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Smart specialisation evaluation with real project data: a general equilibrium model in Portugal's Centro region

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ABSTRACT

As the first smart specialisation planning period (2014–2020) ended, monitoring and evaluation became crucial. Analysing the successes and failures of smart specialisation strategy (S3) through a good monitoring and evaluation system contributes to the evidence base on which an efficient redesign and improvement of S3 can be performed. In this paper, we apply an extended version of the geographic, macro and regional (GMR)-Europe economic impact model to provide a real-life evaluation of the implementation of S3 in Centro region using cohesion policy fund data between 2014 and 2023. Simulations reveal that policy instruments and policy mixes of priorities differ in efficiency and identify where improvements are desired.

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1. Introduction

Smart specialisation strategy (S3) is a place-based innovation and economic development strategy (Foray, 2015, 2019). It aims at economic development through an industrial restructuring of regions that supports promising new activities rooted in the regional economy's strengths, weaknesses, available resources, structure and innovation capacity (Foray, 2015). It seeks to enhance competitiveness by concentrating investment through the prioritisation and concentration of public resources. However, the strategy is not without challenges, during its first period (2014–2020), the design and the implementation of S3 policies faced many criticisms (Hassink & Gong, 2019). Developed regions, due to stronger governance structures, better institutional frameworks and more advanced innovation systems, tend to better adapt to the policy transition. In contrast, several factors (limited institutional capacities, fragmented innovation ecosystems and difficulties in identifying regional specialisations) hinder the strategy's implementation in lagging regions (Kroll, 2015), leading to uneven implementation across Europe.

S3 emphasises learning from past experiences; thus, the follow-up of the first planning period (i.e., monitoring and evaluation) focuses on the effectiveness of measures and supports the modification of the strategy. Monitoring is essential for implementation and evaluation as it highlights critical challenges and deepens understanding of how S3 works (Gianelle et al., 2020). Evaluation assesses the strategy's overall effectiveness by exploring goal attainment, contributing factors and barriers. Evaluation can serve as the basis for developing and implementing future S3 strategies.

A critical issue in the early S3 period (2014–2020) was the lack of a unified applicable approach to monitoring and evaluation. Smart specialisation became integrated into the EU Cohesion Policy framework as a pre-requisite for European Regional Development Fund (ERDF) access. While S3 monitoring was explicitly included in the performance criteria, evaluation was only implicitly required. This regulatory gap led to

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significantly different regional S3 approaches – some even completely omitting evaluation (Tolias, 2019). In the 2021–2027 period, evaluation is now explicitly part of the performance criteria. However, regions can still decide how to plan and carry out the evaluation and use its results (Tolias, 2019), raising concerns about the cross-regional consistency and comparability of results.

The absence of a widely applicable approach hinders the ability to compare outcomes across regions and also diminishes the potential for cross-regional learning, which is a core objective of S3. A more coherent system would enhance accountability and comparability, and ensure that policy lessons are fed back into the policy cycle. This is especially important in resource-constrained regions, where undetected policy failures can have long-term negative impacts. Addressing these issues requires improved data collection, methodological rigor and the integration of innovative modelling techniques capable of capturing S3's complex impacts.

Developing appropriate evaluation systems is challenging. A key challenge is that the regional socio-economic system is very complex (Hegyi & Porta, 2021). Still most regions have not introduced system-oriented evaluation practices (Borrás & Laatsit, 2019). This makes it difficult to isolate policy impacts from other influences, a problem that worsens over time as multiple shocks and feedbacks accumulate. Economic impact models help to overcome this difficulty by simulating real-life economies and running what-if scenarios based on the *ceteris paribus* principle. Thus, intervention impacts can be traced, ruling out interference with other shocks that affect actual economies.

The importance of economic impact estimation in S3 design and evaluation was recognised even in the early foundation studies of S3 (Foray, 2015). Well-designed impact models can reveal how various factors shape the success of S3-related policies in promoting regional growth (Varga et al., 2020b). Despite its relevance to EU Cohesion Policy, impact assessment needs to become a general instrument of policy learning to help redesign or redirect S3 policies – both *ex-ante* and *ex-post*. Models typically evaluate the impacts of interventions like investment support, human capital development or research and development (R&D) subsidies at various spatial levels (Brandsma & Kancs, 2015; Ratto et al., 2009; Varga, 2017). Economy-wide effects stem from diverse interconnections between the supported actors and the broader economy, making it essential to understand these mechanisms in both in the policy design (*ex-ante*) and the evaluation (*ex-post*) stages.

This paper aims to apply a complex impact assessment model to estimate the short- and long-term economic effects of smart specialisation policies by accounting for the most important aspects of the policy approach and using real data on S3 projects. A key challenge of impact assessment in policy evaluation is obtaining detailed intervention data. To address this, we combine the GMR (geographic, macro and regional) model with funding data from two operational programmes (2014–2023) in Centro, Portugal. To evaluate the economic effects of supporting the priorities set, we first extend the one-sector GMR-Europe model into a multi-sector model for the Centro region and, second, we translate the operational programme (OP) interventions into the policy instruments of the model. Then, we run policy simulations and analyse the results.

This paper makes six key contributions. First, it is the first attempt to use real S3 project data and general equilibrium techniques in the evaluation of smart specialisation. The study goes beyond previous evaluations by providing a comprehensive analysis across the entire 2014–2023 planning period in the specific case of Centro. By assessing both short- and long-term impacts, it goes beyond prior studies on evaluating the complete effects of S3 interventions. Second, it advances methodology by applying a *multisectoral* GE model – essential for capturing the complexity of S3 – which extends the standard one-sector GMR framework. Furthermore, this paper accounts for the *sector-specific productivity effects* of S3 interventions by extending the traditionally one-sector productivity block of the GMR model. To account for the impacts of training- and education-related policies, the exogenous policy instrument variable of human capital is endogenised using a small-scale *human capital model*. Third, the modelling results support region-specific policy recommendations that can help fine-tune policy implementation in the future. Given the required data input, this study not only contributes to the evaluation of a concrete implementation of S3 policies but also offers a replicable method for impact assessment that can be applied to other EU regions to enhance the effectiveness of S3.

Our primary objective is to demonstrate the application of the GMR impact model to provide a real-life evaluation of a concrete S3 implementation and not S3 in general. To keep the study concise, technical and

methodological details are reported in a supplementary paper (see Appendix 6 in the online supplemental data). Thus, this study primarily focuses on the first and third contributions outlined above.

The paper is structured as follows. The next section discusses the key challenges of quantitative S3 evaluation. Section 3 broadly introduces the GMR model. Section 4 describes our case study and the translation between the raw dataset and the policy instruments present in the model. Section 5 analyses aggregated and industry-level simulation results and formulates policy recommendations on this. Conclusions close the paper.

2. S3 and innovation policy quantitative evaluation challenges and recent advances

S3 is a result-oriented policy where setting goals, measuring intervention impacts and tracking progress are crucial. However, empirical experiences with monitoring and evaluation are mixed. Regions did not have the necessary skills, knowledge and experience to build effective monitoring systems, and most of them found this task difficult (Marinelli et al., 2019). As a result, establishing the monitoring system started late in many regions (Griniece et al., 2016; Kleibrink et al., 2016;). While there is no universal best practice, the European Commission gathers and publishes useful examples (IE, 2020; SSP, 2020a; SSP, 2020b). Thus, despite the difficulties, the monitoring system began materialising (Griniece et al., 2016).

For the *monitoring system*, there were only a few elements defined as minimum requirements (Gianelle et al., 2016): the definition of *output indicators*, which measure the direct results of political interventions; determination of *result indicators*, which measure the extent to which the socioeconomic goals of the strategy have been achieved; *clear definition* of indicators per priority area; determination of the *logical relationship* ('intervention logic') between the indicators and the expected changes and goals related to them.

For the *evaluation*, there are no such minimum requirements, which may indicate that no clear best practices of developing an evaluation system emerged in the early stages of S3. The system may consist of two elements (Gianelle et al., 2019): process and impact evaluation. Process evaluation relies on output indicators and implementation data to identify factors affecting policy delivery, with the monitoring system serving as an early warning mechanism. Impact evaluation assesses the effects of interventions on socioeconomic outcomes using result indicators and related data. In this case, monitoring can help improve the efficiency of impact assessment by providing detailed and useful data for the analysis, while the needs of impact assessment can shape the monitoring processes in the future.

Many methodological problems hinder the establishment of efficient evaluation systems. First, the complexity of regional socioeconomic systems creates uncertainty around the impacts and transmission channels of public policies. It is difficult to formulate systematic connections between policy objectives and monitoring indicators to determine the intervention logic (Hegyí & Porta, 2021). While the weak evidence base is a broader problem in S3 (Esparza-Masana, 2022; Foray, 2015), it is especially pronounced in evaluation, as most EU member states have yet to adopt 'system-oriented innovation policy evaluation practices' (Borrás & Laatsit, 2019).

Second, even if a sound regional monitoring system is established, it is still difficult to determine the actual impacts of interventions since changes in the result and output indicators are partially caused by factors other than the policy interventions (e.g., national and global economic processes). A sound evaluation system must account for the specific effects of S3 interventions by filtering out additional non-S3-related changes.

Third, there is no uniform solution for all the regions. Identifying suitable indicators and evaluation methods is nontrivial and resource- and data-intensive. Furthermore, generating the first stream of valuable data will take a long time, and even longer, for the impacts to materialise in the data streams (Esparza-Masana, 2022; Hegyí & Porta, 2021; Marinelli et al., 2019;).

Fourth, in many cases, statistical data is available at a much larger aggregation level than necessary for S3 evaluation. Furthermore, regional, national or EU policymakers might be interested in different variables and aggregation levels (Gianelle et al., 2019; Marinelli et al., 2019;). Thus, it is clear that using 'ready-made' statistical data is not enough to evaluate S3 efficiently.

In conclusion, we lack sound, reliable and widely useable tools and methods to show how the monitoring process could contribute to revising policy priorities, policy instruments and the renewal of S3 (Griniece et

al., 2017). The applied evaluation methods, in general, remained simple (e.g., balanced scorecards, peer review, benchmarking) and could not address the above-mentioned key challenges. More sophisticated methods, typically large-scale economic models, are also traditionally used in the assessment of cohesion policy. Despite the advantages, impact assessment has not gained significant ground in smart specialisation since the early adaptation of the policy due to the modelling challenges of new S3-related policy instruments (Varga et al., 2020a) and the sector-specific and regional nature of S3 (Varga et al., 2020b). As a result, only a handful of studies attempted to support the different aspects of S3 evaluation with economic impact modelling (Barbero et al., 2022; Gianelle et al., 2022 Szabó et al., 2025; Varga et al., 2020b;), but a comprehensive evaluation of a complete planning period has not been attempted yet. This paper shows that although economic impact assessment models make assumptions about the mechanisms of the regional socioeconomic system, they can still efficiently contribute to the evaluation mechanism by providing the necessary information to address the four challenges mentioned in the S3 evaluation. First, simulation results and their careful analysis can help regions produce evidence-based ‘intervention logic’, formulate relationships between indicators and objectives, and deal with the socioeconomic system’s complexity. Second, impact models are particularly suitable for separating the expected effects of different policy interventions from any non-S3-related external effects materialised in the data potentially provided by the monitoring system. Third, since it takes significant time for the impacts to materialise in the data, economic models could be useful tools to ex-ante estimate the most important impacts (like gross domestic product (GDP), employment). Fourth, carefully designed economic impact assessment models can provide information on economic impacts at different territorial levels (regional, national, EU) for policymakers. In this paper, we use the GMR model to illustrate how economic impact assessment could contribute to S3 evaluation.

3. Methodology: the GMR model

Impact evaluation of cohesion policy interventions is rooted in different methodological approaches. Econometric counterfactual analysis is frequently used in evaluation by establishing ‘what-if’ scenario that estimates what would have happened without an intervention (e.g., Bachtrögler et al., 2019; Cristofolletti et al., 2023). This method produces estimates of causal impacts when experimental designs are infeasible. Techniques (such as synthetic control method, difference-in-differences, randomisation, propensity score matching, regression discontinuity design) are frequently used to construct control groups that resemble the treated regions, helping empirically isolate the effect of policy interventions (Potluka, 2024). These methods allow for assessments of whether economic outcomes (GDP) are directly attributable to policy interventions. However, counterfactual analysis also has limitations, such as potential biases due to unobserved variables and difficulty in finding suitable control regions (Loi & Rodrigues, 2012). When data is scarce or policy effects diffuse, econometric models may struggle to accurately capture impacts, risking either over- or underestimation (Butts, 2021). Since in this paper, we focus on one specific region, and account for the interregional diffusion of economic impacts, we decided to employ an economic impact assessment model that belongs to the second group of models.

Large-scale modelling of cohesion policy covers different methodological approaches. Macro-econometric models (HERMIN – Sosvilla-Rivero et al., 2006; E3ME – Mercure et al., 2018, MASST, Capello & Caragliu, 2021) account for empirically estimated behavioural patterns, uncertainty but might struggle with endogeneity issues and they are less capable of capturing the structural change in the economy. Due to their limited ability to reflect structural and behavioural changes, econometric models are more vulnerable to the Lucas critique, which warns that observed macroeconomic relationships may shift as agents adapt to new conditions. Additionally, many of these models offer global or national-level analysis (with exceptions, e.g., the MASST¹ model). Dynamic, stochastic, general equilibrium (DSGE) models account for long-run analysis with a strong theoretical foundation, forward-looking optimising behaviour and also uncertainty (stochastic shocks). However, these models (e.g., QUEST – Ratto et al., 2009) only account for the national or global-level effects of different policy interventions. Computable general equilibrium (CGE) models also have strict theoretical foundations based on optimising behaviour, price flexibility and they can account for the structural change of the economy by accounting for all the relevant markets, actors, their behaviour and the feedbacks between them. As a result, they are less exposed to the Lucas critique, however, these models might be sensitive to their assumptions and the benchmark dataset. Their

complexity and data requirements make them difficult to apply and their empirical validation faces many challenges (e.g., Bayar, 2007). Their spatial counterparts are designed to account for the regional-level effects by taking into account geographical effects (e.g., agglomeration effects, spatial mobility of factors of production, trade) (e.g., Rhomolo and Crucitti et al., 2022; GMR – Varga, 2017). However, in many cases they lack the required level of disaggregation due to data availability.

In this paper, we use the GMR model that follows an integrated approach which aims to combine the positive characteristics of the previous modelling approaches. Macroeconomic effects are driven by the macro block, which is based on the QUarterly European Simulation Tool (QUEST) DSGE model, which accounts for the complex macroeconomic dynamics. This macro growth path is then regionalised in the spatial CGE (SCGE) block that accounts for space and geography by simulating the interaction between actors and markets in different regions. The productivity block of the model (which calculates the changes in productivity, which is one of the most important drivers of growth), however is based on an econometric model that grasps the most important factors of innovation and knowledge creation which drive the change of regional and macro productivity levels.

To analyse the economic impacts of S3-specific operative programmes in the Centro region, the original GMR model had to be extended. In what follows, we first discuss the most important characteristics and building blocks of the GMR impact model at appropriate stages. We also give a nontechnical explanation of the model developments that were necessary for the evaluation of the S3 implementation of our case study, namely:

- The multisectorisation of the SCGE model.
- The industrial disaggregation of the productivity sub-model.
- The integration of the small-scale educational sub-model into the productivity block.

Traditionally, the GMR economic impact assessment models facilitate development policy decision-making by simulating different policy interventions' (ex-ante and ex-post) economic impacts. The models calculate the expected effects of various policy instruments (e.g., R&D support, entrepreneurship, human capital development, network policies and investment support). Although there is a growing number of models that offer impact evaluation at the sub-national level (e.g., Hu, 2002; Tombe & Zhu, 2019), impact assessment models that are traditionally used estimate only the national effects (e.g., HERMIN, QUEST, Ecomod) with a few exceptions (e.g., Rhomolo). The GMR models also belong to this approach and consider geographical aspects (agglomeration externalities, trade, migration) and calculate both the national and regional economic impacts.

GMR models are structured around three main model blocks. The *productivity* (total factor productivity, TFP) block captures the most important factors that drive regional innovation and calculates changes in regional productivity. This block is based on theories from the geography of innovation literature (Anselin et al., 1997; Varga, 2000). Many S3 interventions enter the model at this point.

Figure 1 illustrates the structure of the TFP block. New knowledge (measured by regional patent applications) is created using knowledge production factors, specifically R&D expenditures and the stock of existing knowledge in the economy (measured by the national patent stock). Positive agglomeration externalities are proxied by the region's size (measured by employment), which influences regional knowledge production positively. However, knowledge is also available through interregional research networks (measured by the ENQ index, Varga & Sebastyén, 2017) which can enhance R&D expenditure efficiency in the knowledge production process. New knowledge contributes to the accumulation of national knowledge stock, which dynamically feeds back to regional knowledge creation of regions generating local and interregional spillover effects.

Productivity is primarily determined by the regional knowledge stock (measured by the regional stock of patents), but two additional factors influence it. First, human capital, since a better quality of human capital increases the efficiency of applying knowledge in the real economy, which improves productivity. Second, the entrepreneurial environment (measured by the REDI, Szerb et al., 2017) enhances the efficiency of human capital in knowledge application since entrepreneurs transfer knowledge into new economic applications. A better entrepreneurial ecosystem helps new firm formation (Acs et al., 2009), improving the

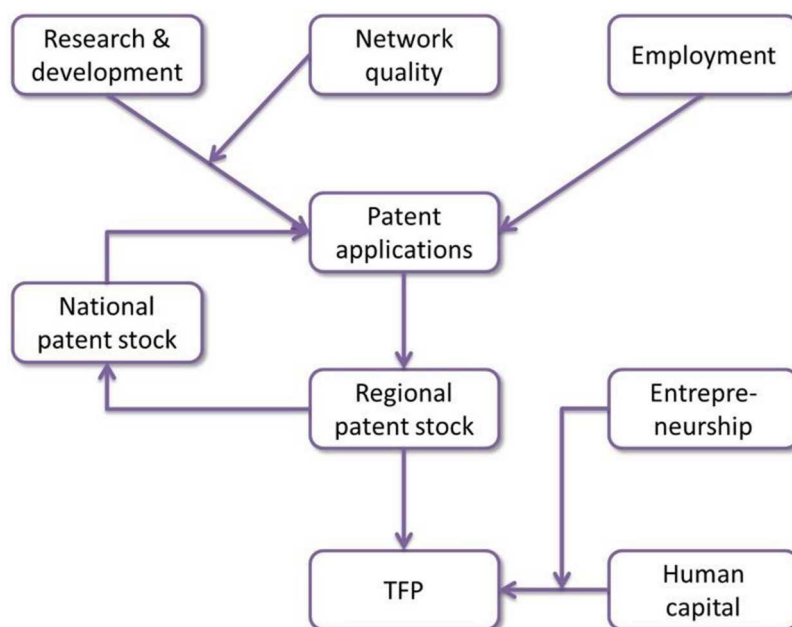


Figure 1. The structure of the TFP block. Source: Based on Varga et al. (2020a, p. 53).

efficiency of utilising the knowledge embodied in human capital and increasing productivity indirectly. Econometrically estimated equations capture all these mechanisms in the TFP block.

To account for all the S3 policy measures in Centro, the TFP block has been extended. First, to translate human capital-related funding into changes in human capital, we employ a small-scale education impact model (Jones, 2002; Varga & in't Veld, 2009), which is used by numerous macro models (e.g., QUEST). This model describes how human capital efficiency changes over time due to interventions channelled directly into the TFP block. Second, we extended the productivity block to account for the industry-specific productivity effects in the Centro region using detailed sectoral human capital development and R&D support data.

The spatial computable general equilibrium (SCGE) block of the model calculates regional economic effects by considering the spatial allocation of activities, migration of production factors, trade and agglomeration externalities. This model block relies on new economic geography (Fujita et al., 1999; Krugman, 1991). Due to data availability limitations, the SCGE block in the original GMR-Europe model is a multi-regional, one-sector CGE model that aggregates economic activities into a single industry at the regional level.

However, evaluating S3 interventions in Centro requires an industry-specific methodology, so we extended the one-sector SCGE block into a multisectoral model. Given data and computational constraints, we only disaggregated the Centro region into a multiregional sub-model, keeping the one-sector approach for all other regions. This is a novel approach compared to previous applications, where the disaggregation consists of three steps. First, we estimate a single-region input-output table (IOT) for Centro, which describes local inter-industry relationships. Second, we build a multisectoral sub-model for Centro using this IOT data, which is then connected to the rest of the GMR-Europe model. Third, we also modified the aggregated TFP block to account for the industry-level local productivity effects.²

The *macro block* is rooted in macroeconomic theories and accounts for the dynamics of the macro-level effects. This block is a large-scale dynamic, stochastic, general equilibrium (DSGE) model. The GMR-Europe model applies the QUEST III model (developed by the European Commission for the Euro area), which has been re-estimated for the additional (Central-European) countries of the GMR-Europe model. The original modelling approach is described in Ratto et al. (2009); the re-estimated model version is discussed in Varga et al. (2018).

Geographical and regional dynamics are incorporated into two GMR model blocks. The TFP block captures agglomeration effects and addresses the problem of the geography of innovation (e.g., interregional knowledge spillover). The SCGE block models trade dynamics and the interregional factor mobility. All of these phenomena are interlinked in a direct or indirect way and shape regional and interregional economic impacts.

Different interventions enter the model in different blocks. Innovation-related interventions affect the TFP block, investment and infrastructure development impact the SCGE block directly, while macro-level policies (e.g., tax regulations, income subsidies) are handled in the macro block. The changes caused by these interventions are transmitted to other model blocks through their interactions (Figure 2), allowing the model to trace their dynamic effects at the macro (EU), national and regional levels.³

The focal point of the model is regional TFP. The productivity block channels interventions that affect different aspects of the regional innovation system into the dynamics of regional TFP. For instance, support to R&D expenditures or interventions that contribute to the increase in human capital in the region are inserted as shocks that directly affect the status quo of the productivity block, describing the innovation system of the region.⁴ These shocks generate changes in all variables of the productivity block, ultimately leading to changes in the regional TFP. The timing of interventions and the built-in dynamic effects of the productivity block (time-lags) generate a dynamic path of regional TFP that differs from the baseline. The resulting change in TFP is then transmitted to the SCGE block, which describes how productivity changes affect the allocation of production resources across sectors and regions. This block captures supply-demand feedbacks through price adjustment and input-output linkages. As a result, interventions in a region or a sector will trigger broader effects on other sectors and regions driven by equilibrium-driven allocation mechanisms. Regional TFP changes are aggregated and introduced into the macroeconomic block as time-specific shocks. The model then recalculates all affected national-level variables. Adjustments in employment and investment are then distributed across regions, reflecting the spatial distribution of TFP effects. Finally, the SCGE model recalculates short-run and long-run equilibrium values for all variables using the updated employment and capital data. These last two steps are repeated until regional aggregate values in the SCGE model converge to their national counterparts.

Other policy instruments may directly affect the SCGE block. For instance, small- and medium-enterprise (SME) investment support contributes to the formation of additional capital stock in the region. This expands production capacity and leads to a reallocation of economic activity across sectors and regions. Investment changes are then aggregated and introduced into the macroeconomic model as time-specific shocks, followed by the recalculation of all national-level variables. Resulting employment and investment adjustments are distributed regionally, reflecting the spatial distribution of investment effects. The SCGE

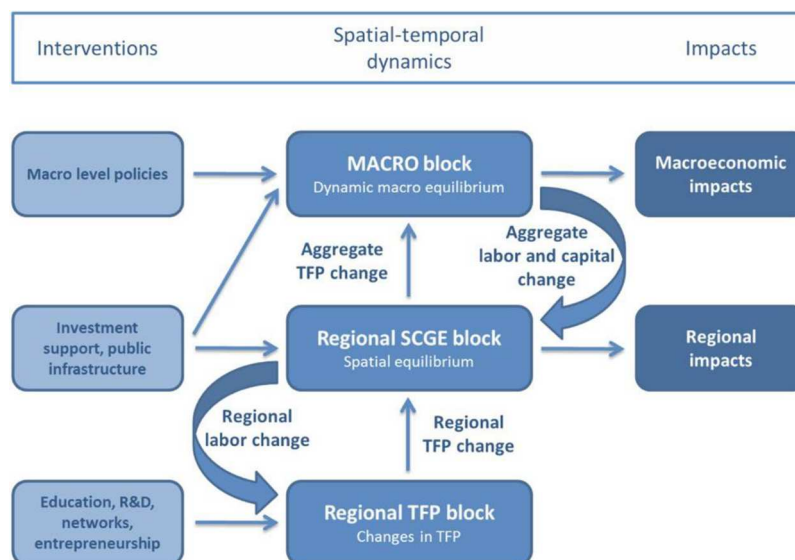


Figure 2. The impact mechanism inside the GMR-Hungary model. Source: Varga et al. (2020a, p. 54).

model recalculates equilibrium values for all variables using the updated employment and capital data. Again, the last two steps repeat until regional and national aggregates align. Even in the case of investment support, the effects can be dynamic partly because policy interventions are distributed over time but also due to agglomeration effects that further increase regional TFP as regional employment grows.

The GMR modelling approach is detailed in Varga (2017) and Varga et al. (2020a), with earlier applications including GMR-Hungary Schalk and Varga (2004), Varga, Szabó, et al. (2020c), GMR-Turkey (Varga & Baypinar, 2016) and GMR-Europe (Varga, 2017). Although these papers demonstrate the model's potential for S3 evaluation, limited data previously prevented real-world application. This paper is the first to fill this gap by using detailed data on smart specialisation policy interventions in the Centro region, Portugal, to provide a case for policy evaluation with the GMR model that can be replicated in other EU regions. S3 priorities represent a mix of thematic, economic and scientific domains that are translated into transversal policy instruments. While specific priorities may differ between regions, the 'families' of instruments are likely to be similar, making comparison and transferability a strong feature of this model.

4. Framing the case study

4.1. The Centro region in Portugal

Centro is an average-performing Portuguese region across several indicators.⁵ It spans 28,000 km² and has 2.24 million inhabitants (31% of Portugal's area, 22% of its population), and contributes about 20% to national GDP. Its GDP per capita (PPS) stands at 21,500, which is below the national average (88%) and the EU-28 average (66%). Centro ranks third in Portugal in R&D intensity (GERD/GDP), which has been increasing over the years. According to the 2021 Regional Innovation Index (Hollanders & Es-Sadki, 2021), it is considered a moderate innovator, reaching 99.7% of national and 78.8% of EU average performance.

Portugal applies a multi-level governance approach to its smart specialisation strategy, where regional S3s were integrated as an appendix to the national strategy. In Centro, the strategy was designed by CCDR-C⁶ as part of a wider regional foresight exercise (Laranja et al., 2019). However, the initial proposal lacked a monitoring system. At the national level, the monitoring system relied on broad hard-to-collect indicators that offered limited insights into place-based S3 impacts (Quartenaire Portugal, 2019). Interviews with national and regional stakeholders (Appendix 1 in the online supplemental data) revealed a general uncertainty about how to effectively measure innovation policy outcomes.

During 2017 and 2018, CCDR-C developed Centro's regional monitoring system with key support from the JRC's Lagging Regions project and other benchmarking exercises. Interviews highlighted that such a system needs to be simple, making regional proposals more feasible than national ones. CCDR-C sees monitoring as a continuous process Caderno (2016) and makes its first attempt to evaluate the alignment of Regional Operational Programme (ROP) projects with the S3-Centro.

Interviews revealed a strong need for a deeper reflection on S3 monitoring. As national and regional S3 strategies are revisited, current discussions target to better specify indicators and success measures. This GMR exercise was also part of CCDR-C's effort to be in contact with other monitoring proposals. It involved presenting the methodology to CCDR-C, a considerable articulation to access data and validate results, and a closed webinar to present and debate the results with S3-Centro stakeholders.

4.2. Translating operative programme funding into policy interventions

We use CCDR-C's database to evaluate the potential economic effects of supporting the priorities in Centro. This database covers two operational programmes between 2014 and 2023: Competitiveness and Internationalisation Operational Programme (POCI⁷) and Regional Operational Programme Centro (CENTRO⁸). As monitoring indicators were unavailable, our analysis solely relies on expenditure data from these programmes.

For both programmes, the database includes project titles and codes, descriptions, beneficiary names and industry codes, approved and eligible funding amounts, investment priorities, intervention areas, NUTS3

Table 1. The selected list of investment priorities^a and the dedicated funds (MEUR, %).

| Priority code | Priority | CENTRO | POCI | Total | Share |
|--------------------|---------------------------------|---------------|---------------|---------------|--------------|
| 1.1 | R&I | 48.6 | 60.5 | 109.1 | 3.5% |
| 1.2 | R&D | 85.6 | 840.3 | 925.9 | 29.7% |
| 3.1 | Entrepreneurship | 32.1 | 0.0 | 32.1 | 1.0% |
| 3.2 | SMEs | 126.6 | 111.3 | 237.9 | 7.6% |
| 3.3 | Product and service development | 615.7 | 1117.7 | 1733.4 | 56.8% |
| 8.5 | Adaption to change | 11.7 | 6.1 | 17.8 | 0.6% |
| 10.2 | Higher education | 15.3 | 0.0 | 15.3 | 0.5% |
| 10.4 | Labour market | 7.2 | 0.0 | 7.2 | 0.2% |
| Total | | 942.7 | 2172.1 | 3114.7 | 78.2% |
| Grand total | | 1597.6 | 2385.1 | 3982.8 | 100% |

Source: Authors own elaboration based on CCDR-C data. Note: ^aSee the description of priorities in Appendix 2 in the online supplemental data.

locations, the start and end date of the operation. It covers 25 detailed priority areas. After consulting with CCDR-C, we focused our analysis on the largest and most important priorities (see Table 1), which still account for 78% of total approved funding.⁹

To translate these funds into GMR-compatible policy instruments, we matched intervention areas to four policy instrument variables¹⁰: R&D support (R&D), investment support (SMEinvestment) and human capital development, which is split into two sub-groups: resource qualification (RESQUA) and higher education (HIGHEDU), to highlight differences between the potential effects of different policy approaches. To show how effectively funding along investment priorities supports research and innovation strategies for smart specialisation (RIS3) policy priorities in the region, we also linked investment and RIS3 priorities. For this, we used the detailed description of each RIS3 priority area (CCDR-C, 2021) and the detailed funding database provided by CCDR-C to intuitively match investment and RIS3 priorities based on their thematic orientation, target industries, aims, the policy instruments they use and type beneficiaries. Our matching shows that the selected investment priorities strongly support ‘Materials, Tooling and Production Technologies’ and ‘Digital Technologies and Space’ out of the six RIS3 priority areas by allocating large amounts of funding to manufacturing industries and ICT activities. To a lesser extent, the ‘Culture, Creativity and Tourism’ priority is also supported by investing in accommodation and catering activities. However, some investment priorities (R&D, R&I and education focus) might have horizontal effects that support all six RIS3 priorities. The details of the matching process and its result can be found in Appendix 2 in the online supplemental data.

We filtered the POCI and CENTRO operational programmes’ (OPs) database by the selected priority areas, the different GMR policy instruments and industries. Figures 3 and 4 show the distribution of funding over the years by priority areas and sectors, where the different colours denote the different instruments, and sectors are labelled with NACE codes (see the full set of industries in Appendix 4 in the online supplemental data). These interventions are used in the simulations with the GMR model.

The temporal distribution of funding is similar to previous funding periods, but considering the industrial distribution of support, it appears that funding covers a large number of industries, which may be contradictory in light of S3’s theoretical foundation of prioritising a few focused areas. Although this is an early challenge of S3 in its first period of implementation (Iacobucci, 2014).

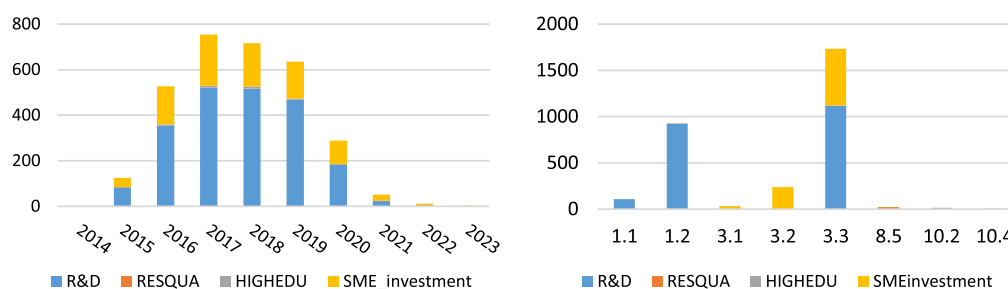


Figure 3. The distribution of funding over time by policy instruments (left-hand panel) and the distribution of policy instrument support by priorities (right-hand panel) (million EUR). Source: Authors.

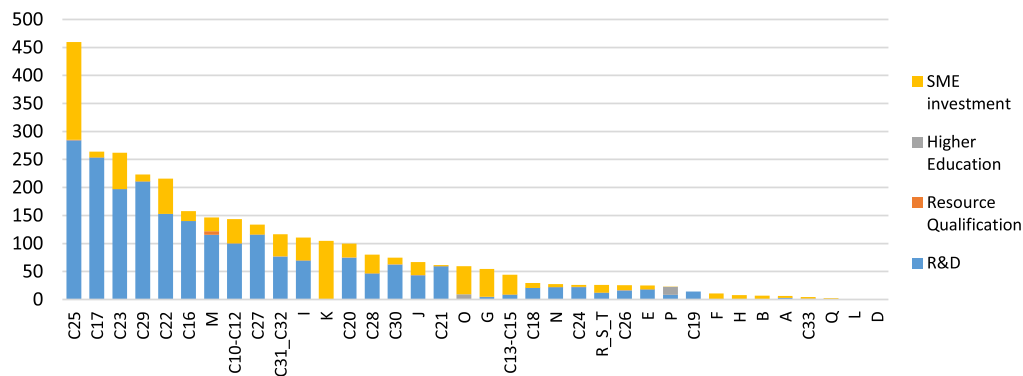


Figure 4. Intervention allocation by instruments and economic sectors (million EUR). Source: Authors.
 Note: See the full set of industries in Appendix 4 in the online supplemental data.

5. Results

5.1. Measuring innovation policy impacts in Centro

This section reports the most important simulation results obtained from the extended dynamic spatial impact assessment model GMR-Europe (discussed in Section 3). We measure the economic impacts of different policies by the relative and absolute change of gross value-added (GVA) and employment at the aggregated regional and sectoral levels. To understand the impact mechanism (intervention logic) of policy measures, we discuss the effects of each policy instrument separately (for a detailed description, see Appendix 3 in the online supplemental data).

5.1.1. Regional impacts by priorities

The regional economic impacts of priorities depend strongly on how the related instruments influence the economic processes (Appendix 3 in the online supplemental data). Moreover, impact size depends on the funding amount and its distribution over time.

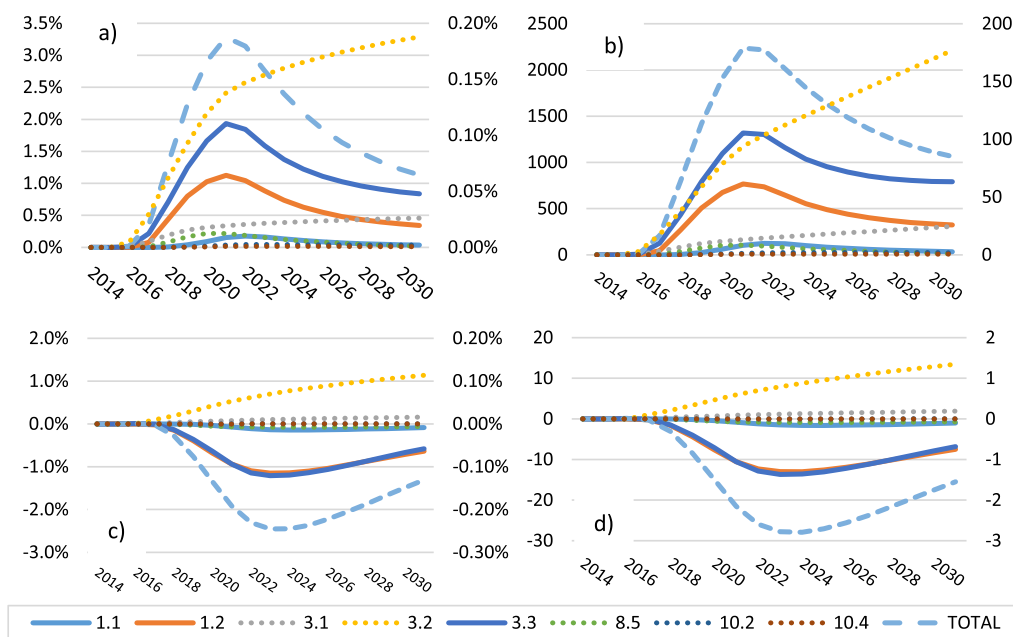


Figure 5. Relative and absolute GVA (panels a and b) and employment (panels c and d) impacts by priorities (% , million EUR). Source: Authors.

Note: dotted curves are projected on the right-hand scale (3.1, 3.2, 8.5, 10.2, and 10.4).

The impact mechanism of priorities 1.1, 1.2 and 3.3, mainly focused on R&D expenditures, follows the logic of R&D support in the TFP block. R&D expenditures support knowledge accumulation, leading to improved productivity, which increases production. GVA impacts follow productivity closely but with reduced magnitude due to substitution effects. As productivity improves, firms substitute labour and technology, decreasing labour demand. Figure 5 shows the relative and absolute GVA and employment impacts of priorities (denoted by different colours) over the years. Productivity and economic effects build up quickly, but these positive effects start to deteriorate as funding runs out due to knowledge depreciation. However, a smaller positive impact persists over the long run. Negative employment effects follow the same pattern. Regarding the amount of funding, priority 1.1 generates only minor effects, while 1.2 and 3.3 induce the largest impact among all the other priorities.

Priorities characterised by human capital development (resource qualification, higher education) exert similar effects. Improved human capital contributes to knowledge application, enhancing productivity and increasing production. Due to substitution effects, a decrease in employment can be observed. Priorities 10.2 and 10.4 are both dedicated to higher education support. In these cases, impacts build up slowly in the initial phase but are maintained in the long run. Since these two priorities are subject to the lowest support, they can exert only moderate economic effects. Priority 8.5 is primarily dedicated to resource qualification policy and, to a smaller part, to R&D. Thus, economic impacts are shaped by the interaction of the two policy instruments' effects. R&D effects are quickly visible in the first few years, but they deteriorate after that, and long-run effects stabilise between those of priorities 10.2 and 10.4.

Finally, priorities 3.1 and 3.2 both support investment exclusively. Additional investment increases the regional capital stock, decreasing the price of capital and making production cheaper. Consequently, the demand for local products increases, followed by expanding local production and employment. Economic impacts accumulate due to the investment multiplier effect, which is strong until the end of the simulation period, so positive GVA effects persist throughout the simulation period, although at a diminishing rate. Priority 3.1. is one of the smallest priorities in terms of funding, so it only has minor positive impacts, while 3.2. accounts for much larger funding and larger effects as well. Similar patterns are revealed for positive employment effects.

Overall, since most of the funding is allocated to the support of R&D and partially to investment, economic effects are mainly driven by the impact mechanism of these policy instruments. Thus, overall economic effects increase quickly to their maximum level in 2021, from where positive outcomes are reduced significantly as R&D supports run out.

5.1.2. Industry-level results

Since S3 is a sector-specific innovation policy, funding aims to promote the development of prioritised activities. This section analyses the economic impacts generated by policy support at the industry level.

Figure 6 shows the industry-specific average GVA and employment impacts of R&D support, where the vertical axis represents the size of economic impact, the horizontal axis indicates the amount of funds, and the blue dots denote the different sectors. R&D support increases industry-level productivity, making

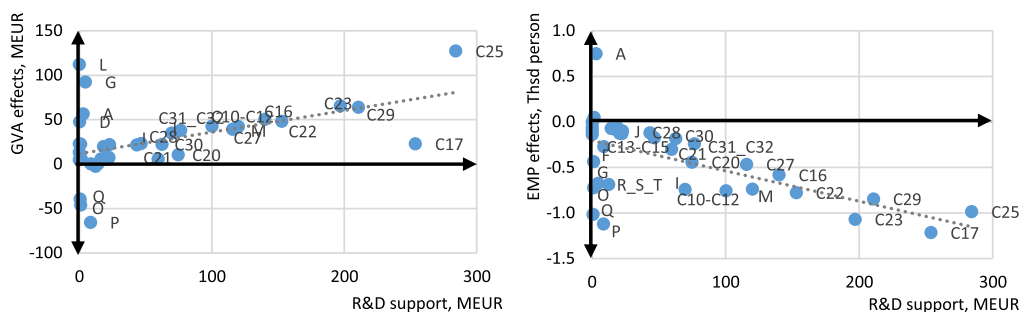


Figure 6. The average absolute GVA (left-hand panel) and employment (right-hand panel) effects by industries (million EUR, thousand persons) concerning R&D support. Source: Authors.

industries more competitive and enabling higher production. Employment effects behave similarly: more productive industries reduce their input demand due to substitution effects.

Supported activities are mainly in the manufacturing industries (including C25, C17, C29, C22, C23, C16, C27). Industries with more support generate larger positive GVA and negative employment impacts, while less supported sectors experience smaller or even negative GVA and smaller employment impacts. Most industries follow this pattern, which underlines the relationship between funding intensity and economic impact.

However, some supported industries cannot generate significant economic effects, while some industries develop without support. Agriculture (A), energy supply (D), wholesale and retail trade (G) and real estate activities (L) are not supported significantly, but, they still perform better than many supported activities. This is explained by industry-specific factors and the strength of local inter-industry connections. These activities are characterised by large capital intensity. Since productivity shocks result in new capital formation and capital is partially mobile between industries, this excess supply of capital can be used by local activities even if they are not supported. Capital-intensive activities become more competitive as their critical production factor becomes cheaper and as a result, the price of capital-intensive products falls, and their demand and production increase compared to labour-intensive products (capital intensity effect).

Inter-industry input-output linkages also influence economic effects since industries strongly connected to supported sectors (as suppliers or buyers) might also benefit from this support (inter-industry spillover effect). In this respect, wholesale and retail trade (G) is a strongly embedded activity since all the industries are intensively using this activity both on the input and output sides (backward and forward linkage effects). Also, products of agriculture (A) are used by many manufacturing industries as inputs, so the backward linkage effect is a source of growth in this industry. Both industries have strong ties to the ones supported by the R&D intervention, further increasing their growth. Real estate activities (L) typically have weaker embeddedness, while it is important for most industries as an input, so expanding its customers can generate significant benefits for this sector as well.

Those industries are affected negatively, which are labour-intensive, have a smaller share in final demand and are connected to supported activities by weak input-output linkages. Industries with relatively large final demand shares, and weak inter-industry connections (P, Q, O) benefit only from the general growth of income (income effect) but not from the positive effects of supported customers/suppliers. They suffer the consequences of decreasing employment due to productivity improvements.

Similar patterns are behind the impact mechanism of the supported activities. For example, C25 and C17 are the two most funded activities with similar profiles. However, their GVA effect significantly differs, which is not explained by the differences in their R&D support. Both of them have strong input-output linkages, and both of them are capital-intensive. However, C25 has a high value-added compared to C17, which amplifies its economic impacts through the income effect.

Employment in agriculture (A) increases significantly compared to other industries. This is caused by the strong inter-industry connections of agriculture since industries with the largest R&D support are the largest users of agricultural products. Since agriculture was not supported, it must increase its factor demand to expand its production, which can overcompensate the negative regional employment effect.

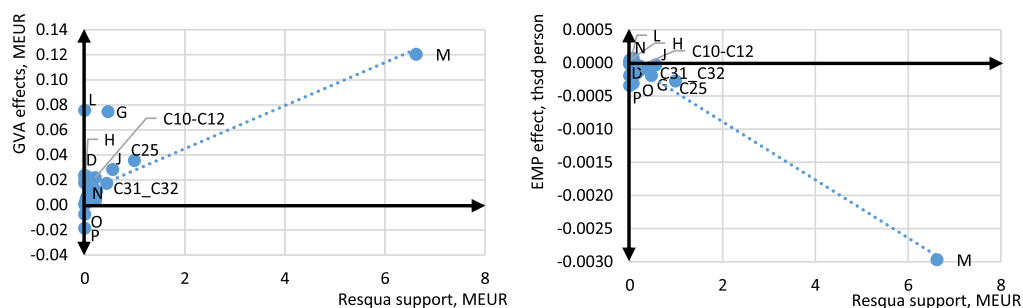


Figure 7. The average absolute GVA (left-hand panel) and employment effects (right-hand panel) by industries (million EUR, thousand persons) concerning RESQUA support. Source: Authors.

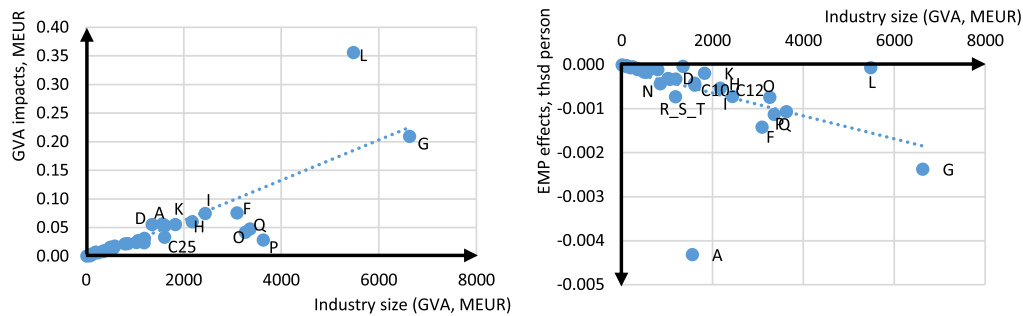


Figure 8. The average absolute GVA (left-hand panel) and employment (right-hand panel) effects by industries (million EUR, thousand persons) in the case of HIGHEDU support. Source: Authors.

Note: See the full set of industries in Appendix 4 in the online supplemental data.

The economic effects of supporting resource qualification are reported in [Figure 7](#). This type of funding is strongly concentrated on supporting professional and scientific activities (M) and partially the manufacture of fabricated metal products (C25). These industries experience a growth in productivity and output, and a reduction in employment (substitution effect). Similarly to the case of R&D support, sectors L and G can grow (even with no or very low support) due to their capital intensity and strong inter-industry linkages. In terms of employment effects, only a few industries managed to increase their employment, and the intervention does not or minimally supports these industries. Activities H and N provide the two most important inputs to sector G, so they were able to increase their employment the most through inter-industry spillover effects. Labour-intensive activities (P, O) without any support tend to experience a decline in terms of output and employment as well.

[Figure 8](#) reports the economic and employment effects of supporting higher education. This intervention results in sector-neutral productivity improvements, thus, industry-level economic effects are mainly driven by industry size and partially by industry-specific factors. In absolute terms, large industries benefit more from the support, but some industries under- (labour-intensive activities: O, P, Q) or overperform (capital-intensive activities: L, D) in terms of the GVA impact. There is slightly more variation in the employment impacts, but industries perform according to their size again, with activities A and L as exceptions. Agriculture is the largest employer in the region, so the industry-neutral productivity improvement causes the largest absolute employment decline in this sector. In contrast, real estate activities are extremely capital-intensive with minimal employment, so their absolute employment change is negligible.

[Figure 9](#) reports the economic effects of SME investment support. In general, those industries achieve larger GVA growth, which gets more support. However, there are large variations across industries. New investment increases capital stock and generates new jobs. The growth of the capital stock favours capital-intensive activities, while the growth of employment enhances the growth of labour-intensive activities. Accordingly, overperforming industries are characterised by strong capital intensity (L, D, A) or strong labour intensity (O, P, Q), which is then accompanied by strong inter-industry embeddedness (G, H, D, A) or large final demand (F, L, G, P, O, Q, I) in many cases.

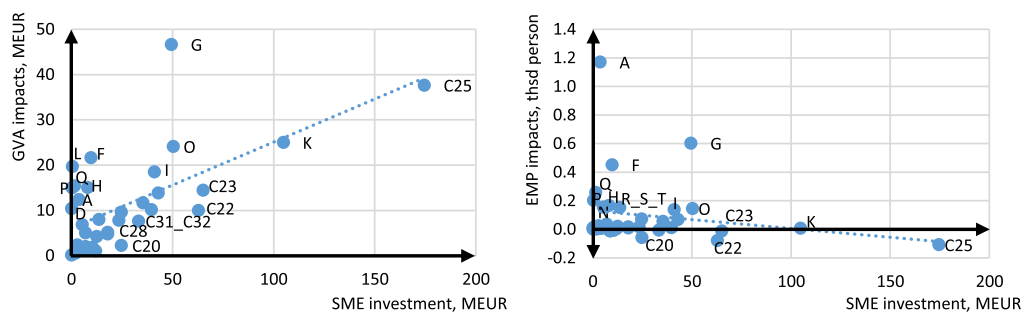


Figure 9. The average absolute GVA (left-hand panel) and employment effects (right-hand panel) by industries (million EUR, thousand persons) concerning SME investment. Source: Authors.

Note: See the full set of industries in Appendix 4 in the online supplemental data.

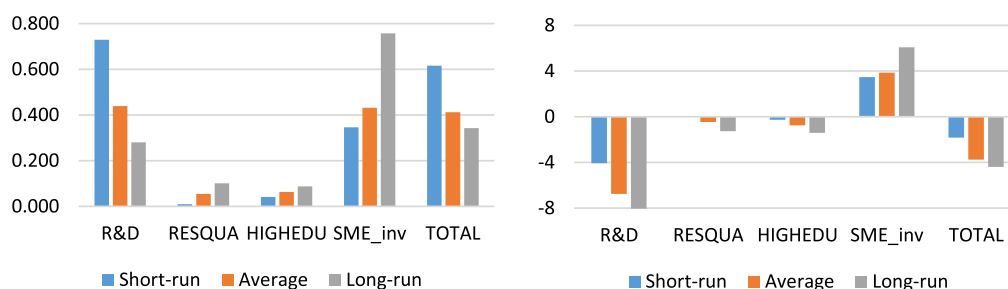


Figure 10. The GVA (left-hand panel) and employment multipliers (right-hand panel) of policy instruments in the short- and long-run (million EUR and person per 1 million EUR support). Source: Authors. Short-run: 2020 – peak year (impacts after seven years), long-run: 2031 – last year (impacts after 18 years).

5.2. Discussion of the policy impacts

The amount of funding and the distribution of funding over time determines the size of policy impacts in the first place. However, many other factors influence economic processes with non-intuitive effects, which can only be estimated with a system-oriented approach and a complex modelling framework. One important factor is the impact mechanism (intervention logic) of different policy instruments. In Section 5.1.1 we analysed the effects of priorities by instruments. Now, we discuss the overall performance of the instruments in the short-run (in 2020, which is the peak year) and in the long-run (in 2031, which is the last year of the simulation). We use multipliers that show the GVA and employment impacts of specific instruments per unit of money spent (see Figure 10). GVA multipliers show the million EUR effect of one million EUR support of different policy instruments, while employment multipliers show the change in the number of employees (person) after 1 million EUR support.

R&D expenditures have a large initial GVA impact through productivity improvements, but the positive effects erode significantly as funding runs out. Developing human capital (resource qualification and higher education) has the lowest multiplier of all the instruments, especially in the short run. As initial positive effects accumulate, the economic impacts of human capital grow over time, thus, long-run multipliers are significantly larger than their short-run counterparts. A similar pattern characterises SME investment since short-run multipliers are considerably lower than long-run results due to the positive additional growth caused by the increased capital stock and employment in the long run.

Economic policy impacts are also shaped by sector-specific factors, such as the supported industry's capital or labour intensity, the size of final demand and value-added, and the extent of the industry's embeddedness in regional input-output relations. These characteristics remain significant even in the case of the sectors connected to supported activities. Industry-specific factors determine the policy's multiplier effects and the impacts on other industries or economic variables. Therefore, determining these characteristics is important when choosing priorities and during evaluation to explore the factors that support or hinder success.

The multiplier analysis shows the performance of the instruments by sector, measured by the GVA impact per 1 EUR of funding (Figure 11). In the case of manufacturing, the largest part of the funding is



Figure 11. The performance of instruments in manufacturing (left-hand panel) and services (right-hand panel) by industries (million EUR GVA impact per 1 million EUR of funding). Source: Authors.

Note: See the full set of industries in Appendix 4 in the online supplemental data.

dedicated to C25, C17, C23, C22, C29, C16, C10–12, C31–32 and C27. The multiplier effect of spending is more or less in line with the selected priorities. C10–12 and C31–32 are two of the industries with the greatest performance in terms of policy funding. C25 is still large but somewhat lower than the top industries. However, C28 and C33 are under-supported compared to their large performance potential. Many industries with weaker potential (and smaller relative specialisation) are also weakly supported (e.g., C13–15, C18, C19, C20, C21). However, C17, characterised by weak performance, is significantly over-supported, thus, reallocating funds from this industry to other more promising areas might increase the overall performance of the policy.

Since service sectors are usually characterised by large value-added, they are more responsive to policy interventions targeting the different components of value added (e.g., productivity, capital). However, since these activities do not rely heavily on inter-industry inputs, they can express weaker inter-industry spillover capacity. Service activities that create a large amount of income through their value-added can benefit from additional expenditure stemming from newly created income and might grow more than others due to this income-multiplier effect. Funding is allocated mainly to six service sectors (G, I, J, K, M, O), but these sectors are characterised by modest or relatively low potential, while the top sectors (E, F, H, N) are only minimally supported. Allocating more funding to these sectors could have improved the overall performance of the OPs.

The simulation results provide essential information for evaluating the accomplishments of the two OPs' goals. Since these goals overlap to some extent, we discuss them together (see details in Appendix 5 in the online supplemental data). To filter out non-policy economic effects, we apply the *ceteris paribus* principle and express the results as differences from a baseline scenario without any policy intervention. One of the aims of the programmes is to increase competitiveness. Due to the policy support, the average annual GDP growth is 1.62% higher in the region and 0.51% higher in the country compared to the baseline. Similarly, the average annual TFP growth impact is 2% in Centro and 0.5% in Portugal. From this perspective, interventions can achieve their goal. The policy also aims to increase SME innovation and enhance knowledge-intensive activities (KIA). Besides the general productivity improvement, the significance of knowledge-intensive sectors increases in the region compared to the baseline. Although the GDP of KIA increases on average by 0.34% per year relative to the baseline, it is less than the average annual regional growth (1.62%). This is due to the low share (18%) of funding allocated to KIA activities and their lower direct economic potential compared to other sectors (see Figure 11).¹¹ The POCI OP targets to help the national strategy converge with more developed EU economies. This endeavour has a significant effect, as the intervention leads to an average annual GDP per capita growth of 0.46% in Portugal compared to the baseline, while this growth impact in the EU is only 0.018%. The policy also aims to strengthen the export orientation of companies, which is successful as the export-oriented sectors achieve an average annual growth of 1.14% compared to the baseline, while the other sectors' average growth is only 0.5%. The CENTRO OP promotes education and qualification in the region. As a result, human capital efficiency improves by 0.017% on average per annum (with a maximum of 0.022%) compared to the case without interventions. The policy also aims at increasing the proportion of GDP spent on research and technical development from 2.7% to 3.3%. This ratio does not achieve its target value due to the general economic growth, and as supports run out, it converges back to its baseline value. Both operative programmes support job creation and an increase in employment. However, our simulation reveals an adverse employment effect, which means that as productivity improves, firms substitute labour for technology to a certain extent, decreasing labour demand. Therefore, our simulation cannot clearly capture the effects of these efforts. The policy also aims to increase public service efficiency, improve transport links, promote sustainable urban development and support a low-carbon economy. However, our model does not include variables that are able to reflect changes in these respects.

6. Conclusions

Smart specialisation policies have been on the European regional policy agenda for some time. However, as implementation preceded solid theoretical foundations, there are still many challenges in planning and implementing these policies. Studies emphasise that S3 implementation is typically limited in less developed European regions, where the institutional capacity for successful implementation is lacking. An important aspect of smart specialisation is continuous learning, the refinement and development of policy objectives, priorities and instruments. However, this learning process must rely heavily on monitoring and evaluation

systems linked to policy planning and implementation. The capacity to set up and operate reliable and efficient monitoring and evaluation systems is also lacking in less developed regions.

One of the main challenges in operating an effective monitoring and evaluation system is that the effects of specific policy interventions are difficult to disentangle from the effects of many other impacts that affect the regional economy during the intervention period. A possible solution to this challenge is using economic policy impact models, which simulate the effects of specific policy interventions while excluding other shocks to the system. As a result, such models provide a clear picture of the estimated impact of a given policy on the non-specific socioeconomic variables in question.

Another challenge for S3 evaluation is that it is difficult to formulate systematic links between policy objectives and monitoring indicators, in other words, to determine the intervention logic. A careful analysis of policy scenarios with a policy impact model is also helpful in this respect, as it highlights the economic mechanisms and their relative importance in shaping the final economic impact of policy interventions.

Finally, we can estimate the relative efficiency of different policy instruments by constructing policy impact multipliers. These multipliers show how efficiently resources spent on specific priorities, instruments or sectors spill over into broader economic impacts, generating output or employment in the local or national economy. This information is essential for achieving the main objective of policy evaluation, which is to fine-tune policies by reallocating resources to areas with the highest economic and social returns.

This paper presents a concrete, replicable application of a policy impact model to evaluate smart specialisation policies and to provide valuable insights into the efficiency of S3 expenditures. We used the GMR Europe model and applied it to evaluate policy interventions in the Portuguese Centro region. Data on specific projects funded by the Portuguese government and targeting S3 priorities are used to run the model and simulate the impact of these interventions on the economy of the Centro region. While several papers have already discussed the potential of the GMR approach in estimating the impact of S3 policies, this is the first study to demonstrate the model's capabilities using real data on specific smart specialisation policy interventions.

The GMR Europe model is adapted in two ways to accommodate S3 policies in the Centro region. First, the Centro region of the model has been developed into a multi-sector economy that can reflect the industry-specific nature of S3 policies. This involves the extension of the spatial CGE model, the estimation of a regional input-output table, and the sectoral disaggregation of the productivity sub-model. Second, a small-scale education impact model is integrated to better account for human capital development policies. This extended model is fed with project data to simulate the effects of smart specialisation policy interventions in Centro along different priorities, industries and instruments.

As expected, the relative weight of funds allocated to different sectors and priorities is a significant determinant of the economic impact of interventions. However, the simulations also reveal additional heterogeneity in these impacts due to the different factor intensities of the supported industries and their inter-industry linkages that transmit impacts across industries. It is shown that the impact of the policy is also significant in those industries that are not directly supported but are closely linked to the supported industries. Overall, the most significant economic impact of the policies analysed can be measured in the short term, and without additional support, the effects gradually diminish over time. The interventions can effectively support most of the objectives of the operational programmes, and most of the priorities appear to be a good choice in terms of the efficiency of the use of funds. However, the overall performance of the interventions could be improved by fine-tuning the allocation of funds between instruments and sectors. By revealing how different policy instruments stimulate economic growth through sector-specific channels and regional linkages, our analysis sheds light on the critical role of targeted, data-informed policy design and funding. These findings underline a key takeaway for policymakers: the economic and social effectiveness of S3 interventions can be enhanced by strategically reallocating funds with the use of impact evaluation models. Although we argue that the use of policy impact models has clear advantages as a way of disentangling the economic effects of specific policy interventions from the impact of other shocks on the economy, it is important to stress that this approach works with simulated effects and simulated economies based on limited economic data and theoretical assumptions, which cannot take into account the full complexity of real economies. The results of these exercises remain estimates and must be treated with caution. Specifically, the GMR Europe model is complex in the way it considers interregional feedback

mechanisms and the interaction between macroeconomic and regional economic dynamics, but it's only a simplified account of the internal mechanisms of regional economies.

The multisectorisation of the model brought in further limiting consequences. First, while the focus region is developed into a multi-sector economy, the rest of the regions in the model remain aggregated, which means that inter-sectoral linkages and feedback mechanisms and their description remain limited in the model simulations. Second, changes in regional industry-specific productivity should generate changes in the entire production function by industry, which should also change the technical coefficients derived from the regional IO table. However, our current methodology could not consider this effect mainly due to data constraints. Currently, TFP improvement increases productivity at the bottom level of the production function, thus it leaves the technical coefficients unchanged. Third, the multisectorisation of the impact assessment model is based on a regionalised input-output table and not on a social accounting matrix (SAM) due to scarce local data availability. A SAM provides rich information on factor incomes and transfers by institutional sectors. Changes in sectoral productivity levels could cause distributional changes in income generation (e.g., between labour and capital), could affect disposable income and its use, and could indirectly influence income redistribution (e.g., transfers), however, in the current model setup, with the use of a regionalised input-output table, these mechanisms are not possible to be tracked. Addressing these limitations could be an important direction for future research.

Furthermore, the GMR-Europe model is equipped with a relatively inflexible labour market regarding labour supply, which typically leads to negative employment effects in the case of productivity improvements. This is because firms that increase their productivity substitute this productivity gain for employment. This must be considered when assessing the employment effects simulated by the model, which will likely be underestimated.

Finally, environmental and social issues are outside the model's scope, so simulations cannot account for the impacts of interventions in these dimensions. As a result, the model's capacity is limited for those interventions or instruments that directly target these objectives, although their economic impacts can still be tracked.

Notes

1. MAcroeconomic, Sectoral, Social, Territorial (MASST) model.
2. A detailed description of the regional IOT and the multisectoral model extensions can be found in the paper's supplementary document (see Appendices 6 and 7 in the online supplemental data).
3. A detailed explanation of the interaction between the model blocks can be found in Varga et al. (2020c)
4. R&D interventions that are discussed in Sections 4 and 5 directly affect the R&D variable, while resource qualification (RESQUA) and higher education (HIGHEDU) support directly influence the human capital in the productivity block. Based on Eurostat data: Area by NUTS 3 region (reg_area3), Population on 1 January by age, sex and NUTS 2 region (demo_r_d2jan), Gross domestic product (GDP) at current market prices by NUTS 2 region (nama_10r_2gdp).
5. Based on Eurostat data.
6. Centro Regional Coordination and Development Commission.
7. Programa Operacional da Competitividade e Internacionalização.
8. Programa Operacional Regional do CENTRO.
9. A detailed description of the links between priorities, intervention areas and policy instruments can be found in Appendix 2 in the online supplemental data.
10. Appendix 3 in the online supplemental data shows the matching scheme.
11. Note that these simulations do not directly account for wider productivity-improving spillover effects of KIA (e.g., innovation induced in other sectors).

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Ethics

This study was conducted in accordance with the principles outlined in the Economic and Social Research Council (ESRC) Framework for Research Ethics (2015) and relevant institutional ethical guidelines. All interviewees gave informed consent prior to participation, with full information provided regarding the purpose of the study, the voluntary nature of participation and their right to withdraw at any stage without consequence. Interviews were conducted either face-to-face, via web conference or, in two instances, through written responses. Care was taken to ensure that no personally identifying information is disclosed in this article, and all data were anonymised to protect the privacy and confidentiality of participants.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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