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***ORIGINAL ARTICLE***

# Attracting Serendipity: The Impact of Investment at the Science/Technology Interface in Fundamental Physics Research Infrastructures

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***ABSTRACT***

A key question in science policy is that of the impact of large-scale basic science facilities. The ATTRACT project provided a suite of resources, including funding, networks, and skills development support, to 180 technology projects that aimed to commercialise technologies that have emerged from research infrastructures. To assess the impact of ATTRACT, a case study analysis examined the ways in which support offered through ATTRACT phase 1 led to impacts such as strengthened innovation ecosystems, commercial applications of innovation, skills development, and broader social goods. The analysis of socio-economic impact leads to conclusions and recommendations in three broad areas. The first area is that of routes to impact, including the roles of RIs and businesses, the role of open innovation, and impacts that fall beyond innovation. The second area is that of technological serendipity, and the efforts of ATTRACT to systematise mechanisms that may support it. Finally, we reflect on CASEIA as a pilot study, and consider its potential contribution to research at the science/technology interface, and make methodological recommendations for ATTRACT's monitoring, evaluation, and learning efforts.

*Keywords: Serendipity; Innovation; Impact; Research infrastructures, PANDA, ATTRACT.*

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## INTRODUCTION

Learning to achieve greater socio-economic impact from investments in basic science is a perennial question for CERN, as well as other large-scale science infrastructures. This learning is central to the ATTRACT project, which aims to accelerate the discovery of innovative applications of technologies from Europe's top science research infrastructures (RIs). The pursuit of fundamental science is uniquely placed to lead to breakthrough technologies (Wareham et al., 2022). When these breakthrough technologies arise through co-innovation between research communities and industry, they can generate societal value more quickly and efficiently, saving costs, research capacity and resources.

As one of ATTRACT's socio-economic studies, a project for the Comparative Analysis of Socio-Economic Impact (CASEIA) developed an analytical framework and methodology for better understanding the socio-economic impact of ATTRACT. Through both primary and secondary research, CASEIA undertakes a comparative case study analysis to better understand how the support offered through ATTRACT phase 1 has led to socio-economic impacts (Gastrow et al., 2024). Using an innovation ecosystems approach, we model the actors and relationships in each case study and assess the enablers and constraints that come to bear on innovation and socio-economic impact goals. We explore the pathways through which ATTRACT phase 1 support led to new processes and products, as well as impacts achieved through knowledge spillovers, learning and capacity development, changes to networks and social structures, technological serendipity, and broader socio-economic impacts.

ATTRACT itself can be seen as a large-scale experiment, with the aim of assessing whether technological serendipity at the science/technology interface can be created through targeted support. ATTRACT phase one's 170 projects each received seed funding of €100,000, as well as network support and capacity development support (ATTRACT, n.d.). In assessing the impact of ATTRACT, we find distinct patterns of socio-economic impact across the three case studies and undertake a comparative analysis that reflects on the dynamics underlying the observed patterns. On this basis we reach conclusions and recommendations about routes to impact, including the roles of RIs and businesses, the role of open innovation, and impacts that fall beyond innovation. We also present new insights into technological serendipity, and the efforts of ATTRACT to systematise mechanisms that may support it. Perhaps most significantly, piloting the CASEIA methodology in three case studies demonstrates its utility in unpacking and better understanding the impact of ATTRACT projects. By applying this method to a larger sample size, conclusions could be reached with a higher level of confidence that they represent the dynamics at play in ATTRACT, and even beyond, as indicative of dynamics at the science/technology interface more broadly.

## THEORETICAL FRAMEWORK

ATTRACT's philosophy, logic and policy experimentation approach (Pennings et al*.,* 2018) are not repeated in detail here. However, to establish the theoretical basis of the study, we focus on three core concepts in the ATTRACT paradigm: RI impact, Serendipity and open innovation.

### Research infrastructures and impact

The impacts of publicly funded research include the development of knowledge, skills, instrumentation, methodologies, networks, social interaction, spin offs, and the 'provision of social knowledge' (Martin and Tang, 2007). Institutional impact assessments of RIs have a considerable history, and from their early days have focused on technologies and supply chains. Bianchi-Streit et al. (1985) had economic utility as their unit of analysis. A related approach is Cost Benefit Analysis, for example as applied to RIs by Florio and Sirtori (2016).

While the focus of research and policy has been on innovation as a source of impact, there are theoretical approaches that consider other avenues. For example, the problematisation by Merton (1973) of scientific norms, rules, beliefs, values, social structure, incentives, and institutions continues to shape thinking about science as a social activity, and hence shape science policy. Enzing and collaborators found that close cooperation between RIs and industry led to a positive effect on societal and environmental outcomes, knowledge transfer, scientific outputs, and economic impact (Enzing et al., 2015). They concluded that RIs need to engage in more applied activities if they are to successfully co-operate with enterprises – a finding that is also salient to the ATTRACT model.

### Serendipity

At its core, ATTRACT is an experiment in systematising technological Serendipity in the context of the EU's RIs (Wareham et al., 2022). The notion of 'Serendipity', in this context, and in the broader innovation literature, means something quite different to its common usage (Murayama et al., 2015). The adoption of the term 'Serendipity' by innovation scholars emerges from its reference to an unexpected discovery found from the combination of accident and sagacity. Since this overlaps with, but is distinct from, luck or provenance, Serendipity can be seen as a capability to be intentionally developed (de Rond, 2014). In short, and for the purposes of this article, it means that ATTRACT aims to find applications for technologies outside their original field of use. In our analysis, we distinguish between four types of Serendipity relevant to ATTRACT: Mertonian, Walponian, Bushian and Stephanian.

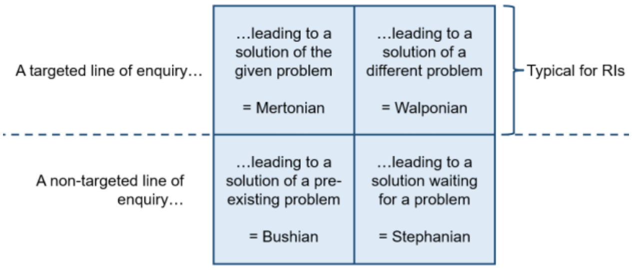


**Fig. 4**. A taxonomy of serendipity, modified from Yaqub (2017).

### Open innovation

Open innovation requires organisations to allow unused and underutilised ideas to go outside the organisation for others to use in their businesses and business models. The definition of open innovation in the ATTRACT paradigm is an "open" outcome at around technology readiness level 6 or 7, where a number of applications and directions are still possible, and where the outcome is not known beforehand (Chesborough, 2015). While open innovation is certainly relevant to these TRLs, other definitions of open innovation are more expansive than Chesborough's – including broader sets of actors, including the public, through mechanisms such as citizen science, unorthodox expertise, and greater diversity of contributors (Curley and Salmelin, 2013).

## ANALYTICAL FRAMEWORK

The core structure for our analytical framework is that of an innovation system: an actor-network structure of institutions and organisations, with relationships between these actors mediated by relationships of, *inter alia*, funding, knowledge, data, intellectual property, governance structures, skills transfer, collaboration, competition, and value chains. Drawing on our review of theoretical and empirical approaches towards impact assessment, we determined six analytical dimensions by which we identify and model causal pathways that enable or constrain positive social and economic impact:

- **Serendipity:** Have there been applications of technology outside their original intended use?
- **Spillovers:** Has knowledge and capability been transferred across different organisations in each case study? How can this be characterised?

- **Spin-offs:** Have there been industry applications, intellectual property generation, or economic outcomes?
- **Skills and learning:** What skills have been developed? What learning has taken place? What new capabilities have been built?
- **Social structures:** Were new relationships, collaborations, or partnerships built?
- **Broader socio-economic impact:** Looking beyond the other analytical dimensions, what are the broader socio-economic impacts?

## METHODOLOGY

Our **case studies** compare two projects from ATTRACT phase 1. The first, OptoGlass3D, was a business-led consortium, whose objective was developing the material and technique for commercial glass manufacturing applications (Kotz et al., 2021). The other ATTRACT case, Scintiglass, was university-led, and its objective was the development of a new component for high-energy physics research infrastructures (Dormenev et al., 2021). Both ATTRACT projects received phase 1 support. However, only OptoGlass3D went on to develop commercial applications, and to receive ATTRACT phase 2 support.

We also examine a non-ATTRACT project closely related to Scintiglass. This comparator case is within PANDA (proton-antiproton annihilation at Darmstadt), a large-scale fundamental physics project, housed within an RI. We identified the sub-project PANDA EMC as our comparator object (PANDA, n.d.) This sub-project has the task of developing the electromagnetic calorimeter (EMC, a detector) for PANDA, based on scintillating crystals. Scintiglass aimed to develop glass scintillators for calorimetric detectors (Dormenev et al., 2021), so from an innovation network point of view, the Scintiglass project fulfilled a research and development role within the technological and institutional context of PANDA EMC. We assess the impact of PANDA using the same fieldwork process and analytical framework as the two ATTRACT projects. The three cases and their defining variables are tabulated in Figure 1.

| Variable | OptoGlass 3D | Scintiglass | PANDA EMC |
|---|---|---|---|
| ATTRACT phase 1 funding | Yes | Yes | No |
| ATTRACT phase 2 funding | Yes | No | No |
| Design thinking student roles | Yes | No | No |
| Business-led | Yes | No | No |
| Research infrastructure led | No | Yes | Yes |
| Commercialisation outcomes | Yes | No | No |
| Knowledge/capabilities outcomes | Yes | Yes | Yes |

**Fig. 1.** The three CASEIA case studies and their defining variables, showing points of comparison and contrast.

The case studies were informed by secondary data, including information provided by ATTRACT. Primary data was gathered through nine in-depth interviews with key role players in each case study, including participants from universities, research infrastructures, supplier firms, and technology partners. The interviews were semi-structured, and approximately an hour in length. Interviews were audio recorded and transcribed.

Drawing on both primary and secondary data, analysis was guided by the analytical framework. For each case study, we examine each of the analytical dimensions, taking into account the structural characteristics of each project. On this basis a distinct impact profile developed for each case study, comparative analysis aims to draw tentative conclusions about the pathways through which ATTRACT support led to socio-economic impact.

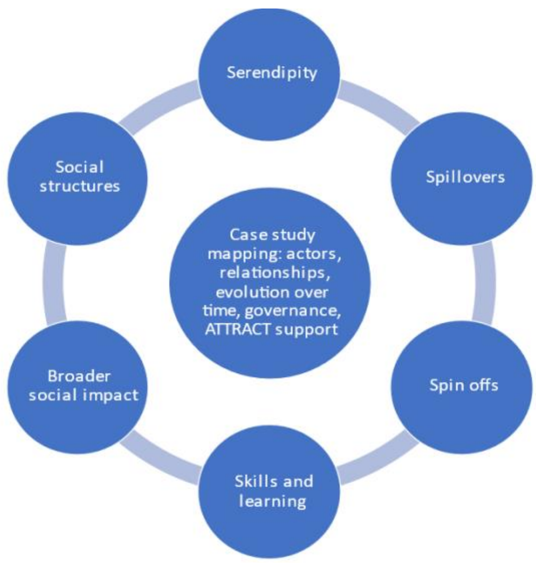


**Fig. 2.** Our six analytical dimensions of socio-economic impact and their mapping variables.

## RESULTS

Only OptoGlass3D demonstrated significant positive impacts in each of the six analytical dimensions. For both Scintiglass and the PANDA project with which it is closely related, the primary positive impacts were in the areas of knowledge production, knowledge spillovers, and skills development (Figure 3).

| Dimension | OptoGlass3D | Scintiglass | PANDA EMC |
|---|---|---|---|
| Serendipity | High | None | None |
| Spin-offs | High | None | None |
| Spillovers | High | High | Some |
| Skills and learning | High | High | High |
| Social structures | High | Some | None |
| Broader social impact | High | Some | Some |

**Fig. 3.** Impacts in our six analytical dimensions, by case.

OptoGlass3D and Scintiglass provide a useful contrast. OptoGlass3D was led by and oriented towards industry. Being embedded in industry cultures and incentives, it ultimately had impact in the industrial sector. Scintiglass was much more closely tied to the world of RIs and universities, and here the support provided by ATTRACT was not sufficient to bridge the innovation gap. OptoGlass3D had a far broader and greater set of impacts than Scintiglass, in relation to the key metrics set out by the ATTRACT framework. On the other hand, the impacts of Scintiglass bear more resemblance to the impacts of RIs in general.

This outcome raises critical questions for ATTRACT. Scintiglass was closely aligned with the initial expectations of ATTRACT, as it was embedded in the RI environment. Conversely, OptoGlass3D had little or no relation to the RI environment. The outcome, therefore, is that a project closely aligned to the ATTRACT paradigm was unsuccessful, while one more marginally aligned was considered sufficiently successful to receive further support in phase 2.

For all three cases, we found several forms of impact (Figure 3). In spaces led by RIs, knowledge spillovers were the main outcome of ATTRACT support. However, the largest areas of impact came from commercialisation. For OptoGlass3D, the broader social impact is the change brought about by its users via the market – a process that is still unfolding.

The definition of open innovation in the ATTRACT paradigm is an "open" outcome at around technology readiness level 6 or 7, where a number of applications and directions are still possible, and where the outcome is not known beforehand (Chesborough, 2015). This definition is useful in understanding why Scintiglass might have been deemed less successful than OptoGlass3D by ATTRACT, with respect to receiving further funding. The desired outcome of Scintiglass was clear from the start, namely a scintillating glass suitable for detectors in high-energy physics. No clearly defined alternative applications were foreseen or emerged during the progression of the project. Conversely, OptoGlass3D (and its phase 2 successor project, Glass2Mass) envisaged a technique with many options for applications, thus aligning well to the ATTRACT objective of open innovation.

The cultural and institutional milieux of the two ATTRACT case studies appear to have influenced the emergence of Serendipity. While Scintiglass revealed no substantial Serendipity in its innovation outcomes, OptoGlass3D exhibited Stephanian, network-emergent Serendipity. ATTRACT was able to foster Serendipity through the composition of project consortia and the involvement of Design Thinking students. However, broader conclusions about ATTRACT's hypothesis - that Serendipity is a factor in fostering innovation – cannot be made from two case studies. This would require a broader project scope and longitudinal examination.

## CONCLUSIONS AND RECOMMENDATIONS

The comparative analysis of socio-economic impact leads to conclusions and recommendations in three broad areas. The first area is that of routes to impact, including the roles of RIs and businesses, the role of open innovation, and impacts that fall beyond innovation. For each of these impact pathways, the main direction of impact flow moves from RIs, to firms, to markets, and thence to the broader socio-economic context. In parallel, however, the long-term prospect of a breakthrough in fundamental physics resents a pathway towards a broader and more fundamental impact. The second focus of our conclusion is on technological serendipity, and the efforts of ATTRACT to systematise mechanisms that may support it. Finally, we reflect on CASEIA as a pilot study. We consider its potential contribution to research at the science/technology interface, and make methodological recommendations for ATTRACT's monitoring, evaluation, and learning efforts.

### Routes to impact 1: the roles of RIs and businesses

The primary route to impact envisaged by ATTRACT is via the market through innovation and entrepreneurship. OptoGlass3D is exemplary in this respect. On the other hand, the RI-driven case of Scintiglass did not succeed in the market and did not continue to phase 2. One tentative lesson is that consortia led by industry may be more likely to achieve market-related impacts such as commercialisation and spin offs – although a larger study would be required to determine this. Another lesson may be that the core missions of RIs are distinct from the motivations of firms, which are focussed on commercialisation. The two sectors are therefore oriented towards very different institutional logics, incentives, and impact pathways. If the route to impact is primarily via the market, higher impact may be achieved by business-led initiatives. However, if an intervention targets underexploited RI knowledge – as is the case in ATTRACT - it needs to prioritise projects with a strong link to RIs.

**Routes to impact 2: open innovation**

ATTRACT adopts the Chesborough definition of open innovation as a technology with an open outcome in terms of field of application. This, too, could be an innovation accelerator if coupled with tools for Stephanian Serendipity. We saw that openness in this sense could be an indicator of impact via radical innovation. This leads us to our second recommendation: If the envisioned path to impact is via disruptive innovation, interventions like ATTRACT need to choose projects with open outcomes or coach innovators to seek open outcomes. This requires the involvement of risk-affine and failure-tolerant actors, as argued in Wallmon's "Manifesto for Anarchist Innovation" (2014).

**Routes to impact 3: beyond innovation**

Innovation does not necessarily lead to impact, nor does impact necessarily result from innovation. In Scintiglass, we saw that negative innovation outcomes can have positive impact. In this case, a failed attempt at batch production of glass beads using inorganic redux had lasting positive knowledge spillover effects within the consortium. If an intervention like ATTRACT is measured only by its innovation outcomes, valuable positive impacts can be overlooked and hence underreported. Any future intervention needs to decide whether to foster innovation or impact or, if both, to commit to impact pathways leading from innovation outcomes to Socio-economic impact largely via the market.

**Systematising Serendipity**

ATTRACT is an experiment. One of its key hypotheses - that Serendipity can be systematised to foster innovation - was not tested with academic rigour within the intervention. From our two ATTRACT case studies alone, we cannot conclude that Serendipity was systematised within ATTRACT; nor can we confirm the routes by which Serendipity might foster innovation. The true merit of the ATTRACT Serendipity hypothesis needs rigorous longitudinal testing in any follow-up intervention.

While a broad notion of Serendipity underpins ATTRACT (Wareham *et al.,* 2022) the programme had relatively few Serendipity tools at its disposal. ATTRACT relies on sectoral diversity in the innovation consortium to create fertile ground for Mertonian and Walponian Serendipity. A more pro-active tool for Serendipity is the involvement of Design Thinking students. Design Thinking asks where ideas come from, and uses creativity and play to address a problem from the needs side – a Walponian approach (Vignoli et al., 2021). Since the ATTRACT paradigm foregrounds serendipity, we recommend that it expand its serendipity toolbox, applying a more diverse set of Serendipity tools, which might readily be forged at the CERN Idea Square. Examples include:

- Multidimensional diversity in consortia, with the aim of fostering Mertonian and Walponian Serendipity;
- Further Design Thinking elements and user consultations – perhaps drawing on the quintuple helix model of innovation (Carayannis and Campbell, 2010) - to foster Walponian Serendipity;
- Selecting for "open" outcomes to foster Bushian Serendipity;
- Curated brokerage such as AIMdays (Uppsala University, n.d.), and AI-supported combinatorics, fostering Stephanian Serendipity.

**Measuring impact**

The analytical framework developed and tested in CASEIA has as its ultimate objective a step forward in methodologies to assess the socio-economic impact of interventions at the science/technology interface more generally. Its initial testing in a comparative case study analysis demonstrates its utility at this scale. At a larger scale, its application could be significantly extended. By drawing on a larger sample size, or by extending to new contexts, broader conclusions could be reached about impact at the science/technology interface. Methodologically, the first major application in this instance would be in drawing conclusions about factors extrinsic to the framework. For example, the six analytical dimensions could be mapped against a number of specific research questions, such as the role of differing TRLs, or the question of who leads the funded consortium. This is a dynamic aspect that has the potential to be responsive to emerging questions, and thus build knowledge over time. Another application of the framework, given a larger sample, would be its use to better understand the dimensions intrinsic to the framework by focusing on the intersections between two or more dimensions. Such a bivariate disaggregation would provide a framework for situating a wide range of research questions that could potentially be asked by the broader community of science and technology policy makers interested in impact at the science/technology interface.

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