgrading but also to structural change at the industry level, while a new technological paradigm may not necessarily initiate structural change towards more knowledge-intensive industries.

Policymakers often focus on increasing the share of knowledge-intensive goods and services in the economy (structural change), as evidenced by what some call the competitiveness-induced “obsession” with “high-technology” goods and services (see Godin, 2004). Empirical evidence however shows that structural upgrading as an outcome of innovation is equally relevant for economic performance. Kline and Rosenberg (1986) point to the example of the US electric power generation industry which achieved high rates of productivity growth without introducing any single major innovation but by constantly upgrading in the form of slow, cumulative improvements in the efficiency of centralised thermal power plants[9]. Robertson et al. (2009) observe that the development of both higher-quality products and new products can offset the maturation of older industries, limiting declines in demand for goods and services of low knowledge-intensity sectors. A firm-level analysis of the global paper industry by Ghosal and Nair-Reichert (2009) finds that the impact of investments in modernisation builds up over time to create significant performance differences with respect to firms’ productivity and competitive position. The empirical literature agrees that innovation outputs significantly influence economic performance in all industries, including less knowledge-intensive ones, either through product differentiation or cost reduction (Peneder, 2010; Kirner et al., 2009).

[9]“… it is a serious mistake (increasingly common in societies that have a growing preoccupation with high technology industries) to equate economically important innovations with that subset associated with sophisticated technologies” (Kline and Rosenberg, 1986, p. 278).

Also the international trade literature provides evidence on the importance of structural upgrading. In Grossman and Helpman's (1991) North-South trade model, every traded product is positioned on a "quality ladder". Its production will move to the 'South' once the 'South' is able to imitate its technology. As a result, firms from the 'North' are forced to innovate and bring out the next generation of higher quality products in order to escape low cost competition. The empirical trade literature confirms this effect as advanced countries try to cope with the adjustment pressure from rising emerging economies (see, e.g., Schott, 2008; Martin and Mejean, 2014). Bloom et al. (2016) show that Chinese import competition led to two distinct effects among European firms. A "within"-effect increases productivity at the firm level and a "between"-effect reallocates employment towards more innovative and technologically advanced firms. In summary, the available evidence points to the fact that both structural change and upgrading at the industry level are important types of innovation outcomes.

### 2.3 Measuring structural change and structural upgrading

The measurement of outcomes of innovation at the industry level has several benefits in comparison to measuring outputs or outcomes at the firm level. One is that spillover effects can be captured, i.e. the spread of benefits from the innovating firm to other firms, possibly located in different industries. A general framework of structural change and upgrading is in principle able to capture innovation outcomes wherever they originated, in both manufacturing and services and irrespective of the type of innovation (product, process, marketing or organisational). Measuring outcomes rather than outputs also alleviates the problems related to identifying an innovation's degree of novelty. Eventually, from an economic perspective, the degree of novelty of an individual innovation – be it related to technological or service characteristics - matters less than the economic benefits of this innovation.

There are a variety of indicators to measure the extent of structural change towards sectors with higher knowledge, R&D or innovation intensity (e.g., Peneder, 2010; Hatzichronoglou, 1997; and Godin, 2004, for a survey). The most common approach is to calculate an international average of knowledge intensity for each sector and then determine the shares of knowledge-intensive sectors in national output. The fragmentation of international value chains particularly in manufacturing may however produce misleading results (Janger et al., 2011). As the knowledge intensity of industries is calculated on international averages rather than on country-specific data, a country can have high shares in knowledge-intensive sectors even when it hosts only less knowledge-intensive parts of the value chain, such as final assembly (an example being Hungary; see also Srholec, 2007). The fragmentation of the value chains then penalises countries specialised in the high quality or knowledge-intensive segments of less knowledge-intensive sectors (e.g., Austria and Italy).

Upgrading indicators can correct for this bias by showing a country's position in different knowledge intensity or quality segments within industries, but they are more difficult to build. So far, the most commonly used survey-based indicator which could be regarded as an indicator for structural upgrading is the sales share of product innovations (when weighted by industries' shares in total output). This indicator has been used both in analyses of sector and country innovation performance (particularly by the Innovation Union Scoreboard, see European Commission, 2014) and in firm-level studies of innovation performance (Mairesse and Mohnen, 2002; Laursen and Salter, 2006; Leiponen and Helfat, 2010; Klingebiel and Rammer, 2014). Interestingly, the EU 2020 Innovation Indicator refrained from adopting this indicator for measuring innovation output, presumably due to reservations about its reliability: while the sales share of product innovations is useful to quantify the outcome of a firm's (product) innovation efforts, comparability across firms, sectors and countries is limited (Kleinknecht et al., 2002; Knell and Srholec, 2009; Rammer et al., 2009). First, perceptions by firms of what constitutes an innovation and how novel it is may differ. While firms from countries at the frontier of technological change and innovation are likely to apply higher standards for changes to products in order to qualify as innovations, firms from catching-up countries may regard the adoption of a standard product as an innovation if that product has not been offered on their market yet. In addition, the concept of new-to-market innovations, which is frequently surveyed as a qualifier of product innovation,[10] is also a problematic one since firms may refer to very different geographic and product markets when reporting market

[10] Innovation surveys of the CIS-type usually collect information on the introduction of product innovations, followed by separate questions on the degree of novelty, using new-to-market vs. only new-to-firm as the main novelty dimension.

novelties. Second, comparison between industries is complicated by the fact that the sales share of new products is strongly driven by product life time. For this reason, the first and second edition of the Oslo Manual suggested collecting data on the average or typical length of the product life in order to control for this interference, but only a few innovation surveys implemented this idea. Potentially related to life-cycle aspects, but also to changing perceptions of innovativeness and technical survey issues such as sampling, the indicator is also quite volatile.

Janger et al. (2011) suggest two outcome indicators on structural upgrading that are not based on firm survey data: one measuring "export quality", i.e. the share of low-, medium- and high-quality exports of an industry (manufacturing only), and the other measuring R&D intensity of countries by correcting for industrial structure of both manufacturing and services. The first is now becoming more commonplace in different methodologies (e.g. Vandenbussche, 2014). "Export quality" is measured by unit values of exports (price per unit of weight). This proxy has certain shortcomings (see Aiginger, 1997, for a discussion). But all in all, higher shares in the higher quality segment should indicate innovation outcomes or commercial success of innovations, as innovations change the competitiveness of goods through changes of cost and quality, as outlined in section 2.2. The second indicator, R&D intensity of a country's business sector corrected for industrial structure, is not per se an outcome indicator. However, knowing whether a country —relative to an average of R&D intensive benchmark countries— is R&D intensive or not given its industrial structure, allows for an assessment of its position on the segments of an industry in terms of its knowledge intensity. This indicator can also be used as a weighting scheme for structural change indicators (Reinstaller and Unterlass, 2012), adding an outcome dimension. As such, it could serve as a proxy for an outcome indicator when used in conjunction with structural change indicators. Both indicators empirically perform well in explaining performance differences between countries, complementing the information obtained from structural change indicators.

In the following section, we will discuss the new EU 2020 Innovation Indicator against the background of our framework. As a takeaway, lack of differentiation between radical and incremental innovation should not overly matter if one is more interested in the economic effects of innovation, but any indicator trying to capture outcomes should integrate dimensions of structural change and upgrading. We will now continue with presenting the EU

2020 Innovation Indicator in more detail and assessing to which extent its measurement approach takes into account the conceptual consideration presented in this section.

# 3 Assessment of the EU 2020 Innovation Indicator and a Proposal for a Modified Indicator

## 3.1 The EU 2020 Innovation Indicator

The EU 2020 Innovation Indicator is a composite indicator that consists of four components intended to measure different aspects of innovation outputs and outcomes: patent applications, economic significance of knowledge-intensive sectors, trade performance of knowledge-intensive goods and services, and employment in fast-growing firms in innovative sectors. These indicators have been proposed by a High Level Panel on the Measurement of Innovation (2013). A fifth indicator recommended by the High Level Panel —labour productivity— has not been included in the EU 2020 Innovation Indicator, mainly because of a perceived too weak link between productivity and innovation outcome. A detailed description of each indicator and technical details on how the composite indicator is calculated can be found in Vértesy and Tarantola (2014). In the following, we assess the four components of the indicator with respect to the types of innovation output and outcome they represent.

The first component is the number of PCT patent applications[11] per billion GDP (PCT). It has become very common in large parts of the innovation literature to use patents as proxy for innovation output (among many others see Acs and Audretsch, 1989; Crépon et al., 1998; Bronzini and Piselli, 2016), partly because of the broad international availability of patent data. Nonetheless, treating patents as innovation outputs is conceptually problematic. In fact, already in their foundational paper, Griliches and Pakes (1980) were very explicit that patents are proxies for knowledge and thus often closely linked to knowledge generating processes

[11] Applications filed under the Patent Cooperation Treaty (PCT) which name the European Patent Office as designated office in the international phase of the application procedure.

such as R&D. Yet, they need not be very informative about innovation output for many reasons.

For example, patents may not lead to actually implemented innovations as they may merely be used to impede innovations by competitors (Blind et al., 2006; Moser, 2013; Hall and Ziedonis, 2001). As a consequence, patent counts can overestimate innovation output, because patented technologies are not always brought into use. At the same time, large parts of innovation outputs are not patentable at all, leading to potential downward biases when measuring innovation output by patents only (Arundel and Kabla, 1998). Several authors show that downward biases are particularly strong in sectors with low propensities to patent, such as services (Scherer, 1983; Arundel and Kabla, 1998; Brouwer and Kleinknecht, 1999).

The choice of measuring innovation outputs via patent data therefore implies conceptual problems. In particular, patents reflect knowledge related throughputs rather than innovation output. In our context of measuring innovation outcomes, patents are also likely to entail further measurement problems because patenting propensities differ considerably by sector, with high propensities found in particular in high-technology manufacturing. Using patents therefore reinforces a bias towards technology-driven sectors. Beyond this general bias, the patent component of the EU 2020 Innovation Indicator induces a further bias, because it reflects the development of inventions to be used on global markets by focusing on PCT patents. In many industries, and particularly in SMEs, innovations are not targeted towards global but rather to national or regional markets. As a result, firms often seek patent protection at national patent offices and do not go through a costly PCT application process. The current PCT component of the EU 2020 Innovation Indicator hence does not capture innovation throughputs targeted at these national or regional markets.

The second component measures the share of employees in knowledge-intensive industries in total business enterprise sector employment (KIA). Knowledge-intensity of industries is measured for Europe as a whole rather than based on country-specific data, using one third of employees having a higher education degree as a threshold. As a result, countries can only improve their score on this indicator by employing more people in a pre-specified set of knowledge-intensive industries. Increased employment in sectors that are not regarded as knowledge-intensive will lead to a decreased score even if this increased employment is due to significant investments in innovation.

The third component should represent the competitiveness of knowledge-intensive goods and services by evaluating trade performance (COMP). It consists of two sub-components, the share of medium-high and high-tech goods in total exports (GOOD) and the share of knowledge-intensive services in the total service exports (SERV), again applying the same definition of medium-high and high-tech goods and knowledge-intensive services for all countries. Both components receive equal weights to calculate a single indicator. This implies that a country's specialisation on either services or manufacturing is not considered. Moreover, as with the indicators on the employment share in knowledge-intensive sectors, the innovativeness of exports is determined through international averaging, so that it is not known for a specific country how knowledge-intensive the goods and services in question really are. For example, high-tech goods are identified through international classifications, rather than through real information on the knowledge content of country exports. Note that countries with a high share of tourism services exports will also be penalised, as any knowledge-intensive services will get a comparably lower score, even if e.g. the share of knowledge-intensive services in GDP between two countries was the same.

The fourth component should represent dynamism and reflects the employment in fast-growing firms from innovative sectors (DYN). Three types of information are combined: the innovativeness of a sector, the knowledge intensity of that sector, and the number of employees in fast-growing firms in that sector as a percentage of total sector employment. Both innovativeness and knowledge intensity of sectors are measured at the European level. Fast-growing firms are firms with ten or more employees and an average employee growth of 10% per year over three years. Again, countries can only improve their score on this indicator through fast-growing firms in sectors that are, on average across countries, highly innovative. This is the case even if the local firms in that sector are not at all innovative. Similarly, highly innovative, fast-growing firms in sectors which are on average in the EU less innovative will not lead to a higher score.

Three components (KIA, COMP, DYN) reward countries that reallocate resources to a pre-specified set of knowledge-intensive, innovative sectors which are the same for all European member states. As such, these components are indicators of structural change, i.e. of the reallocation of economic activities away from industries with lower levels of knowledge intensity to industries with higher knowledge intensity. They fail to capture path dependent evolutions and structural upgrading in sectors that are on average less innovative and less knowledge-intensive, but that may be crucial for the economic development of a country or region. They also fail to spot country differences in actual innovation outcomes of sectors classified as knowledge-intensive.

This measurement approach is not in line with the European Commission's new policy concept of "smart specialisation", the goal of which is to boost regional innovation and economic growth by enabling regions or countries to focus on their relative strengths. A smart specialisation reasoning argues that a region or country (a) should not spread its scarce resources over a too wide range of activities, and (b) should diversify not by focusing on the same 'popular' activities as other countries (cf. the vast number of regions attempting to become world class biotech players), but by instead building on its own relative strengths. The three last components of the EU 2020 innovation indicator fail to capture such specialisation efforts in established sectors, inciting all regions and countries to reallocate their resources and activities to the exact same set of sectors. We can conclude that the four components of the EU 2020 indicator provide a rather limited coverage of the range of innovation outputs and outcomes discussed in section 2.

As an empirical illustration of the issues arising from focusing on structural change, Table 1 shows countries' shares of value added in knowledge-intensive manufacturing industries[12] and of employment in knowledge-intensive activities (KIA) as defined above (including both manufacturing and services) along with the EU 2020 Innovation Indicator rank and GDP per capita. We show two different industry classifications because some countries such as Luxembourg, the UK and Cyprus achieve very high shares in KIA mainly due to a (less R&D intensive) large financial services sector (also contributing to their SERV score), whereas other countries such as Hungary, Slovakia and the Czech Republic achieve relatively large shares of R&D intensive technology-driven manufacturing industries due to their integration

[12] We use an updated version of the classification developed by Peneder (2002) which is based on a cluster analysis of economic variables (labour intensity, capital intensity, advertising sales ratio, R&D sales ratio) obtained from the US manufacturing industry in the period 1990-1995. "Technology oriented" manufacturing industries include chemicals and biotechnology; new information and communication technologies; and vehicles for transport. We obtain similar results when using the OECD's high-tech classification (Hatzichronoglou, 1997).

in global value chains of innovation-intensive industries such as automobiles (affecting also their DYN and GOOD scores).[13]

**Table 1: Sector specialisation in knowledge-intensive industries, EU 2020 Innovation Indicator rank and GDP per capita, sorted by GDP per capita, 2012**

| | Employment share of education intensive sectors in total economy (KIA), in % | Value added share of technology-driven industries in manufacturing, in % | EU 2020 Innovation Indicator Rank | GDP per capita in PPS (EU28=100) |
|---|---|---|---|---|
| Luxemburg | 25.4 | 1.0 | 4 | 264 |
| Netherlands | 15.2 | 13.4 | 10 | 133 |
| Ireland | 20.1 | 56.9 | 3 | 130 |
| Austria | 14.2 | 13.8 | 9 | 129 |
| Sweden | 17.6 | 21.7 | 2 | 126 |
| Denmark | 15.5 | 25.7 | 6 | 125 |
| Germany | 15.8 | 24.9 | 1 | 123 |
| Belgium | 15.2 | 20.4 | 11 | 120 |
| Finland | 15.5 | 7.1 | 5 | 116 |
| UK | 17.8 | 22.6 | 7 | 107 |
| France | 14.3 | 22.6 | 8 | 107 |
| Italy | 13.2 | 13.2 | 17 | 101 |
| *EU28* | *13.9* | *20.0* | | *100* |
| Cyprus | 16.9 | 7.5 | 18 | 94 |
| Spain | 11.9 | 13.5 | 21 | 94 |
| Malta | 17.0 | 0.0 | 16 | 85 |
| Slovenia | 14.1 | 16.2 | 14 | 82 |
| Czech Republic | 12.5 | 15.4 | 13 | 82 |
| Portugal | 9.0 | 7.5 | 24 | 76 |
| Greece | 12.3 | 5.9 | 23 | 74 |
| Slovakia | 10.1 | 15.2 | 15 | 74 |
| Estonia | 10.8 | 4.8 | 19 | 71 |
| Lithuania | 9.1 | 3.3 | 28 | 69 |
| Poland | 9.7 | 9.4 | 20 | 66 |
| Hungary | 12.5 | 23.8 | 12 | 65 |
| Croatia | 10.4 | 8.7 | 25 | 61 |
| Latvia | 10.3 | 0.9 | 27 | 60 |
| Romania | 6.5 | 6.4 | 22 | 53 |
| Bulgaria | 8.3 | 6.6 | 26 | 45 |

Source: Eurostat, European Commission.

Comparing the EU innovation indicator rank and GDP per capita leads to a couple of observations:

[13] R&D intensity in financial services in the UK was 0.3% in 2013, compared with 4.4% in total manufacturing, based on OECD MSTI data.

- Some countries with relatively large shares of knowledge-intensive sectors (e.g., catching up countries such as Hungary, Slovakia, Czech Republic, in technology-driven manufacturing, but also advanced countries such as the UK, in education-intensive sectors) achieve relatively high innovation scores compared with their level of GDP per capita.
- Some countries with relatively lower shares of knowledge-intensive sectors achieve better GDP per capita compared with their scores (e.g., Spain, Italy, Portugal, but also the Netherlands and Austria, in particular in technology-driven manufacturing).

High shares of knowledge-intensive sectors have been shown to be associated with GDP levels and growth (e.g. Peneder, 2003), so policy-wise the second group of countries should clearly be very worried. Given that markets are open and globally competitive, one wonders how these countries achieve their GDP performance given their low average innovation scores and relatively high wages. We suspect that in some instances, the first group of countries may not be at the top end of quality ladders (with the exception possibly of countries benefitting from large financial services sectors), or further away from the frontier in knowledge-intensive sectors, while in the second group, countries are closer to the frontier in less knowledge-intensive sectors.

### 3.2 A modified version of the EU 2020 Innovation Indicator

In the preceding sections we argued that the EU 2020 Innovation Indicator has a strong focus on structural change as a mechanism for promoting innovativeness at the country level, while it neglects structural upgrading. In order to illustrate our framework, we compare the EU 2020 Innovation Indicator with an indicator, called the SU indicator in what follows. Out of the three indicators of structural upgrading we outlined in section 2.3 we chose (1) the export quality and (2) the sector-adjusted R&D intensity.[14] We then present the results for a modified EU 2020 Innovation Indicator which is calculated as the arithmetic average of the four

[14] More details on how the two structural upgrading indicators are calculated are provided in the Appendix.

indicators used in the EU 2020 indicator and the two indicators of the SU indicator.[15] If our arguments are valid, we should observe that countries with a focus on sectors classified through international averaging as knowledge-intensive perform better in the EU 2020 Innovation Indicator than in the modified version when they are further away from the frontier in these sectors.

Table 2 shows the country values for the two upgrading indicators outlined in section 2.3[16], next to the four components of the EU 2020 Innovation Indicator. We see that some countries with relatively high or close to average shares of knowledge-intensive sectors show very negative values in the indicator for sector-adjusted R&D intensity, implying that they are active in the less knowledge intensive segments of these activities, possibly focusing on product assembly (e.g. Hungary, Czech Republic, Slovakia or Malta).[17] Some countries with relatively lower shares of knowledge-intensive sectors show less negative adjusted R&D intensity (e.g., Portugal, Spain, Italy) than the group above, others even very positive values, implying specialisation in the top R&D-intensive segment of less knowledge-intensive sectors (e.g., Austria, Belgium, Netherlands). In export quality as well, countries such as Italy achieve a higher value than countries such as Luxemburg and the Czech Republic which are above Italy in the EU 2020 Innovation Indicator. Some top performers such as Denmark and Sweden are good in all indicators, suggesting that they are both specialised in knowledge-intensive industries as well as at the top of the quality ladders within those activities.

Figure 3 compares the SU indicator, built as a linear average of the export quality indicator and the sector-adjusted R&D expenditures, with the linear average of the four components of the EU 2020 Innovation Indicator. The left panel of Figure 3 shows differences in ranks resulting from their values, as the ranks are often the most important policy information

[15] As the focus of the current paper is more conceptual, we will not go into the issue of weights used in composite indicators, and will use one of the simpler weighting methods. The problem of weights used in composite indicators has been discussed elsewhere (e.g., Grupp and Schubert, 2010)

[16] It should be noted that some data problems are present in our analyses. In small countries, small export volumes reduce the robustness of export quality data (e.g., Cyprus, Malta). For Ireland and Croatia, sector-adjusted R&D data are not available. We are very grateful to the authors of the cited papers for providing us with the data, in particular Irene Langer, Susanne Sieber and Fabian Unterlass.

[17] We refer again to the two taxonomies used in table 1, “KIA” and the technology-driven manufacturing sectors.

triggering further analysis.[18] Countries with a negative score on Figure 3 have a lower ranking according to the EU 2020 Innovation Indicator than according to the SU indicator.

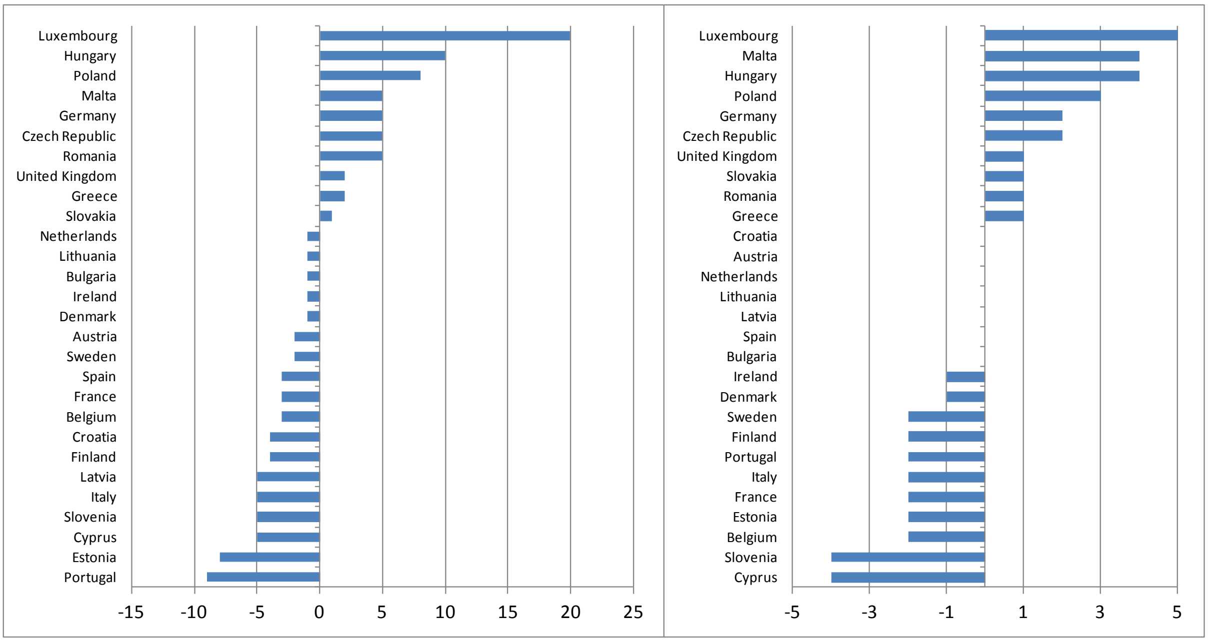
**Table 2: Original values of the EU 2020 Innovation Indicator and the SU indicator, 2012**

| | PCT | KIA | COMP | DYN | Sector-adjusted R&D intensity | Export quality |
|---|---|---|---|---|---|---|
| EU28 | 4.0 | 13.9 | 5.8 | 17.9 | -0.13 | 72.6 |
| Austria | 5.4 | 14.2 | 5.1 | 17.2 | 0.48 | 75.4 |
| Belgium | 4.0 | 15.2 | 5.1 | 15.6 | 0.30 | 67.9 |
| Bulgaria | 0.4 | 8.3 | 3.4 | 16.2 | -0.72 | 42.7 |
| Croatia | 0.8 | 10.4 | 3.5 | 15.0 | ... | 54.2 |
| Cyprus | 0.3 | 16.9 | 4.5 | 16.7 | -0.52 | 70.0 |
| Czech Rep. | 0.7 | 12.5 | 5.6 | 18.7 | -1.05 | 63.6 |
| Denmark | 6.6 | 15.5 | 6.2 | 18.5 | 0.84 | 76.9 |
| Estonia | 2.3 | 10.8 | 4.8 | 14.7 | 0.36 | 56.1 |
| Finland | 10.5 | 15.5 | 4.9 | 17.1 | 1.42 | 70.4 |
| France | 4.2 | 14.3 | 5.6 | 20.8 | 0.43 | 79.0 |
| Germany | 7.8 | 15.8 | 6.9 | 19.1 | 0.00 | 84.1 |
| Greece | 0.4 | 12.3 | 4.2 | 16.8 | -0.43 | 38.3 |
| Hungary | 1.5 | 12.5 | 5.5 | 19.1 | -1.57 | 67.2 |
| Ireland | 2.4 | 20.1 | 6.9 | 21.8 | ... | 88.6 |
| Italy | 2.1 | 13.2 | 4.8 | 15.3 | -0.64 | 67.9 |
| Latvia | 0.5 | 10.3 | 3.9 | 11.3 | -0.89 | 52.9 |
| Lithuania | 0.4 | 9.1 | 3.0 | 12.3 | -0.90 | 39.7 |
| Luxembourg | 1.7 | 25.4 | 7.1 | 18.8 | ... | 52.8 |
| Malta | 0.7 | 17.0 | 4.5 | 17.5 | -1.89 | 76.1 |
| Netherlands | 5.5 | 15.2 | 4.4 | 16.2 | 0.12 | 64.4 |
| Poland | 0.5 | 9.7 | 4.8 | 19.3 | -1.15 | 45.3 |
| Portugal | 0.6 | 9.0 | 4.2 | 14.7 | -0.25 | 55.4 |
| Romania | 0.2 | 6.5 | 5.6 | 16.0 | -1.57 | 48.7 |
| Slovakia | 0.5 | 10.1 | 5.4 | 19.2 | -1.61 | 73.5 |
| Slovenia | 3.2 | 14.1 | 4.7 | 15.3 | 0.08 | 63.7 |
| Spain | 1.7 | 11.9 | 4.5 | 15.9 | -0.57 | 57.4 |
| Sweden | 10.1 | 17.6 | 5.3 | 18.9 | 1.20 | 80.1 |
| United Kingdom | 3.3 | 17.8 | 6.6 | 18.6 | -0.15 | 79.7 |

Source: Vertesy and Tarantola (2014) and authors' own calculations. Note: no data for Croatia, Ireland and Luxembourg in the sector-adjusted R&D intensity; export data for very small countries such as Luxembourg, Malta and Cyprus to be interpreted with caution.

[18] Note that due to the different weighting, the ranks for some countries are slightly different than in Table 1 for the EU 2020 indicator, but the direction of change is unaffected.

**Figure 3: Change in ranks: SU indicator vs. EU 2020 Innovation Indicator (left panel), modified EU 2020 indicator vs. EU 2020 Innovation Indicator (right panel)**




Source: Vertesy and Tarantola (2014) and authors' own calculations. The full set of normalised values is provided in Table A1 in the Appendix.

The comparison between the SU indicator and the EU 2020 Innovation Indicator reveals that several countries outlined above as showing relatively high specialisation in knowledge-intensive sectors, without necessarily being at the frontier in these activities, perform worse in the upgrading indicator in terms of losing several ranks (e.g., Hungary, Czech Republic, but also Luxembourg, which profits from large financial services). Among the "winning" countries are several which tend to focus on less knowledge-intensive sectors, but are at a higher position on the rungs of the quality ladder (e.g., Portugal, Italy, Belgium and Austria). Some countries do equally well on both dimensions of innovation outcomes (e.g., Sweden, France, Denmark).

This brief analysis supports the view that an indicator set that ignores elements of structural upgrading consistently understates dimensions of innovative performance that are more pertinent in countries focusing on sectors with less knowledge intensity, and overrates innovation outcomes of less-knowledge intensive activities within knowledge-intensive sectors. We next evaluate the strength of the bias resulting from the omission of the structural upgrading component. To this end we construct a modified EU 2020 indicator, which is calculated as the arithmetic average of the four indicators of the EU 2020 Innovation

Indicator[19] and the two indicators of the SU indicator. As the modified indicator contains more “change” than “upgrading” components, structural change receives higher weight. Although the literature surveyed in section 2 would actually support a higher weight for upgrading than used in the modified indicator, this point requires further research. We compare the results for the ranking according to the EU 2020 Innovation Indicator and the modified EU 2020 indicator in the right panel of Figure 3. Again, countries with a negative score on Figure 3 have a lower ranking according to the EU 2020 Innovation Indicator than according to the modified EU 2020 indicator.

The results of the ranking confirm that primarily countries specialised in knowledge-intensive sectors which are further away from the frontier perform worse under the modified indicator. Examples include Hungary (rank 14 instead of 10), the Czech Republic (15 instead of 13) and Slovakia (16 instead of 15). Countries with large financial sectors but few other innovation outcomes (the EU 2020 Innovation Indicator implies that the size of financial services contributes to innovation outcomes) lose as well (e.g., Luxemburg ranks 8 instead of 3). Among the countries that would gain under the modified version of the EU 2020 indicator are countries specialised in less knowledge-intensive sectors and focusing on high quality, such as Italy (17 instead of 19) and Portugal (22 instead of 24). Some countries that already did well in the EU 2020 Innovation Indicator even improve their position when structural upgrading is taken into account (e.g., Finland, Sweden, Denmark) while some countries which were already low ranking in the EU 2020 Innovation Indicator also stay at the bottom in the modified version (e.g., Latvia and Lithuania).

Our analyses should be understood as a first attempt at shedding more light on the process of structural upgrading, with clear room for further improvement. Data are not available for all countries; unit values are not always related to product quality; and clearly, additional indicators are needed to cover further upgrading dimensions, such as quality in services (exports). In spite of these limitations, in terms of the range of innovation outcomes covered in both manufacturing and services, it adds upgrading dimensions to the EU indicator and is

[19] This procedure deviates from the one used by the EU Commission which assigns different weights to each component (COMP: 0.43, PCT: 0.23, KIA: 0.18, DYN: 0.15).

hence relevant for a much larger part of the EU economies (e.g., the knowledge-intensive activities in the KIA indicator make up between 10-20% of most EU economies, while our outcome indicators cover potentially the whole market economy (sector-adjusted R&D intensity) and all of manufacturing (export quality).

In summary, we find that neglecting structural upgrading penalises countries that are close to the frontier in less knowledge-intensive sectors. By contrast, countries which boast large financial sectors or which are part of international value chains in knowledge-intensive sectors but at the least knowledge-intensive part of the chain (e.g., assembly) obtain higher rankings. Finally, countries that perform equally well (or equally poorly) on both dimensions are least affected by the omission of structural upgrading indicators.

## 4 Conclusions

European research and innovation policy over the past decade focused considerably on increasing inputs to innovation. In 2002 the Barcelona goal was announced, aimed at bringing R&D expenditure in the EU to 3 percent of GDP by 2010. When this target was not reached, 2020 was set as the new target year. In order to evaluate the efficiency of increasing inputs, a thorough understanding and monitoring of the outputs and outcomes to be achieved by these inputs is needed. We showed that the new EU 2020 Innovation Indicator does make an attempt in this direction, but falls short in terms of measuring innovation outputs and in terms of the dimensions of innovation outcomes it captures.

Measuring innovation outputs and outcomes for the purpose of indicator-based country comparisons is difficult. The EU 2020 Innovation Indicator mainly focuses on innovation outcomes and includes little information on output. It only uses patents, which we have argued are difficult to use as an innovation output indicator because they conceptually do not need to imply actual innovations. In that respect the patent indicator used in the EU 2020 Innovation Indicator should be considered as measuring the ”throughputs”, but not the outputs of innovation, contrary to the title of the communication by the EC (2013).

Throughputs are conceptually closer to the capability to create new knowledge, rather than to translate this knowledge into commercially successful products, or to derive economic benefits from this new knowledge. However, if one is interested in these economic benefits of innovation, which is the declared aim of the EC as stated in its communication (2013), then information on the quantity and quality of innovation throughput and output (e.g., how many innovations introduced, how path-breaking they are from a technological perspective) matters less than information on innovation outcomes, i.e. the economic impacts of innovations.

We argue that for adequately measuring innovation outcomes at the country level, both structural change (reallocating economic activity towards more knowledge-intensive sectors) and structural upgrading (getting closer to the frontier in sectors countries are already specialised in) should be considered. The latter is certainly a major innovation outcome and reflects an important trend in competitive strategy. In order to defend competitive advantage against low-cost competitors, countries attempt to climb up the quality ladder and move to more innovation-based activities within a given sector. At the same time, structural upgrading mirrors the increased path dependency of technological progress due to more complex knowledge bases. So far, the structural upgrading dimension has been widely neglected in innovation outcome indicators and is barely integrated in innovation performance rankings.

This is also true for the EU 2020 Innovation Indicator as three out of the four components primarily focus on structural change as an innovation outcome; the patent indicator reinforces this focus on knowledge-intensive sectors. This is somewhat surprising given the priority of EU policy on smart specialisation, which acknowledges the merits of strengthening industries that have comparative advantages regardless of being high-tech or low-tech, knowledge-intensive or capital-intensive. The EU 2020 Innovation Indicator systematically favours countries specialised in industries classified as more knowledge-intensive, even if the actual activities performed within the country are not that knowledge intensive. At the same time, it neglects important innovation outcomes in terms of upgrading, thereby underrating countries that are specialised and close to the frontier in less knowledge-intensive sectors.

For policy makers, the EU 2020 Innovation Indicator will be of little additional value as it does not address sufficiently well the questions that are typically posed to a policy-oriented innovation indicator: How successful is my country in terms of innovation outputs and in particular eventual outcomes? Does my country invest enough given its specific situation? How well do inputs eventually translate into outcomes? In fact, the indicator may even mislead policy makers and discourage from further investment. If higher investment in R&D and innovation is not mirrored in better outcome measures, innovation policy makers will find it difficult to argue for higher budgets, particularly in a situation of tight government budgets and calls for cuts in government expenditure. A proper and comprehensive measurement of innovation outcomes is hence critical for demonstrating the importance of higher investment into the generation and exploitation of new knowledge.

We believe that measuring innovation outcome in a comprehensive way based on indicators requires a more balanced approach than the one chosen by the European Commission. Our article can in itself be seen as a response to the call of the High Level Panel on Innovation Measurement (2013, p. 24) for a "substantial research effort on conceptual foundations" as well as empirics of innovation measurement, which it could not provide due to the limited time available for its report. We propose a conceptual framework that stresses the differences between structural change and structural upgrading as two important dimensions of innovation outcomes and show that results can differ quite substantially for some countries if structural upgrading is taken into account. In times of globalisation of innovation systems and fragmented value chains, it is not enough to look at between-sector variation only. We need to take into account the actual innovation outcomes and look at within-sector variation as well, and consider the positions countries assume in different segments of the quality ladder. General knowledge intensity of sectors (calculated as an international average) needs to be combined with variations in the actual knowledge intensity within sectors. Such an approach covers the entire business sectors and not just a narrow subset of pre-defined sectors.

In policy terms, our framework opens up a potentially fruitful agenda for further research, as drivers of structural change can now be compared to drivers of "upgrading". Depending on their starting position, countries may strive for higher shares of knowledge-intensive sectors and/or move towards more knowledge-intensive activities across all sectors. E.g., countries at the top of the quality ladder in less knowledge-intensive sectors may prioritise efforts to diversify into new areas of strength, using tools such as fostering spin-offs from academic research. By contrast, countries further away from the frontier in knowledge-intensive sectors may aim to upgrade through an increase in the innovation intensity of existing firms, e.g. through R&D subsidy programmes or increased cooperation of firms with universities. There is a clear case for further empirical research on how science, technology and innovation policies influence the two dimensions of innovation outcomes.

In terms of innovation outcome measurement, more work is clearly needed to improve indicators. The upgrading component of outcomes needs to be covered by additional indicators, showing complementary dimensions. A major step forward would be to measure the actual innovativeness of fast growing firms and their contribution to employment in all sectors, rather than just measuring the employment share of fast growing firms in knowledge-intensive sectors. This would also better illustrate upgrading in services. While our sector-adjusted R&D measure covers manufacturing and services, our measure of export quality is restricted to manufacturing. With regard to indicators on structural change, while both manufacturing and services are included, different industry classifications at the international level complicate comparisons (as also pointed out by the High Level Panel, 2013), calling for better harmonised industry classifications. Determining the relative importance of "upgrading" and "change" for improving a country's innovation performance would be helpful, too. This can also inspire the further investigation of the relationships between outputs and outcomes to inform policies about their effectiveness.

While we have not contributed to improving output measurement, we have outlined that the subjective approach has difficulties developing internationally comparable measures of innovation output, while the objective approach is too cumbersome and patents have well known limitations. At the same time, existing statistical tools to measure innovation outputs have to be advanced with a view on better international and inter-sectoral comparability. This is particularly true for innovation surveys of the CIS-type which theoretically should serve research and policy with data on innovation outputs, but so far have largely failed to deliver. There is hence a clear need for further research on appropriate indicators for outputs and outcomes. Based on a new conceptual framework, we hope that our article will provide a new impetus for research on innovation output and outcome measurement which will eventually contribute to reducing uncertainty in policymaking.

**Acknowledgements**

We thank Irene Langer and Anna Strauss for research assistance, and Irene Langer, Susanne Sieber and Fabian Unterlass for sharing data. We are grateful to two anonymous reviewers and the participants of the 5$^{th}$ CONCORDi conference in Seville for valuable comments.

## 5 References


Acs, Z.J., D.B. Audretsch (1989), Patents as a Measure of Innovative Activity, *Kyklos* 42, 171–180.

Aiginger, K. (1997), The Use of Unit Values to Discriminate between Price and Quality Competition, *Cambridge Journal of Economics* 21, 571–592.

Arrow, K.J. (1962), The economic implications of learning by doing, *Review of Economic Studies* 29, 155–173.

Arundel, A., I. Kabla (1998), What percentage of innovations are patented? Empirical estimates for European firms, *Research Policy* 27(2), 127–141.

Bernstein, B., P.J. Singh (2006), An integrated innovation process model based on practices of Australian biotechnology firms, *Technovation* 26, 561–572.

Blind, K., J. Edler, R. Frietsch, U. Schmoch (2006), Motives to patent: empirical evidence from Germany, *Research Policy* 35(5), 655–672.

Bloom, N., M. Draca, J. van Reenen. (2016), Trade Induced Technical Change? The Impact of Chinese Imports on Innovation, IT and Productivity, *The Review of Economic Studies* 83( 1), 87–117.

Bronzini, R., P. Piselli (2016), The impact of R&D subsidies on firm innovation, *Research Policy* 45(2), 442–457.

Brouwer, E., A. Kleinknecht (1999), Innovative output, and a firm's propensity to patent: An exploration of CIS micro data, *Research Policy* 28, 615–624.

Chen, K., J. Guan (2011), Mapping the innovation production process from accumulative advantage to economic outcomes: a path modeling approach, *Technovation* 31, 336–346.

Coombs, R., P. Narandren, A. Richards (1996), A Literature-based Innovation Output Indicator, *Research Policy* 25, 403–413.

Crépon, B., E. Duguet, J. Mairesse (1998), Research, Innovation And Productivity: An Econometric Analysis At The Firm Level, *Economics of Innovation and New Technology* 7(2), 115–158.

Dosi, G. (1982), Technological paradigms and technological trajectories: a suggested interpretation of the determinants and directions of technical change, *Research Policy* 11, 147–162.

Dosi, G. (1988), Sources, Procedures, and Microeconomic Effects of Innovation, *Journal of Economic Literature* 26, 1120–1171.

Dosi, G., R.R. Nelson (2010), Technical Change and Industrial Dynamics as Evolutionary Processes, in B.H. Hall, N. Rosenberg (eds.), *Handbook of the Economics of Innovation*, Vol. 1. North-Holland, 51–127.

Edquist, C., J.M. Zabala-Iturriagagoitia (2015), *The Innovation Union Scoreboard is Flawed: The case of Sweden – not being the innovation leader of the EU*, CIRCLE Working Paper 2015/16, Lund.

European Commission (2002), *More Research for Europe. Towards 3% of GDP*, COM(2002) 499 final.

European Commission (2013), *Measuring Innovation Output in Europe: Towards a New Indicator*, SWD(2013) 325 final.

European Commission (2014), *Research and Innovation Performance in the EU 2014. Innovation Union Progress at Country Level*, Brussels.

Freeman, C., L. Soete (1997), *The Economics of Industrial Innovation*, 3rd edition, Routledge.

Frietsch, R., U. Schmoch (2006), Technological Structures and Performance as Reeflected by Patent Indicators, in U. Schmoch, H. Legler, C. Rammer (eds.), *National Systems of Innovation in Comparison*, Springer, 89–105.

Freeman, C., L. Soete (2009), Developing science, technology and innovation indicators: What we can learn from the past, *Research Policy* 38, 583–589.

Geroski, P. (1994), *Market Structure, Corporate Performance, and Innovative Activity*, Clarendon Press and Oxford University Press, Oxford and New York.

Ghosal, V., U. Nair-Reichert (2009), Investments in modernization, innovation and gains in productivity: Evidence from firms in the global paper industry, *Research Policy* 38, 536–547.

Godin, B. (2003), The emergence of S&T indicators: why did governments supplement statistics with indicators? *Research Policy* 32, 679–691.

Godin, B. (2004), The obsession for competitiveness and its impact on statistics: the construction of high-technology indicators, *Research Policy* 33, 1217–1229.

Godin, B. (2007), Science, accounting and statistics: The input–output framework, *Research Policy* 36, 1388–1403.

Griliches, Z., A. Pakes (1980), *Patents and R&D at the Firm Level: A first Look*. NBER Working Paper No. 561.

Grossman, G.M., E. Helpman (1991), Quality ladders in the theory of growth, *Review of Economic Studies* 58, 43–61.

Grupp, H. (1994), The measurement of technical performance of innovations by technometrics and its impact on established technology indicators, *Research Policy* 23, 175–193.

Grupp, H. (1997), Messung und Erklärung des Technischen Wandels, Springer, Heidelberg.

Grupp, H., T. Schubert (2010), Review and New evidence on Composite Innovation Indicators for Evaluating National Performance, *Research Policy* 39, 67–78.

Hall, B.H., R.H. Ziedonis (2001), The Patent Paradox Revisited: An Empirical Study of Patenting in the US Semiconductor Industry, 1979-95, *RAND Journal of Economics* 32(1), 101–128.

Hatzichronoglou, T. (1997), *Revision of the High-technology Sector and Product Classification*, OECD STI Working Paper 97/2.

High Level Panel on the Measurement of Innovation (2013), *Elements for the Setting-up of Headline Indicators in Support for the Europe 2020 Strategy*, European Commission.

Hölzl, W., J. Janger (2014), Distance to the frontier and the perception of innovation barriers across European countries, *Research Policy* 43, 707–725.

Janger, J., W. Hölzl, S. Kaniovski, J. Kutsam, M. Peneder, A. Reinstaller, S. Sieber, I. Stadler, F. Unterlass (2011), *Structural Change and the Competitiveness of EU Member States*, WIFO.

Kirner, E., S. Kinkel, A. Jaeger (2009), Innovation paths and the innovation performance of low-technology firms—An empirical analysis of German industry, *Research Policy* 38, 447–458.

Kleinknecht A., K. van Montfort, E. Brouwer (2002), The non-trivial choice between innovation indicators, *Economics of Innovation and New Technology* 11(2), 109–121.

Kleinknecht, A., J.O.N. Reijnen (1993), Towards Literature-based Innovation Output Indicators, *Structural Change and Economic Dynamics* 4, 199–207.

Kline, S.J., N. Rosenberg (1986), An overview of innovation, in R. Landau, N. Rosenberg (eds.), *The Positive Sum Strategy: Harnessing Technology for Economic Growth*, National Academy Press, 275–305.

Klingebiel, R., C. Rammer (2014), Resource allocation strategy for innovation portfolio management, *Strategic Management Journal* 35(2), 246–268.

Knell, M., M. Srholec (2009), *The Novelty of Innovation and the Level of Development*, Paper presented at GLOBELICS 7th International Conference, Dakar.

Laursen, K., A. Salter (2006), Open for innovation: The role of openness in explaining innovation performance among UK manufacturing firms, *Strategic Management Journal* 27(2), 131–150.

Leiponen, A., C. Helfat (2010), Innovation objectives, knowledge sources, and the benefits of breadth, *Strategic Management Journal* 31(2), 224–236.

Lundvall, B.-Å. (2010), *National Systems of Innovation: Toward a Theory of Innovation and Interactive Learning*, Anthem Press.

Mairesse, J., P. Mohnen (2002), Accounting for innovation and measuring innovativeness: An illustrative framework and an application, *American Economic Review* 92(2), 226–230.

Martin, J., I. Mejean (2014), Low-wage country competition and the quality content of high-wage country exports, *Journal of International Economics* 93, 140–152.

Mathieu, A., B. van Pottelsberghe de la Potterie (2010), A Note on the Drivers of R&D Intensity, *Research in World Economy* 1, 56–65.

McLaughlin, J.A., G.B. Jordan (1999), Logic models: a tool for telling your programs performance story, *Evaluation and Program Planning* 22, 65–72.

Moser, P. (2013), Patents and Innovation: Evidence from Economic History, *Journal of Economic Perspectives* 27(1), 23–44.

OECD (2015), *Frascati Manual 2015: Guidelines for Collecting and Reporting Data on Research and Experimental Development, The Measurement of Scientific, Technological and Innovation Activities*, OECD Publishing.

OECD, Eurostat (1995), *Measurement of Scientific and Technological Activities: Manual on the Measurement of Human Resources Devoted to S&T - Canberra Manual*, OECD Publishing.

OECD, Eurostat (2005), *Oslo Manual. Guidelines for Collecting and Interpreting Innovation Data*, 3rd Edition, OECD Publishing.

Pakes, A., Z. Griliches (1984), Patents and R&D at the firm Level: A First Look, in Z. Griliches (ed.), *R&D, Patents and Productivity*, University of Chicago Press, Chicago, 55–72.

Pavitt, K. (2005), Innovation processes, in J. Fagerberg, D.C. Mowery, R.R. Nelson (eds.), *The Oxford Handbook of Innovation*, Oxford University Press, 86–114.

Peneder, M. (2002), Intangible investment and human resources, *Journal of Evolutionary Economics* 12(1), 107–134.

Peneder, M., (2003), Industrial structure and aggregate growth, *Structural Change and Economic Dynamics* 14, 427–448.

Peneder, M. (2010), Technological regimes and the variety of innovation behaviour: Creating integrated taxonomies of firms and sectors, *Research Policy* 39, 323–334.

Rammer, C., D. Czarnitzki, A. Spielkamp (2009), Innovation success of non-R&D-performers: Substituting technology by management in SMEs, *Small Business Economics* 33(1), 35–58.

Reinganum, J.F. (1983), Uncertain Innovation and the Persistence of Monopoly, *American Economic Review* 73, 741–748.

Reinstaller, A., F. Unterlass (2012), Comparing business R&D across countries over time: a decomposition exercise using data for the EU 27, *Applied Economics Letters* 19, 1143–1148.

Robertson, P., K.H. Smith, N. von Tunzelmann (2009), Innovation in low and medium-technology industries, *Research Policy* 38, 441–446.

Rogers, E.M. (2003), Diffusion of Innovation, 5th edition, Free Press,.

Roper, S., J. Du, J.H. Love (2008), Modelling the innovation value chain, *Research Policy* 37, 961–977.

Saviotti, P.P., J.S. Metcalfe (1984), A theoretical approach to the construction of technological output indicators, *Research Policy* 13, 141–151.

Scherer, F.M. (1983), The propensity to patent, *International Journal of Industrial Organization* 1, 107–128.

Schott, P.K. (2008), The relative sophistication of Chinese exports, *Economic Policy* 23, 5–49.

Schumpeter, J. (1939), *Business Cycles: A Theoretical, Historical, and Statistical Analysis of the Capitalist Process*, Vol. 1, McGraw Hill.

Schumpeter, J.A. (1961), *The Theory of Economic Development: An Inquiry Into Profits, Capital, Credit, Interest, and the Business Cycle*, Transaction Publishers.

Smith, K. (2005), Measuring innovation, in J. Fagerberg, D.C. Mowery, R.R. Nelson (eds.), *The Oxford Handbook of Innovation*, Oxford University Press, 148–177.

Srholec, M. (2007), High-tech exports from developing countries: A symptom of technology spurts or statistical illusion? *Review of World Economy* 143, 227–255.

Vandenbussche, H. (2014), Qual*ity in Exports. Directorate General Economic and Monetary Affairs* (DG ECFIN), European Commission.

Vértesy, D., S. Tarantola (2014), *The Innovation Output Indicator 2014. Methodology Report*. JRC Technical Reports, Publications Office of the European Union.

Vogelstein, F. (2013), And Then Steve Said, “Let There Be an iPhone.”, *The New York Times*, Oct. 4th.

# 6 Appendix

**Table A1: Full range of normalised values for indicators used in section 3**

| | PCT | KIA | COMP | DYN | Sector-adjusted R&D intensity | Export quality | EU2020 modi-fied | SU indi-cator | EU2020 original |
|---|---|---|---|---|---|---|---|---|---|
| EU28 | 0.37 | 0.39 | 0.68 | 0.63 | 0.53 | 0.68 | 0.55 | 0.38 | 0.52 |
| Belgium | 0.37 | 0.46 | 0.52 | 0.41 | 0.66 | 0.59 | 0.50 | 0.41 | 0.44 |
| Bulgaria | 0.02 | 0.10 | 0.09 | 0.47 | 0.35 | 0.09 | 0.19 | 0.06 | 0.17 |
| Czech Rep. | 0.06 | 0.32 | 0.63 | 0.70 | 0.25 | 0.50 | 0.41 | 0.19 | 0.43 |
| Denmark | 0.62 | 0.48 | 0.77 | 0.69 | 0.82 | 0.77 | 0.69 | 0.55 | 0.64 |
| Germany | 0.73 | 0.49 | 0.94 | 0.74 | 0.57 | 0.91 | 0.73 | 0.61 | 0.73 |
| Estonia | 0.21 | 0.23 | 0.44 | 0.32 | 0.68 | 0.35 | 0.37 | 0.22 | 0.30 |
| Ireland | 0.22 | 0.72 | 0.96 | 1.00 | ... | 1.00 | 0.78 | 0.47 | 0.72 |
| Greece | 0.02 | 0.31 | 0.30 | 0.52 | 0.44 | 0.00 | 0.27 | 0.16 | 0.29 |
| Spain | 0.15 | 0.29 | 0.38 | 0.44 | 0.40 | 0.38 | 0.34 | 0.22 | 0.31 |
| France | 0.39 | 0.41 | 0.63 | 0.90 | 0.70 | 0.81 | 0.64 | 0.40 | 0.59 |
| Italy | 0.19 | 0.35 | 0.44 | 0.38 | 0.38 | 0.59 | 0.39 | 0.27 | 0.34 |
| Cyprus | 0.01 | 0.55 | 0.38 | 0.51 | 0.41 | 0.63 | 0.42 | 0.28 | 0.36 |
| Latvia | 0.03 | 0.20 | 0.21 | 0.00 | 0.30 | 0.29 | 0.17 | 0.12 | 0.11 |
| Lithuania | 0.02 | 0.14 | 0.00 | 0.10 | 0.30 | 0.03 | 0.10 | 0.08 | 0.06 |
| Luxembourg | 0.14 | 1.00 | 1.00 | 0.71 | ... | 0.29 | 0.63 | 0.57 | 0.71 |
| Hungary | 0.13 | 0.32 | 0.60 | 0.74 | 0.10 | 0.57 | 0.41 | 0.22 | 0.45 |
| Malta | 0.05 | 0.56 | 0.36 | 0.59 | 0.00 | 0.75 | 0.38 | 0.31 | 0.39 |
| Netherlands | 0.52 | 0.46 | 0.34 | 0.47 | 0.61 | 0.52 | 0.49 | 0.49 | 0.45 |
| Austria | 0.51 | 0.41 | 0.50 | 0.56 | 0.72 | 0.74 | 0.57 | 0.46 | 0.49 |
| Poland | 0.03 | 0.17 | 0.43 | 0.76 | 0.22 | 0.14 | 0.29 | 0.10 | 0.35 |
| Portugal | 0.05 | 0.13 | 0.28 | 0.32 | 0.50 | 0.34 | 0.27 | 0.09 | 0.20 |
| Romania | 0.00 | 0.00 | 0.64 | 0.45 | 0.10 | 0.21 | 0.23 | 0.00 | 0.27 |
| Slovenia | 0.29 | 0.40 | 0.41 | 0.38 | 0.60 | 0.50 | 0.43 | 0.35 | 0.37 |
| Slovakia | 0.03 | 0.19 | 0.58 | 0.75 | 0.08 | 0.70 | 0.39 | 0.11 | 0.39 |
| Finland | 1.00 | 0.48 | 0.45 | 0.55 | 1.00 | 0.64 | 0.69 | 0.74 | 0.62 |
| Sweden | 0.96 | 0.59 | 0.57 | 0.72 | 0.93 | 0.83 | 0.77 | 0.77 | 0.71 |
| Unit. Kingdom | 0.31 | 0.60 | 0.89 | 0.70 | 0.53 | 0.82 | 0.64 | 0.45 | 0.62 |
| Croatia | 0.06 | 0.21 | 0.14 | 0.35 | 0.37 | 0.32 | 0.21 | 0.13 | 0.19 |

Source: Vertesy and Tarantola (2014) and authors' own calculations.

***Calculation of sector-adjusted R&D intensity***

Direct comparisons of R&D expenditures relative to GDP are flawed as especially the business R&D expenditures (BERD) are heavily influenced by the industrial structure of each country. Smith and Sandven (1998) have therefore proposed a decomposition that identifies country and sector effects in BERD and therefore permits to compare R&D intensities in the business sector across countries. Starting point for the decomposition is the observation that

$$I_{M,j} = \frac{RD_{M,j}}{VA_{M,j}} = \frac{RD_{1,j}}{VA_{M,j}} + \cdots + \frac{RD_{n,j}}{VA_{M,j}} = \left(\frac{RD_{1,j}}{VA_{1,j}}\frac{VA_{1,j}}{VA_{M,j}}\right) + \cdots + \left(\frac{RD_{n,j}}{VA_{n,j}}\frac{VA_{n,j}}{VA_{M,j}}\right) \rightarrow$$

$$I_{M,j} = \sum_{i=1}^{n} I_{i,j} w_{i,j}, \ldots (1)$$

where $RD_{M,j}$ and $VAM,j$ are the aggregate R&D expenditures of the business sector $M$ in country $j$, and the index $i = 1,..,n$ indexes the single industries $i$. Variables $I_{i,j}$ and $w_{i,j}$ are then the industry specific R&D intensities and the weight of the sector in aggregate business sector output $VA_{M,j}$.

Simple expansions of the above expression yield

$$I_{M,j,t} = \sum_{i=1}^{n} \bar{I}_{i,t} w_{i,j,t} + \sum_{i=1}^{n} (I_{i,j} - \bar{I}_i) w_{i,j,t}, \ldots (2)$$

and

$$I_{M,j,t} = \sum_{i=1}^{n} \bar{I}_i w_{i,j,t} + \sum_{i=1}^{n} (I_{i,j,t} - \bar{I}_{i,t}) \bar{w}_{i,t} + \sum_{i=1}^{n} (I_{i,j,t} - \bar{I}_{i,t})(w_{i,j,t} - \bar{w}_{i,t}), \ldots (3)$$

where $\bar{I}_{i,t}$ and $\bar{w}_{i,t}$ are the averages of the R&D intensity in industry *i* and the contribution to value added of industry *i* to the aggregate output of the business sector respectively. Averages for $\bar{I}_{i,t}$ and $\bar{w}_{i,t}$ are taken over a group of benchmark countries.[20] The first right hand side component of equation (2) presents the industry structure effect in aggregate BERD. It presents the intensity of aggregate business R&D if all business sectors would invest into R&D at levels equaling the cross country average of the benchmark countries. The second right hand side component of equation (2) captures the country effect on BERD. It is the weighted sum of the sector specific deviations of industry specific R&D intensities from the

[20] The following countries have been selected as benchmark countries: AT, BE, DE, DK, FI, FR, NL, NO, SE, UK, US.

cross country industry specific average R&D intensity. Equation (3) instead decomposes the second right hand side (RHS) term of equation (2) further into an effect due to the change of R&D intensity in the industries of a country (second RHS term in equation 3) and an interaction effect combining the effect of differences in industrial structure and the effect of change in R&D intensity across industries in a country (third RHS term in equation 3).

This decomposition allows for a comparison of R&D expenditures across countries by separating structural effects from country specific effects. Controlling for industry structure it is therefore possible to compare whether in the aggregate the industries in a country perform better or worse in comparison to the group of benchmark countries.

In order to carry out this comparison data from different sources have been consolidated into one data set. The principal data sources for this analysis are taken from the OECD's databases STAN and ANBERD as well as Eurostat's BERD and Value Added databases. In assembling the database for the decomposition analysis several issues had to be dealt with. The principal problems were missing values either for the value added or the BERD data, inconsistencies in the classification of industries across countries and/or over time leading in some cases discontinuities, gaps and anomalies in the data. In particular, while the decomposition is mainly based on the NACE (Rev. 2) 2-digits level, some of the industries had to be aggregated.[21]

***Calculation of the export quality indicator***

The calculation of the export quality indicator is based on export unit values in manufacturing which are used to define price segments within each 6-digit NACE (Rev. 2) sector (see also Aiginger, 1997, for a discussion of the relationship between unit values and product quality). Manufacturing exports data for 2012 are taken from the Eurostat Comext database. 27 individual EU member states with the exception of Croatia are covered, for each of them all

21 The following sector aggregates have been used (if deviating from the 2-digits level): 01-03, 05-09, 10-12, 10-33, 13-15, 31-32, 35-36, 37-39, 41-43, 45-47, 49-53, 55-56, 59-60, 62-63, 64-66, 69-75 (excl. 72), 77-82, 87-88, 90-93, 94-99.

reported bilateral exports values and quantities are used. For Malta and Luxemburg a smaller set of unit values was available, therefore the result for these countries should be interpreted with caution.

Bilateral export unit values in 6-digit NACE (Rev. 2) sector *j* are calculated as the ratio of values of exports *P*Q* from country *k* to country *s* (expressed in €) to quantities *M* of the same exports (in kg), whenever both information on export values as well as quantities is available and when they are above a certain threshold (10,000€ for values and 2 tons for quantities).

$$UV_{k-s,j} = \frac{P_{k-s,j} * Q_{k-s,j}}{M_{k-s,j}}$$

Afterwards for each 6-digit NACE level sector *j*, the 33.3 and 66.7 percentiles *P* of the distribution of all bilateral export unit values of the 27 individual EU member states covered are defined as cut-off points or boundaries *B* for three price segments (high, medium or low) as a proxy for quality segments.

$$B_{j,low} = P^{33.3}_{UV_{1-27,j}}$$

$$B_{j,high} = P^{66.7}_{UV_{1-27,j}}$$

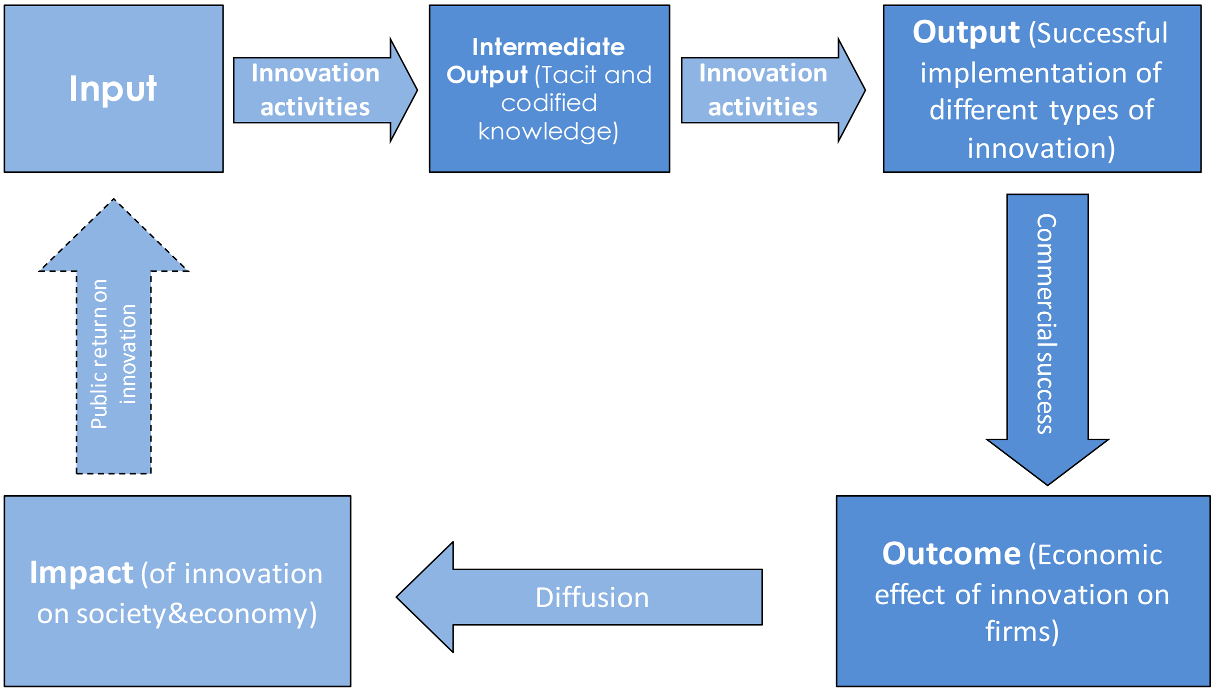
The boundaries are identical for all countries at the 6-digit level. These boundaries are then used to classify each bilateral export value at the 6-digit level into one of the three price segments *S*, for example all unit values below the 33.3 percentile threshold form therefore the low price segment category *S* across all countries

$$UV_{k-s,j} \in S_{j,low} \text{ if } UV_{k-s,j} < B_{j,low}$$

In the end, the corresponding exports' values *P*Q* are summed up for each country *k* to different aggregation levels (total country exports – all sectors N - as well as groups of sectors) for each price segment category. The resulting aggregated export values for the low, medium and high price segment are than expressed as the respective share in total exports *E* of country *k*, for the example of the low price segment:

$$E_{k,S_{low}} = \left( \sum_{j=1}^{N} (P_j * Q_j) \,\forall (UV_j < B_{j,low}) \right) / \sum_{j=1}^{N} (P_j * Q_j)$$

**Figure A1: Innovation outputs and outcomes in an innovation production process model**

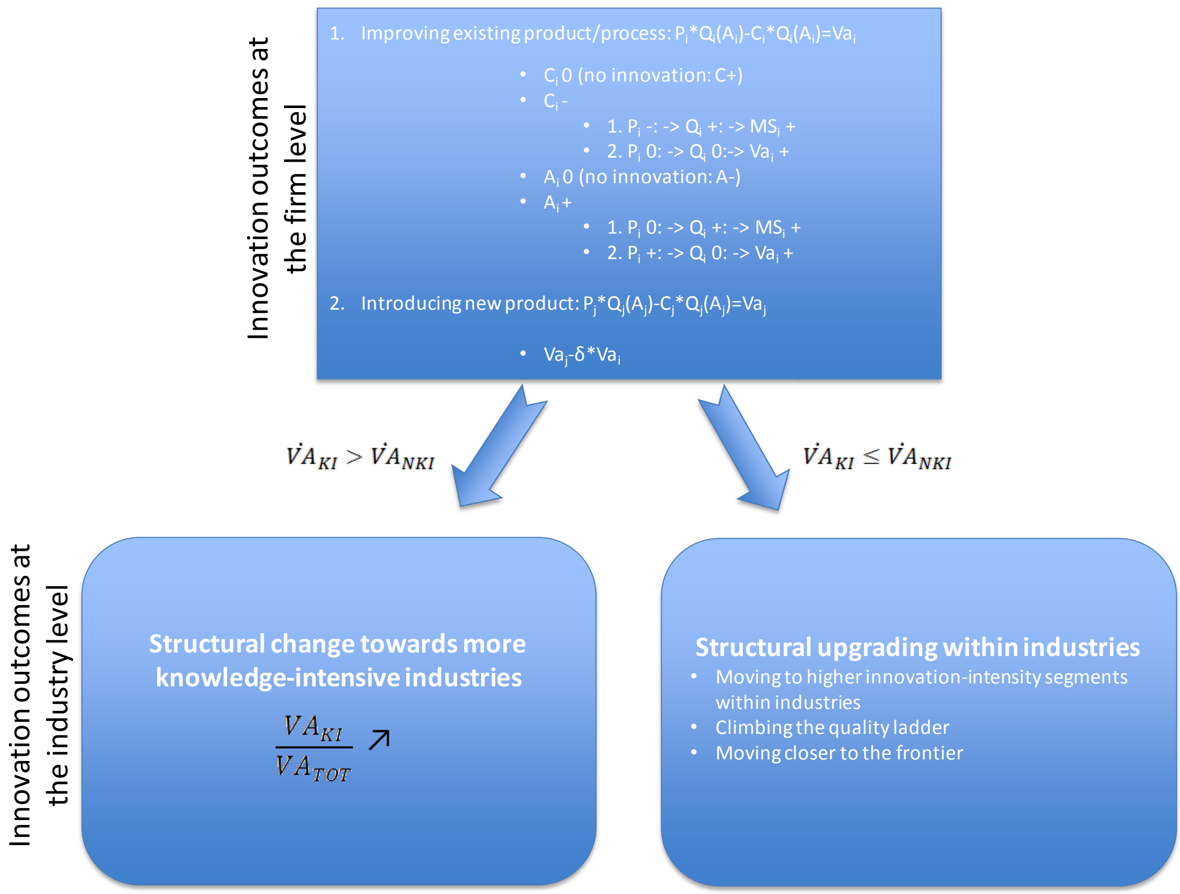



Source: Authors' own presentation.

***A formal conceptual model of innovation outcomes at the firm and industry levels***

Figure A2 starts with innovation outcomes at the firm level, which relate to the characteristics of innovation output: First, changes to existing products and processes can affect production costs *C* of product *i* (e.g., through increased process quality), decreasing *C* or keeping *C* constant relative to competing firms, which are also trying to reduce costs. Depending on the amount of relative cost reduction and ensuing price setting, value added *Va* and market shares *MS* generated by product *i* may remain unchanged or increase following changes in quantities sold *Q*. Innovations can also change product quality *A*, keeping product quality unchanged relative to competitors or increasing it, with impacts on value added or market shares as a function of corresponding price setting. Second, a new product *j* generates value added levels net of any substitution effects with the older product *i* it may replace, indicated by an elasticity of substitution $\delta$. These outcomes of innovation activity at the firm level translate either into economic effects of innovation changing the sector composition of activities (structural change through higher value added growth of industries characterised by high knowledge intensity ($VA_{KI}$) relative to industries showing lower knowledge intensity ($VA_{NKI}$)); or into changing the intra-sector composition of activities, by moving towards segments of higher knowledge intensity within the same industry.

**Figure A2: A formal conceptual model of innovation outcomes at the firm and industry levels**




Source: Authors' own presentation.