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The œconomia of iron and steel.

*Material transformations, manual skills, and technical improvement
in early modern Sweden**

1. Introduction

In the preface to *Regnum subterraneum sive minerale de ferro*, from 1734, the Swedish philosopher and mining official Emanuel Swedenborg placed his ambitious text within a framework of proto-enlightenment ideals, stating that it should be in the interest of all individuals to «contribute to sciences and professions coming to a richer prosperity» (Swedenborg 1923, xxvi). He took aim at the advancing «field of metallurgical science», more precisely the processing of iron. *De Ferro* was divided into three parts, sequentially introducing the reader to production methods, assaying, and chemical experiments. This order was not chosen at random, as the author stated that an improved understanding of work processes provided a sound foundation for knowledge about finding «riches and treasures hidden in the ores, and make fuller use of them», while also enabling «as much experimentation as chemical science with its furnaces and abundance of appliances» (Swedenborg 1923, xxiv). Thus, Swedenborg imagined a bottom-up process, starting with the procedures by which nature was transformed into useful matter by working men.

Swedenborg was indeed not alone in stressing the materiality of work as the basis for metallurgical inquiries. In France, René Antoine Ferchault de Réaumur promoted «ingenious practices» attached to the «manipulation» of nature. Rejecting old alchemical principles, his work gave inputs to the «practical investigation of materials», but it also «made the body of the artisan a subject of observation and experimentation». Embodying these values, *L'art de convertir le fer forgé en acier*, from 1722, linked the pursuit for improvements in the iron and steel trade with ideas of a general «technical and economic advancement», put into motion by the uniting efforts of learned men and benevolent politics (Bertucci 2017, 54-5; 61-8). Similar endeavours took place in the German lands, where, according to Ursula Klein (2012; 2017), «savant officials» of cameralist administrations played crucial parts in shaping the evolving field of metallurgical expertise.

Réaumur's book provided inspiration for Swedenborg, with references and transcripts being made throughout *De Ferro* (Zenzén 1923, xvi; Fors 2015, 96-7). However, there were areas where the two authors differed, notably so regarding artisanal work. Réaumur, despite his emphasis on metalworking practice, distanced

* The authors gratefully acknowledge financial support from Jernkontoret (*Stiftelsen Marie Nissers fond för bergshistorisk forskning*).

himself from artisans, whom he saw as «automata» and «obstacles to the encyclopedic endeavour» (Bertucci 2017, 55). Inventions would instead be spread from «the savant's laboratory» in a top-down fashion (Bertucci 2017, 74), primarily benefiting those «who can put artisans to work, just as artisans can put their tools to work» (Réaumur 1956, 8). Swedenborg connected craftwork to knowledge-making in a somewhat more nuanced way, stressing that the know-how of «smiths, smelters, and suchlike professionals» should be «preferred or at least equated with much scientific insight», since it was «altogether connected with the actual work». Consulting artisans' «experience and knowledge», from the «practical domain», was thus a key in making «countless of secrets» known to the «scientific world». Still, and in line with Réaumur, this was not the same as to suppose anything «brilliant or ingenious» to arise out of the metalworkers' everyday toil; they were, after all, «simple people with sooty faces like the Cyclops». Moreover, the wider spread of useful know-how could hardly be entrusted to those involved in the «making of metals». Trade secrets held sway among artisans, and some of them went to great lengths to guard skills and technical competencies, thereby «withholding them from the eyes of working peers» (Swedenborg 1923, xxiv-xxv).

Unlike this «envious group» of people, members of «the society of learned Muses», to which Swedenborg included himself, would never evade from bringing valuable knowledge into public light (Swedenborg 1923, xxv-xxvi). The metal trades, being of considerable economic interest to early modern European states, was a well-chosen area for such a project. Swedenborg had gathered an extensive experience from working within the Swedish Board of Mines (*Bergscollegium*), a state organ that was deeply involved in the cross-border circulation of technical knowledge (Fors and Orrje 2019). In 1716, he was elected to an extraordinary position in the Board and from 1724, he held a permanent position as *assessor*. He made several tours in Sweden, inspecting mines and ironworks, and also travelled in Europe, gathering information about metalworking (Zenzén 1923, xiv-xv; Dunér 2013-19, 498-500; Fors 2015, 83-97).

Swedenborg's practical experiences are reflected in the rich palette of techniques described in *De Ferro*, with Sweden at the centre, but with detours to Europe. Read along other eighteenth-century printed treatises and handwritten memos, the book highlights the complex set of work methods that formed the basis of metal processing. This body of written sources informs us about, with Ursula Klein and Emma C. Spary's (2010, 19) words, «the continuous trafficking between material manipulations, explanations, and uses, and ... the various purposes served by made materials and claims to material expertise.» Zooming in on the making and adaptation of iron and steel, our text proceeds from such an objective, as it aims to scrutinise the changing interplay between manual practices, nature, and technology within the early modern knowledge economy. In doing so, we show how the working of metals in furnaces and forges was closely related to ideas of improvement in the northern outskirts of enlightenment Europe. Moreover, our discussion provides insights into the interactions between material makings and perceptions of work in a society that was still, albeit to a gradually lesser extent, dominated by ideas of a divine order.

The materiality of knowledge-making in early modern societies has been increasingly debated by scholars from various disciplines, with several publications breaking new ground in highlighting activities and movements at the basis of industrial and scientific developments. Some have bridged the spheres of «hand» and «mind», or practice and theory, by exploring links between manual work and theoretical knowledge. Others have nuanced previous understandings of one-way transfers by analysing the circulation of skills, ideas, and objects across geographical distances and social divides (e.g., Roberts, Schaffer, and Dear 2007; Davids and De Munck 2014; Smith 2019a). Metal processing is at the heart of these discussions. As noted by Pamela O. Long, mines and metalworking sites were important «trading zones» in the pre-industrial knowledge economy, stimulating encounters between learned men, officials, and artisans, while also promoting the diffusion of «practical know-how and technological expertise» through written treatises. Thus, the metal sector became a field for technical projects, linked to visions of military power and economic betterment, but it also «created disciplines of learning suitable for a readership of both the wellborn and the technically skilled.» (Long, 2001, 208-9; 2011, 107-12). Klein has similarly used the metal trades to discuss the consolidation of academic, administrative, and artisanal domains in eighteenth-century Europe. Highlighting the doings of state-employed «hybrid experts», she stresses how metalworking localities became sites for «technical work and technological research» as well as «systematic natural observation and experimentation», at the same time as «methods and experience acquired in practical contexts» gave rise to «exact and analysing natural sciences» (Klein 2017, 303).

Three aspects from previous research are of particular interest, as they place focus on useful knowledge within the «practical domain», while at the same time enabling discussions of long-term changes in a broader context of knowledge-making. First, craft skills and manual methods need to be placed at the centre of analysis. According to Pamela Smith, artisans' bodily engagement with nature and epistemological claims gave decisive input to the development of «an active science» from the sixteenth century, one that «came to include the production of effects, or productive knowledge». Thus, emerging linkages between «*episteme*, *praxis*, and *techné*» during the early modern period were built on the workshop-based shaping of a «vernacular 'science' of matter» by skilled craftspeople (Smith 2004, 7-8, 17-19). Smith has also stressed the connectedness of metalworking techniques, like measurement and testing, and «empirical practices» employed in emerging sciences (Smith 2010, 31-5; 2014, 18). More specifically, in relation to steelmaking, Phillippe Dillmann *et al* (2011, 15-19) has accentuated that the refinement of iron into steel linked «analytical science and operational knowledge».

In tandem with innovative achievements in the eighteenth-century metal sector, artisanal procedures gradually came into focus for investigation and negotiation. Many craftsmen, as proven by French cases, took active part in this changing context of skilled work, contributing to the formation of «specific patterns of open knowledge» (Hilaire-Pérez 2007, 137, 139-43; Pérez 2008, 234-36) and promoting the importance of «sensorial intelligence» to academies and state authorities (Bertucci 2017, 158-60). Similar examples can be shown from other parts of Europe, such as Sweden, where state-supported metal manufacturers played key roles in dis-

seminating new working methods (e.g. Jansson 2017). On the one hand, this development gave rise to standardisation and the launching of organisational schemes not favoured by working people, although we should not, as Ken Alder (1997, 146-53) points out, equate these measures with ‘deskilling’. On the other hand, the interest in understanding and categorising the manifold operations employed to refine natural resources were significant in nurturing visions of inventiveness, utility, and improvement, as demonstrated by Denis Diderot’s grandiose encyclopaedic project. Later, and above all through the work of Johann Beckmann, it underpinned the rise of technology as a scientific discipline (Hilaire-Pérez 2002, 137-43; Carnino and Hilaire-Pérez 2017, 18-28).

The references to Beckmann and *Technologie* bring us to our second point, namely that metalworking skills were linked to the manipulation of nature, or to several processes by which underground riches were transformed into metal products. Consequently, metalworking relied on investigations of the material world, through «observation» and «experimentation», activities that, in turn, generated information about «the structures of this world» (Bartels 2010, 73). The handling of metals, and changing perceptions of ways of working them, could thus inform us not only about manufacturing processes, but also about larger «material complexes», or «systems of knowledge that include materials, people, practices, and ideas» (Smith 2019b, 8). In employing such a perspective, we can also appreciate the multivalence of rudimentary objects, things that «were investigated using methods and concepts belonging to the scholarly world, but were never severed from the world of artisanal production, commercial circulation, and everyday consumption» (Klein and Spary 2010, 10).

It should be emphasised that the many levels and spheres of society for a long time were imagined as one divine, harmonious, and static whole. In early modern Sweden, where economic policy was formulated in line with cameralist ideas about resource utilisation and ‘useful’ industries, metalworking was seen as a key component of an inclusive *oconomia*, stretching down from the divine sphere, via the «common household» of the realm, to specific trades and individual households. Thus, the persistent trope of a prosperous householding regime in cameralist textbooks included a symbiosis between divine mineral resources, state regulation, and diligent work (Frängsmyr 1972; Rydén 2017). Similar perceptions of an all-embracing order, or, as put by Cynthia Koepp (2007, 97), that «the transformation of nature’s matter by human labour and machines is simply an extension of God’s original act of creating the world», can also be found in popularised books on arts and crafts.

In this text, we emphasise the «trafficking» between the manual working of metals and explanations of these manipulations. While eighteenth-century Sweden is placed at the centre, we duly realise, like Swedenborg, the need to insert our study within a larger context of movements and markets, our third feature. Iron and steel are good starting points, as these materials transcended the boundaries of individual economic domains, at the same time as they connected localities and work practices within Europe through trade, migration, and technical transmission (Harris 1998; Evans and Rydén 2007; Belhoste 2004). Thus, the «practical domain» of iron- and steelmaking was continuously shaped by «circulation, exchange, and appropriation»

(Klein and Spary 2010, 18), movements and activities that provide a basis for questioning ideas about «one-way communication processes» (Schilling and Vogel 2019, 11). In highlighting Swedish ironworks and steel furnaces, this study adds to previous research on the transfer of skills and technical know-how, while also demonstrating how these processes «implied plural and multicentered circulations» (Hilaire-Pérez and Verna 2006, 544). The following sections present empirical cases in a chronological order, and illustrate specific interactions, market relations, and movements. Taken together, they point to modified relations between manual skills, nature, and technology in the metal trades.

2. Manipulating the divine nature

Seventeenth-century Swedish metalworking was integrated in the European market, with growing amounts of copper and iron being exported from Swedish ports. The making of bar iron, benefitted from the immigration of Walloon workmen, saw a particular boost, and new ironworks (*bruk*) were founded close to ore deposits in the central Swedish mining region *Bergslagen* (Hildebrand 1992). This expansion also promoted steelmaking and arms production, areas linking state surveillance, commercial interests, and technical innovation (Sahlin 1931, 59-68; 73-86; Heckscher 1936, 500-6). The Great Northern War (1700-21) had a negative impact on the metal trades, but the making of arms also triggered an intensified activity at some places, like Vedeväg in *Bergslagen*, where production was directed towards fine wares. By the 1730s, when the British steel sector became a key market for Swedish bar iron, domestic steelmaking and iron manufacture were on the verge of a broader growth (Rönnow 1944, 80-154; Evans and Rydén 2007, 71-121).

In line with this development, people in the metal sector saw steelmaking as a prioritised area; «Steel ores» from Swedish *Stahlberg* could «easily [be] transformed into real steel» (Swedenborg 1923, 239). Two techniques, the making of crude and blister steel, dominated production, and continued to do so until the nineteenth century. In the former, steel was made by melting pig iron in finery forges, and then refined by welding and reheating. The resulting product was often referred to as welded steel (*gamstål*). The latter method was based upon the conversion of bar iron in steel furnaces, rendering a material that was covered in blisters, hence blister steel (*brännstål*). The making of crude and blister steel were introduced to Sweden at an early date. More lasting projects developed during the seventeenth century, depending on technical transfers from Central Europe and a well-supervised utilisation of the *Stahlberg*-resources (Sahlin 1931, 40-54). The «practical domain» of steelmaking became a subject of thorough description in reports and travelogues. The Vedeväg manufactory, producing both crude and blistered varieties, along with fine steel wares, offers good insights into the interplay of techniques, materials, and ideas about work, belonging to the same or different circulatory processes.¹

The making of crude steel was initially scrutinised by Otto Dress, involved in the production at Vedeväg (Rönnow 1944, 38-45; Kromnow 1945). In 1687, he

¹ On the processes discussed in this section and the following, see also Jansson and Rydén 2003.

used his experiences to place metalworking within a broader frame of nature, technology, and movements. Regarding crude steel, he stressed the need for good materials, focusing on the supply of iron; after all, steel was «no particular metal, but only burnt iron». When aiming for a «hard, iron-free and strong steel», the rule was that the qualities of the pig iron were kept inside the material, so that «the steel becomes as the iron is». Consequently, one should look for a hard and «very tough» iron. From «soft iron» one could only expect a «brittle and weak» material. A trained eye could spot quality differences already during the initial processing in the blast furnace. Pig iron with an «ash gray» body was free of slag, indicating that it would melt «quickly» when «penetrated» by the steelmaker's fire. Iron that was instead «white as ice» retained internal impurities that made the steel fragile.²

Swedenborg (1923, 239) also noted that crude steel tended to «come close to the nature of iron». Like Dress, he emphasised that there were ways to learn about applicable iron sorts, a knowledge that was linked to bodily experiences of the *Stahlberg*; it was a question of observing and touching quality materials. Discussing the prominent Trollbo steelworks, he stressed that a key feature was the ore extracted from the Bispsberg mine and refined into pig iron at Vikmanshyttan. This fine ore was recognised both by its «blackish» colour and by the fact that it was «not compact but composed of many small grains and crumbles between the fingers into a steel-like powder». When processed, it produced pig iron that was «very tough and all the way through consisting of sinewy fibres». The divine nature had, thus, been ordered so that underground riches were designed for unique uses, and the Bispsberg ore was «particularly suited» for making steel (Swedenborg 1923, 232).

If nature, to contemporary observers, played a decisive role in the making of crude steel, the skills of those who worked to improve nature's good properties also became a subject of extensive interest. The «material complex» of crude steel production, relating to Pamela Smith's discussion, brought together a highly varied set of methods and practical experiences. The first step of the process, to melt the pig iron, should, according to Dress, take place in specially adapted hearths, where iron pieces were placed together with charcoal. The blast had to be strong to achieve an intense fire that purified the material, so that «all the iron in it is completely burned away». This «good art» of the steelmaker, Dress noted, was one «most difficult and significant science», since several interacting factors had to be considered, including the type and amount of charcoal and the placement and rhythm of the bellows. If any of the elements failed, and a high heat was not maintained, the result was a «bad and iron-blended steel, especially in the middle of the melted piece, where the slag usually remains».³ Controlling the melting material itself was, however, always the most critical aspect of the smith's art, involving a comprehensive «sensorial intelligence», to use Bertucci's (2017, 159) term. In 1727, the Vedevåg supervisor Lars

² Uppsala universitetsbibliotek (UUB), *Handskriftssamlingen*, D.1620, Otto Dress «Beskrifning om Wapen och Gewähr, som Harnesk, Järn, och Kåppar Stycken, dem lätta och starka, kunna bekomma, Sampt om Lätta och Rätt skjutande Muaquete, Pijstole, Carabine, och studsare Pipor. Goda och Rena Låås der till, Om Ståhls Tillwårkningh, I synnerhet till Fiäddrar, lätta starka fina Klingor, sampt om andre angelägne Krig Instrumenter af Järn och Stål, af Otto Dress», 28-32; 49. Rönnow 1944, 80.

³ UUB, *Handskriftssamlingen*, D.1620, Dress, «Beskrifning», 33-8.

Harmens described how crude steel makers used a special method to separate the slag from the metal, so that the latter ended up «running dry» in the hearth. In doing so, they also «regularly powder the steel with ash, vitriol [and] alum», to enhance its quality, a procedure kept among the artisans like «a great arcanum». ⁴ Swedenborg (1923, 234-35) added that such a process required cautious testing, which further highlights the importance of dexterity and experience. The moment when the iron was «in a proper liquid state, just about turning into steel», could be detected by manually inspecting the consistency of the mass as well as by observing the changing colour of the fire. Only after a second manual test, to determine if the melted lump had «hardened» to steel at the hearth's bottom, the piece was taken to be drawn out under the hammer.

The melting-hammering procedure was repeated until the desired quality had been obtained, and then the steel was forged out into squared bars. According to Swedenborg (1923, 236), this product was referred to as «melter's steel» or «forging steel». Despite such names, it was «not yet entirely composed of a real steel substance», and had to be refined by welding to become even and solid. The latter process improved during the first decades of the eighteenth century, in connection with growing ambitions to produce fine steel wares. When Dress commented on the Vedevåg steel, he noted that it lagged behind other places, and a reason was that the smiths did not employ a special forging hearth (chafery), but welded the steel in the same hearth as where the melting took place. The result was an impure material, lacking the qualities needed to make fine wares like cutleries. ⁵ Alterations took place, however, and Harmens described a more sophisticated procedure, with a forge equipped with two separate hearths. Crude bars were placed together in bundles, reheated, and drawn out under the hammer, and the anticipated quality decided the number of welding rounds; «blade steel» was welded four times, while the harder «spring steel» went through the same procedure eight times. During this process, the steel was continuously assessed; a good bar should, when broken and inspected, be «completely white» in the fracture, «like white-boiled silver», and not «spiny or streaky, with dark spots». Marking the number of welds on each bar, the smiths also provided the works' manufacturers with a quality guarantee. ⁶

Refinement by welding, the «bundling» of crude bars, was another method by which skilled artisans manipulated the divine nature, making the material «throughout uniform» and adapting it for different uses. According to Swedenborg (1923, 238), it was a way to achieve «equal if not better quality», when compared to the renowned brands from places like Carinthia and Styria. Visiting England in the early 1720s, Henric Kalmeter observed a variety of metalworking practices in towns like London, Birmingham, and Sheffield, noticing the consumption of steel from Solingen and Styria. British steelmakers, like their Swedish colleagues, had also found ways to imitate Central European methods, creating brands such as «English Ger-

⁴ Riksarkivet (RA), *Bergskollegijum huvudarkivet*, E2i:3, Lars Harmens, «Berättelse om Wedwog och Qwarnbacka Jern och Stål Manufacturie, Upsatt år 1727», section 2.

⁵ UUB, *Handskefiftssamlingen*, D.1620, Dress, «Beskrifning», 48-49.

⁶ RA, *Bergskollegijum huvudarkivet*, E2i:3, Harmens, «Berättelse», section 2.

man Steel». ⁷ Such transfers of production techniques depended on workforce migration and the embodied dissemination of skills, clearly illustrated by the Swedish case. At Vedevåg, the steelmaking Hilphert-family descended from Thuringian immigrants. At the competing steelworks in Gravendal, the owners instead contracted an experienced Solingen-smith, Johan Wilhelm Piper, who arrived from Cologne in 1727 to supervise the making of welded steel «according to the Styrian manner». ⁸ Other places followed suite, and steelmakers were far from the only artisans arriving in Sweden. At Vedevåg, the Hilpherts provided steel to a growing number of foreign artisans, from France, England, Denmark, and Thuringia, many of whom were specialised in making fine steel wares like cutting tools. ⁹ The impact from these craftsmen requires more research, but it is not hard to imagine that «[t]he daily contact» between makers and users «benefitted the steel's quality» (Sahlin 1931, 61). Harmens noted that the foreign workers «at first did not know how to use our Swedish steel, but ... when becoming accustomed to it, they admitted, that some Swedish steel is almost as good as the Styrian». ¹⁰

Such a comment points to the importance of learning about steel by working it. Despite a variety of controls during production, the material only revealed its true nature when being further manipulated. In promoting his own invented steel – equal to «the best Styrian or any other European steel» – Dress noted that he, with «much diligence» and «the Lord's help», had contributed to the advancement of domestic steelmaking. Still, in order to determine the steel's quality, the material had to be «examined» by skilled craftsmen in Stockholm, including a Royal gunsmith and a watchmaker. Thus, a steelmaking entrepreneur like Dress was always dependent upon the manual dexterity and know-how of trained artisans. ¹¹

The efforts to improve welded crude steel paid off, with rising volumes entering the domestic market or being exported. In 1737, the new steel forge at Vedevåg, «large and complete» with two hearths and two water-powered hammers, employed three members of the Hilphert-family and two apprentices. They made blade and spring steel as well as «Styrian» varieties, a large part of which was sent to Stockholm and exported. ¹² At the same time, however, the sector faced problems, one of which was the dearness of production. Harmens noted that 115 kilograms of pig iron and 2100 litres of charcoal were needed to make just one *centner* (ca 42,5 kilograms) of spring steel. ¹³ Secondly, notwithstanding the attempts to refine the material through welding, crude varieties were always ambiguous. The quality of a single batch could be highly variable, with some bars being pure, others remained tainted by iron-strands or impurities. For this reason, makers at Vedevåg preferred another steel, one «freed from the coarse sulphur by firing». This «blistered» steel

⁷ Kungliga biblioteket (KB), *Handskriftssamlingen*, M.249, «Henrik Kalmeters resa», vol. III, 75-78; 732-38; 751-59. See also Evans and Rydén 2007, 135-40.

⁸ RA, *Bergskollegium huvudarkivet*, E4:178, 1155; Sahlin 1931, 164; 186.

⁹ RA, *Bergskollegium huvudarkivet*, E2i:3, Harmens, «Berättelse», sections 2 and 3.

¹⁰ RA, *Bergskollegium huvudarkivet*, E2i:3, Harmens, «Berättelse», section 2.

¹¹ UUB, *Handskriftssamlingen*, D.1620, Dress, «Beskrifning», Preface.

¹² RA, *Frihetstidens utskottshandlingar*, R. 2684, No. 8.

¹³ RA, *Bergskollegium huvudarkivet*, E2i:3, Harmens, «Berättelse», section 2.

could more easily be adapted by the manufacturing smiths, «by welding and hardening», and «applied for whatever type of work they want».¹⁴ While Dress stated that «steel made from burnt bar iron in furnaces» always was inferior to crude sorts,¹⁵ commentators in the 1720s and 1730s tended to agree with Harmens's observation, and held blister steel in higher esteem.

A steel furnace was erected at Vedevåg in 1721, built by bricks made from «French clay» to become «stronger and more fireproof». The cementation was carried out according to a traditional – «German» – method, using charcoal. About 2,5 tons of bar iron were packed together with «coal dust, French clay and ash», and the furnace was closed and ignited. It took about three weeks before the heated iron had transformed into steel, some of which was «unevenly burnt» and had to be «knocked off» before being handed over to the manufacturing smiths.¹⁶ Similar projects took place in the following decade, in some cases relying on English technology. These ventures show how the making of blister steel was as dependent on a generous nature as the crude steel production. While in England, Kalmeter observed how high-quality bars, mainly «Oregrund» iron from *bruk* in Uppland, were «the most coveted varieties». In Stourbridge, these bars were put into «pans, or chests», together with coal, and «converted» to steel in a week. The temperature was raised gradually, only to be lowered during the final phase, during which special care was taken so that «the iron does not melt or become fluid». The works-owner could also, contrary to crude steel production, maintain control over the cementation process, by inspecting so-called «test bars» to see if the iron was fully «converted». In Kalmeter's view, however, it was the use of coal and Swedish iron that gave the «merits of English steel».¹⁷ This combination of raw materials was also in focus at the Tyresö manufactory, outside Stockholm, where attempts were made during the mid-1730s to get to grips with the «faulty internal quality» and «weak matter» of Swedish crude steel. The English-born entrepreneur John Peter Smith succeeded, after having persuaded his steel-making brother William to join him, to set up a coal-fired furnace, which was intended to provide metalworking artisans with «steel prepared according to the English manner».¹⁸

As with crude steel, the efforts to improve blister steel production also hinged on embodied know-how. At Vedevåg, expert professionals were brought in from the outside. «[S]ince only two furnaces [batches] have been made per year for the needs of the works», Harmens noted, the steelmaker was «paid for each furnace, including expenses for travelling from and back to Stockholm» and, moreover, provided with «two assistants».¹⁹ William Smith at Tyresö moved longer distances to put the steel business in motion, as he made a «difficult, dangerous, and expensive journey» back to his native country, to procure coal, building materials, and tools. While in England, he also recruited several craftsmen, needed «for the continua-

¹⁴ RA, *Bergskollegium huvudarkivet*, E2i:3, Harmens, «Berättelse», section 2.

¹⁵ UUB, *Handskriftssamlingen*, D.1620, Dress, «Beskrifning», 28-30.

¹⁶ RA, *Bergskollegium huvudarkivet*, E2i:3, Harmens, «Berättelse», section 2.

¹⁷ KB, *Handskriftssamlingen*, M.249, «Henrik Kalmeters resa», vol. III, 732-38.

¹⁸ RA, *Bergskollegium huvudarkivet*, E4:178, 72-75; E4:181, 114-15.

¹⁹ RA, *Bergskollegium huvudarkivet*, E2i:3, Harmens, «Berättelse», section 2.

tion» of the English-style furnace, including steelmakers, cutlers, and file makers.²⁰ These cases illustrate how workforce circulation was a key in shaping a «material complex» during the early decades of the eighteenth century, one that also incorporated transports and uses of raw materials and the adaptation of building techniques. From mid-century, blister steel production rose on the agendas of state experts and entrepreneurs, as it was formed by changing ideas about work and markets as well as by movements of men, matter, and technical knowledge.

For Dress, Harmens, and Swedenborg, it was clear that God had equipped Sweden with particularly good prerequisites for metalworking. The iron trade generated valuable incomes for the state as well as for private groups, and it was therefore seen as a crucial aspect of the domestic «householding» order. To benefit from these resources, however, Swedish makers needed to improve their capacities to refine the iron, and in this context, steelmaking came to occupy an important role, as a link between iron production and metalware manufacture. While the three authors were familiar with the «practical domain» of iron and steel – Dress managed to promote a ‘self-invented’ steel variety and Harmens supervised the production at Vedevåg – they all lacked the embodied know-how required to bring about lasting improvements in the realm of everyday work. The possible ways of making and working steel remained ‘unseen’ in the sphere of craftsmanship; methods and skills could be observed and described, but were still largely inaccessible to outsiders. This gradually changed over the following decades, as some *savants* not only took over the task of describing what happened in forges and furnaces, but also engaged in transforming the divine nature themselves.

3. Hybrid experts and the quest for improvements

The development that begun in the 1710s and 1720s, at places like Vedevåg, intensified at mid-century, as new markets opened and large, state-catered, investments were made in the domestic manufacturing sector. Again, outside impressions were crucial. Travelling in the German lands, Swedish officials observed crude steel production, with an array of techniques and work practices that played an important part in a larger system of trade and consumption. In 1758, Reinhold Angerstein described various steel brands made in the Bergishes Land, many of which were exported to Britain and the Low Countries.²¹ His colleague Sven Rinman, who travelled in the same region a decade earlier, reported about the ways in which pig iron was turned into crude steel and adapted for special uses through sorting and welding, activities highlighted as the «foremost science of the steelmaker».²² From Sweden, the state supervisor for fine metal manufacture, Samuel Schröder, de-

²⁰ RA, *Bergskollegium huvudarkivet*, E4:178, 84; E4:181, 114-15; E4:183, 872-73.

²¹ RA, *Bergskollegium huvudarkivet*, E3:27, Reinhold Rüdker Angerstein, «Om Järnwärcken Bägge Sidor Rhenströmmen, Ifrån Bodensee i Sveitz till Coblentz, Af Reinhold Angerstein, utgifwen År 1758», 93-97.

²² Kungl. Tekniska Högskolans bibliotek (KTHB), *Manuskriptsamling, Bergsskolans biblioteks manuskript*, K12, Sven Rinman «Utdrag af Beskrifningarne öfwer Någre Utländske Jern och Stål Fabriqwer besedde År 1747, af Swen Rinman, Första stycket», 17-53.

described a similar structure. In 1756, he noted that eleven types of welded crude steel from Graninge and Sollefteå were sold in Stockholm. Among them were varieties previously described by Rinman, made by «Solingen-smiths».²³

This diversification was important, as it provided a foundation for the attempts to elevate domestic manufacture (Jansson 2017, 72-4; 127-38; 220-4). At the same time, the state officials were aware of the risks of building such an expansion solely on the unpredictable nature of crude steel, especially when competing with British makers. A special attention was paid to Oreground iron. Reporting from Tyresö, in 1744, Samuel Linder stated that other bars had been «completely useless» when converted in the English-style furnace.²⁴ Schröder stressed that most of the Oreground iron was «sold to England», where steelmakers already had proven that «these sorts make the best blister steel». Thus, Sweden, with only «a few furnaces», had to follow the English example (Schröderstierna 1925, I, 53). However, he did not have the technical know-how to lead such an enterprise. This instead became a task for his colleagues, Sven Rinman and Bengt Qvist. Zooming in on a «test furnace» in Vissboda and a steelworks in Stockholm reveals how the making of blister steel was adapted to Swedish ‘nature’. These practices illuminate the shaping of hybrid expertise in the intersection of science, state making, and craftwork, or, relating to Chris Evans and Alun Withey’s (2012, 555) discussion, how «new types of “enlightened” activity» became «stimulants to technological innovation».

Rinman embodies the idea of a «hybrid» individual. He was educated at Uppsala University, before entering a junior position at *Bergskollegium*. After several study tours, he rose through the mining administration. From an early age, he had combined academic studies with craftwork, and acquired experiences from training with metalworking artisans.²⁵ This inclusive approach was seen when Rinman, as state supervisor for the coarse manufacture from 1760, involved himself ‘hands-on’ in working activities, notably so in the making of blister steel. A key event, one that also made a significant imprint in Rinman’s authorship, was the encounter with Johan Ludvig Robsahm, and the attempts to construct a «Swedish» firewood-furnace at the Vissboda *bruke* in *Bergslagen* (Sahlin 1931, 90-3; Boëthius 1955, 48-62). Their task was to transform Oreground iron into high-quality steel, with the use of fuels other than imported coal or charcoal. Rinman never visited England, but Robsahm had seen coal-fired furnaces during his foreign study tour. He was willing to make further investigations at his own *bruke*, with Rinman becoming his companion (Nordenvall 1998-2000, 252). In 1766, Rinman visited Vissboda, to partake in «trials for the improvement of steelmaking», and «examine what benefits that can be expected from such new cementation methods».²⁶

²³ KB, *Handskriftssamlingen*, X.283, Samuel Schröder, «Dagbok rörande Directeurs-Sysslan öfver Jern- Stål- och Metall-Fabrikerne i Riket af S. Schröder», vol. I, 1756, 105; Sahlin 1931, 58-9; 162-3.

²⁴ RA, *Manufakturkontoret huvudarkivet*, D5:180, Samuel Linder, «Beskrifning öfwer en Engelsk Stålugns byggnad samt om processen af siefwa Bränningen el: Stålets beredan - ingifwen d. 1 Junij 1744».

²⁵ UUB, *Handskriftssamlingen*, X.286, Sven Rinman, «Lefverne och Meriter, 1789». See also Nisser 1998-2000, 212-19.

²⁶ Tekniska museets arkiv (TMA), *Sven Rinmans arkiv*, S-E:11b, Sven Rinman, letter to *Bergskollegium*, 1766-10-16.

During this ‘open-air’-experiment, Rinman made systematic observations. Four types of bar iron, three of which were Oreground brands, were packed in the two chests together with a special «additive», composed by «the same substances» as in England. Robsahm then began the process «with a slow firing». Wood was added, «every half or quarter of an hour», increasing the heat until the point when «test bars» were taken out and examined. After the furnace was cooled down, Rinman noted that most of the bars were properly «converted into steel». This was confirmed by additional tests, made by «breaking and forging» some of the bars. They proved to be «pretty strong and less brittle than the usual Swedish blister steel». Importantly, the steel was «as good as that made in coal-fire».²⁷

Rinman saw several «advantages» with the method. It was less resource intensive and therefore less costly, especially if compared to the charcoal-based production. The process also demanded «less experience and art during the firing and the maintenance of the furnace». Since the ‘new’ fuel gave a «more even heat», and thus a more evenly burnt steel, one did not have to rely on «a trained and diligent master». During the tests, Robsahm oversaw the entire cementation, assisted by one «helper».²⁸ Compared to crude steel production, Rinman added, blister steel making in «Swedish» furnaces contributed to even greater savings in terms of human resources, not only by reducing the direct labour costs, but also by avoiding the «difficulty of getting skilled welding smiths ... recruited from Germany».²⁹ Finally, in terms of dissemination, Rinman envisioned that the «test furnace» at Vissboda could inspire similar facilities elsewhere. The new technology was, thus, not site-bound, but could serve «the benefit and enlightenment» of others, a fact that the mining official took advantage of, when leading the work of replacing coal-fired furnaces with firewood-versions in Uppland during the 1760s.³⁰

Rinman took an active role in implementing the new technology, but it was a gradual process dependent upon skilled workmen. Rinman elaborated the design for a charcoal-fired furnace at Åkerby *bruk* in 1763, but it was masons and a master builder who erected the construction. An experienced steelmaker from Nykvarns *bruk*, was hired to make the first batch of steel, but also to train an apprentice, Carl Boivie, who later took charge of production. In 1768, when designing a new firewood furnace, Rinman was also responsible for the cementation, selecting fuels and iron bars as well as overseeing the firing process. It was only during the second batch that Boivie retained full responsibility of making steel at Åkerby.³¹

With the problems of furnace construction and fuelling being partially resolved, the challenge of refining the blistered bars still remained; blister steel was, although it was often purer than crude varieties, still «a very imperfect material» (Evans and Rydén 2007, 137). Welding offered a solution, but from the 1760s, growing attention was paid to another technique: crucible steel. This area of production involved

²⁷ TMA, *Sven Rinmans arkiv*, S-E:11b, Rinman, letter to *Bergskollegium*, 1766-10-16.

²⁸ TMA, *Sven Rinmans arkiv*, S-E:11b, Rinman, letter to *Bergskollegium*, 1766-10-16.

²⁹ TMA, *Sven Rinmans arkiv*, S-K:8, 71-3, Sven Rinman, essay on steelmaking.

³⁰ TMA, *Sven Rinmans arkiv*, S-E:11b, Rinman, letter to *Bergskollegium*, 1766-10-16; Sahlin 1931, 90-3.

³¹ Leufsta bruksarkiv, *Leufstaarkivet*, vol. 246, 290, 292, and 297-9.

Rinman's former assistant, Bengt Qvist, who, during a tour to England in 1766 and 1767, made observations of ways in which blister steel was brought to its «highest level» through «re-melting» in specially-made crucibles.³² Back in Sweden, he initiated the construction of a crucible steel works in Stockholm, a project that, even though it ultimately failed, has been highlighted as a pioneering technical achievement (Boëthius 1955, 76-80).

In Qvist's view, the re-melting of blister steel required a sound knowledge about the materials being processed. He stressed «the care required for the steel to retain its previous elements while dissolving in the fire», and later added that «a more evenly burnt, iron-free, and hard blister steel renders the finest, most compact, and hardest crucible steel», so that it kept its «natural qualities». Still, handling this manipulation was more a matter of finding technical solutions than of relying on the practical experience of craftsmen.³³ Reporting in 1769, he dealt in detail with the erection of air furnaces and the correct ways of putting in, heating up, and casting the steel, but said less about the proficiencies required to handle the process. A steelworks with six furnaces needed just two workers, hired to perform rudimentary chores such as inserting and removing the crucibles.³⁴ Thus, the making of crucible steel was, according to Qvist, an art almost entirely depending on the technical expertise of men like himself. Another English traveller with an interest in crucible steel, Gustaf Broling, later made similar conclusions, detailing that the «main circumstances» of production were a set of technical and material components – proper furnaces, good crucibles, and a «powerful» fuel – together with the use of high-quality blister steel (Broling 1817, 24-53).

Paradoxically, expert *savants* like Broling – who also experimented with the making of crucible steel – and Qvist had to rely on artisanal dexterity in the processing and, not least, the examining of steel. Broling stressed how the hardening process, a decisive task when making delicate items such as razors, depended on a vast «experience» in visually assessing the correct degree of heat as well as on proper manual skills gained through the «extensive handling» of the material (Broling 1817, 74). When Qvist, in 1787, after several unsuccessful attempts, presented the «improvements» made at his steelworks, he exposed similar dependencies. Parts of the output had been distributed to investigate potential markets, and among the recipients were highly reputed manufacturers, such as the Royal Swedish watchmaker Eric Lindgren and the Parisian cutler Jean-Jacques Perret. The latter responded to Qvist that he had made «different tests» with the steel, and queried if it was «made without having passed through the state of iron».³⁵ In his *Mémoire sur l'acier*, Perret (1779, 6-7) had distinguished such «natural melted steel» (*acier fondu naturel*) from

³² KTHB, *Manuskriptsamling, Bergsskolans biblioteks manuskript*, E12, no. 5, Bengt Qvist Andersson, «Beskrifning om Gjutståls beredningen».

³³ KTHB, *Manuskriptsamling, Bergsskolans biblioteks manuskript*, E12, no. 5, Qvist, «Beskrifning om Gjutståls beredningen»; TMA, *Sven Rinmans arkiv*, S-K:2, Bengt Qvist Andersson, memo to *Jernkontoret*, 1787-04-26.

³⁴ KTHB, *Manuskriptsamling, Bergsskolans biblioteks manuskript*, E12, no. 5, Qvist, «Beskrifning om Gjutståls beredningen».

³⁵ TMA, *Sven Rinmans arkiv*, S-K:2, Jean-Jacques Perret, letter to Bengt Qvist, 1783-08-01.

«artificial» blister steel, while also admitting that the «secret» British crucible steel was «the finest» variety in trade. Later writing to Qvist, he recognised the high quality of the Swedish-made imitation, and noted that «no one has been as close as you, to access its English foundation». Moreover, as a gift, Perret had made six razors from the tested materials, which were sent back to Stockholm.³⁶ Qvist later noted that these were «quite good, although some of them were too hard». Unfortunately, Perret died before a second consignment arrived from Sweden – including samples of «acier fondu nature» – and Qvist had to make do with shaving himself with his own steel.³⁷

In a concrete way, these examples illustrate how the manual handling of metals played a crucial role in producing knowledge, but it also shows how the work of hybrid experts in Sweden was intimately entangled with a complex set of makings, movements, and market contacts. As noted, such practical experiences also made an imprint on the *savants'* writings. Rinman and Qvist were not only practical men, but also writers about metalworking. If Swedenborg was our starting point to the process of treating metals within a cameralist discourse, Rinman should be placed at its tail end. He published three major publications in the last two decades of his long service to the Swedish mining administration. In 1772 appeared his *Anledningär til kunskap om den gröfre jern- och stålförädlingen och des förbättrande* and ten years later came *Försök til järnets historia*. In 1788-89, he crowned his achievement with a two-volume encyclopaedia, *Bergwerks Lexicon*. There is a clear development between these publications, with the first being a hands-on book on metal processing, while the second took a more scientific approach, compiling many experiments undertaken by Rinman. The encyclopaedia was both practical and scientific (Rinman 1772; 1782; 1788-89; Holmberg, *forthcoming* [2023]).

The beginning to Rinman's *Anledningär* was the concept of *œconomia*, and its two parts, work and nature. The crucial point was that humans manipulated nature when making goods, but the processed materials always kept some of their properties, and thus remained more or less the same, so that «art could do bits, but nature the most». Even work was a part of nature, as artisans received their skills by imitating each other, but, in the end, these talents were infused to workers through divine intervention. Dealing with skills, Rinman used concepts that stemmed from connotations to the hand, such as *handalag* (manual skills) and *hand-arbete* (manual work), but also referred to «art» as something aiming to imitate the creation. All human making were, thus, embedded in a divine and static structure, also encapsulating markets and consumption. When Rinman discussed the marketing of goods, stating that it required «all possible householding», he had a zero-sum-game in mind. If Sweden could sell steel on the European market, other makers would lose out. He talked about improving Swedish metalworking and its *œconomia*, but what he had in mind was to adjust the Swedish trade in accordance to the best practice of «more trained nations» (Rinman 1772, 5; 12; 55; 252; 256).

Qvist was not as prolific as a writer, but his two speeches in front of the Swedish Academy of Sciences were published, and the first one is worth highlighting.

³⁶ TMA, *Sven Rinmans arkiv*, S-K:2, Perret, letter to Qvist, 1783-08-01.

³⁷ TMA, *Sven Rinmans arkiv*, S-K:2, Qvist, memo to *Jernkontoret*, 1787-04-26.

He followed the same path as Rinman, but due to its compact format, he presented his ideas in a more stringent way; Qvist's speech became a kind of swansong for Swedish cameralism. His beginning was to put «more working hands» to utilise Sweden's underground «treasury», and to do that «at foreigners' expense». Sweden should make bar iron for foreign markets, but also develop steelmaking and the metal trades to expand exportation further (Qvist 1776, 3-4). As Qvist delivered his speech in 1776, it is difficult not to make comparisons with Adam Smith's *The Wealth of Nations*. Even if Qvist belonged to the cameralist 'camp' there were similarities, with an analytical link drawn between markets and production, and from there to what Rinman called a «general improvement». The latter concept, however, hardly contained what we today see as economic growth or a changing society. Neither Qvist nor Smith imagined any dramatic transformations within the sphere of production. To Smith, it was all about the division of labour, and to this, the Swedish writers added the importance of understanding the actual practices and processes of work, notably so by drawing on experiences from having interacted with artisans and involved themselves in the everyday manipulation of nature. Neither of them dwelled on ideas of technological change, and they could not do so, as the concept was introduced into the scientific discourse one year later. In 1777, Johann Beckmann published his *Anleitung zur Technologie*, but to him as well technology was a science of how to make things «in systematic order», and could almost be equated with division of labour. Rinman similarly defined «technology» as «the knowledge of how to prepare raw materials from the three natural kingdoms and to make use of them for œconomy, factories, arts and crafts» (Beckmann 1777; Sebestik 1983, 31; Rinman 1789, 969). While hybrid experts like Rinman and Qvist had entered the world of artisanal work in a more active way, it became the task of others to contribute additional layers to the understanding of work and nature, placing human makings within a framework of changing markets and technical progress.

4. Seeing the previously unseen

The dawn of the eighteenth century became a watershed for Swedish metalworking, and the new century saw an altered relationship between «*episteme*, *praxis*, and *techné*», but with the market in a more prominent position. There were different causes behind this rupture, such as the Napoleonic wars, but a more penetrating force was the dramatic development in Britain. The British market was the main outlet for Swedish bar iron and the wars hampered Swedish export, but new ways of making metals gradually grew into an even greater obstacle. The traditional narrative of this development is one of a British industrial revolution, leaving the rest of the world trailing; Swedish ironmaking faced the full power of coke smelting, steam engines, and puddling, and lost its dominant position (Harris 1988). In recent years, a more nuanced approach has been elaborated, with technological development being inserted in a social setting, embracing division of labour, tariff regimes, and market-related issues. Having said that, it is beyond doubt that British ironmaking was transformed from mid-eighteenth century, with small furnaces and forges being replaced by large ironworks. In places like Merthyr Tydfil, thousands of

workers produced more iron than the entire Swedish iron trade (Evans and Rydén 2005; Jansson and Rydén 2022).

Tony Wrigley (1988; 2010) has seen this development as one from «an organic economy» into «the mineral based energy economy», but with an «advanced organic economy» in between. With the latter, he meant a society with a foundation based upon organic energy sources, but with division of labour, intensified labour regimes, and a growing coal consumption. Qvist and Rinman belonged to this «advanced» stage. During his English tour in the 1760s, Qvist saw many ironmaking sites, and his report points to a society slowly moving out of the organic economy.³⁸ He noted processes where coal had replaced charcoal, as in roasting and reheating blooms, and described coke smelting and attempts with «bar iron making in air furnaces». However, these remarks were noted in passing and not heralded as something radically new. Instead, they were described as different ways of making iron, neither better nor worse compared to ironmaking in Sweden. In fact, he always placed Swedish charcoal-made iron, with its higher quality, ahead of British iron. In 1776, he remained in tune with the traditional matrix, in which *techné* was subordinated to the praxis of doing, and where knowledge about this praxis remained in the domain of artisanal work. Change was not on the horizon.³⁹

Qvist's report was the end of a tradition, from two angles. He was the last predecessor of Swedish ironmaking going to Britain for three decades, but more importantly, he was the last to portray English furnaces and forges in the language of cameralism. In his view, Sweden and Britain were parts of an integrated system, regulated as a zero-sum game. What Sweden lost in the British market had to be regained by an «Intrusive spirit» (Qvist 1776, 4-9; 22; 27-28). Eric Thomas Svedenstierna, who left Sweden at the turn of the century, would produce an entirely different description. After studying chemistry and mineralogy in Paris, he arrived in London in 1803, and set out for a journey to British metalworking sites, including the gigantic works at Merthyr Tydfil. His narrative includes the first Swedish descriptions of the mineral-based energy economy, with coke smelting, puddling, rolling, and steam engines (Svedenstierna 1804).

Svedenstierna was educated at Uppsala University, and entered a career in the mining administration at *Jernkontoret*, before being given the important task of supervising people employed at blast furnaces. This assignment later came to include bar iron making as well, and, from early on, he was involved in experiments to know more about the properties of both iron and steel. Although he was not an entrepreneur like Qvist, or involved in the practical side of the trade as Rinman, Svedenstierna was an «unmistakable talent [with] wide-reaching scientific and general interests, technical brilliance and fruitful ideas», and thus a perfect candidate for the task of observing British ironmaking (Boëthius 1955, 4). After his return, he became a pioneer in editing volumes on ironmaking. His intellectual beginning was similar to the one ruling at mid-eighteenth century, with a static worldview, but the journey to Britain changed all that. The market remained crucial, and Svedenstierna

³⁸ RA, *Jernkontorets arkiv, Fullmäktiges arkiv*, FIIa:20, Benct Qvist Andersson, «Anmärkningar uti Hvarjehanda förefallande Ämnen samlade på resan i England åren 1766 och 1767».

³⁹ RA, *Jernkontorets arkiv, Fullmäktiges arkiv*, FIIa:20, Qvist Andersson, «Anmärkningar».

was aware that Swedish iron producers lost ground, balancing «on the outer edge [...] undermined and weakened by foreign industry» (Svedenstierna 1810, 47, 52), after «a surprising development of England's Political, Industrial and Trade System».⁴⁰ In order to scrutinise the Swedish dependency on Britain, he developed a model centred on industry, market, science, and progress (Svedenstierna 1807a). A precondition for this analysis was the deconstruction of the previously dominating concept of trade, as an amalgam of production, commerce, and consumption. Svedenstierna began to see them as independent entities, and made a distinction between «construction methods and labour processes». He abandoned Beckman's definition of *Technologie*, as «the knowledge of handicrafts», for an analysis of technological development with a potential to change society. Physical artefacts like puddling furnaces and steam engines were placed at the centre, while labour was pushed to the background. Technology, as understood more in the modern meaning of the term, became Svedenstiernas main theme.

This replacement of labour by technology was complemented by the introduction of a novel concept, that of industry. The word existed in eighteenth-century Swedish, meaning to be diligent, but with Svedenstierna it got a modern connotation of a workshop-based production, pointing especially at British ironmaking (*Svenska Akademiens ordbok*, «industry» [<https://www.saob.se/artikel/?seek=industry,2021-08-10>]). With this discursive change, he altered the link between the market and production, to one where the market was attached to one specific type of production, that of industrial production (Svedenstierna 1807a; 1813, 60; 62). If the *praxis* of skilled workers had been at the forefront before, the internal balance of production had swung towards *technē* and *episteme*. The key features were machine makers and their machinery, and technology became the solution to a successful iron production. According to Svedenstierna, «English ironmaking can count its beginning» from the introduction of James Watt's steam engine, and the «mineral-based energy economy» had opened «prospects for a future with almost endless production» (Svedenstierna 1807a; 1807b, 27; 1813, 14; 16).

Svedenstierna thus left the static world of cameralism behind him, for one with change and progress. If British entrepreneurs had escaped the shackles of the organic economy, the same would be possible for Swedish ironmasters; the English development became not only a threat, but also a path to follow. Technology could be copied, and Svedenstierna stressed that one should have faith in development; it was necessary to «tirelessly [follow] the direction of the age and hence the improvements arising» (Svedenstierna 1807a). Gustaf Broling concurred: England was «the most industrial country», and he wanted Sweden to follow the British path (*Svenska Akademiens ordbok*, «industriell» , [<https://www.saob.se/artikel/?seek=industriell,2021-08-10>]).

In 1810, Svedenstierna outlined a future for Swedish ironmaking. Sweden had been blessed with «rich deposits of iron ore», and he told the story of how ironmaking had developed towards a progressive and enlightened present. During the eighteenth century, it reached a «greater height than ever before». The causes were a

⁴⁰ RA, *Jernkontorets arkiv, Fullmäktiges arkiv*, FIIIa, bunt 39, Eric Thomas Svedenstierna, «Allmän öfversikta af de sedan år 1805 i Svenska Jernhandteringen gjorda förbättringar».

«corporative spirit» among everybody involved in the trade, together with the «competition» on the British market. New production methods grew in importance, the «happy inventions by known *Mechanics*», and Rinman was seen a key actor in this process. However, this development reached an end with the turn of the century, as the coal technology altered the frame for Swedish producers. It was the effects of rising British output, caused by coke-fired blast furnaces, puddling, and rolling mills powered by «Mr. WATT'S improved Steam Engine», that placed Swedish ironmasters on that «outer edge». This did not mean that Svedenstierna lost the faith for the future, as «the improvement of the sciences and their application; common enlightenment and connected consideration, industriousness and thrift» meant that one only had to follow «the direction of the age», and «new ways» to markets would open. (Svedenstierna 1810, 37, 41-5, 52-5). However, it was not with Svedenstierna that this prognosis was fulfilled. The situation got worse towards the end of the wars, with a slumping production and export, and it became obvious that British industry was the main cause behind the problems; it was during the wars that puddling and rolling made the breakthrough. Only Oreground iron had a secure position on the British market, supplying Sheffield steelmakers with coveted bars.

Gustaf Ekman, a «hybrid figure» from a later generation, was the one to lead Sweden towards a brighter future, but the process was more complicated than first anticipated. Puddling was tried at a few Swedish works, but due to the lack of mineral coal, this proved to be a wrong turn. Ekman wrote that it «was difficult to directly apply English ironmaking in Sweden», but a better information about what happened in Britain would improve the knowledge «about the qualities of iron», and that in turn would make it easier to «compete». Quality was another obstacle, as puddling often gave inferior iron.⁴¹ This proved to be Ekman's approach, of trying to combine an imitation of British ironmaking with an iron of high quality. In 1828, he travelled to Britain for the first time, visiting Merthyr Tydfil as well as smaller ironworks, and after his return, he was put in charge of Lesjöfors *bruk*, in *Bergslagen*, which became his testing place for novel technology.

Ekman discovered small pockets of charcoal-made iron in South Wales and Lancashire, referring to it as the «English Walloon process», a technology with few resemblances to Swedish forges, but with charcoal usage as a crucial link. The British hearths were different, and inserted in a structure similar to the one at Merthyr Tydfil. Pig iron arrived from coke furnaces, while the blooms were taken to coke-fired welding furnaces, and the bars were shaped in rolling mills. Steam engines powered mills and hammers, and what Ekman saw was an industrial form of charcoal-made iron (*Jernkontorets Annaler* 1836, 170-250). When he returned to Sweden, Ekman set out to emulate what he had seen. The first step was to develop new hearths, but the main obstacle was welding. British coal-fired furnaces generated more heat than was possible with charcoal, but in the 1840s, Ekman developed a gas-generator that gave a more intense heat. The new technology, renamed to «Lancashire forging», began to spread among Swedish ironworks. Ekman also installed new hammers and blowing machines, seen in Britain, along with equipment to supply hearths and furnaces with pre-heated air.

⁴¹ RA, *Jernkontorets arkiv*, *Fyllmäktiges arkiv*, FIIa:12, «Directeur G. Ekmans Utländska Resa» 1833.

Others followed Ekman's trail, equipped with Svedenstierna's ideas, with the market tied to industry, and with production centred on *technē* and not on artisanal skills. They saw themselves as masters of technology. Their task was to observe British technology and bring back to Sweden what was possible to implement (Harris 1998). Teofron Munktell set out in a typical way. From a small ironworks in Leeds, he stressed that his «attention was principally drawn to [it] as its size corresponds to what [Swedish] ironmasters can erect». In a similar vein, J.S. Bagge noted that the purpose of his journey was to «acquire closer acquaintance [with] the proper machine making», and added that it was with «new inventions and improvements [that] each manufacturer took one step ahead of his competitors».⁴²

With observations like these, and a gradual implementation of new technologies, Swedish bar iron production expanded from the end of the Napoleonic wars, but the breakthrough took place with the introduction of Lancashire forging. British steelmaking was once again the main outlet for Swedish iron. Oreground iron remained the most coveted bars, but as the production of blister and crucible steel rose from mid-nineteenth century, the demand for new iron brands increased. Lancashire iron filled a void, although it always ranked as inferior to Oreground iron. French metallurgist Frédéric Le Play noted that bars from the prominent *bruk* in Uppland were purchased for prices twice as high as bars from other places (Attman 1986, 14-22; Barraclough 1987, 246-259; Rydén 1998; Le Play 1845).

A new worldview reigned within Swedish ironmaking from the early nineteenth century, with the British developments seen as both a threat and a possibility. The new generation of «hybrid figures» wanted to copy small ironworks and new machinery, with Ekman as the paramount example. He strived to combine English technology, with new hearths, welding furnaces, and blowing machines, with a continuous reliance on charcoal. For Svedenstierna, this was to «tirelessly [follow] the direction of the age», and technology was the solution. Still, a man like Ekman was also aware of the importance of skilled workers for the success of British industry. In 1833, he noted that one of the causes for the English superiority was the «common spread enlightenment among the working classes, especially the practical sciences», and he added that the development of puddling initially was hampered by the puddlers «being untrained in this profession». It was only later when «enough used workers had been created», with a «required level of skills», that the new process could spread.⁴³ The labour question returned as the novel technology was implemented at Swedish ironworks. Ekman was aware of the importance of skilled workers, when he elaborated the new refining hearths. The forgers were not used to a faster tempo resulting from higher temperatures, nor did they know the proper «work method» (*Jernkontorets Annaler* 1830, 291; 328; 331-32). Other writers likewise became painfully aware of the need for skilled artisans when introducing novel technology, but it was Ekman who led the way. He remarked that Swedish forgers had «difficulties in adapting the necessary vivacity in their motions needed for this method», and three years later, he lamented the problems with «the worker's training» (*Jernkontorets Annaler* 1832, 172; 1834, 69).

⁴² RA, *Jernkontorets Arkiv, Fullmäktiges Arkiv, FIIa*: 8-17.

⁴³ *Jernkontorets Arkiv, Fullmäktiges Arkiv, FIIa*) 12, Riksarkivet; *Jernkontorets Annaler* 1831, 531.

Some opposing voices could be heard, as when one writer noted that the quality of the iron would in the future «depend less on the forgerman's skill, industriousness and consideration» (*Jernkontorets Annaler* 1832, 105-106). Another commentator similarly stressed that the introduction of new welding furnaces could be a way of controlling artisans' work. The high temperature reached in the furnaces gave «a technical advantage», and, in so doing, these devices acted as «incorruptible controllers» to the forgermen's work at the refining hearths (*Jernkontorets Annaler* 1847, 126). The comments from Ekman show, however, an awareness of the reliance on good workers throughout the first half of the nineteenth century; the introduction of British novelties did not make artisanal skills redundant.

5. Concluding remarks

This study has highlighted the interplay between manual practices, nature, and technology within the early modern knowledge economy, using the making of iron and steel in Sweden as our main example, although integrated in a wider context of enlightenment Europe. Our analysis provides insights into the interactions between material makings and perceptions of work in a society that was still, albeit to a gradually lesser extent, dominated by ideas of a divine order encapsulating both humans and nature. With such an approach, we add to recent discussions about industrial and intellectual developments in the early modern period, elaborating on the relationship between «hand» and «mind», practice and theory, and exploring the circulation of skills, ideas, and objects across geographical distances and social divides. In these debates, the metal trades have a pronounced position, but seldom from the viewpoint of rudimentary objects such as iron and steel bars. Our study highlights the making, testing, and consuming of these bulky metal things, activities that often brought together skilled artisans and state-employed «hybrid experts».

The analysis builds on three empirical cases, all illustrating the centrality of craft skills and the manipulation of nature, but at the same time stressing the wider spatial context, with movements of people and technology, as well as changing markets. We have shown how, in the early eighteenth century, the making of both crude and blister steel relied on a sound knowledge of nature and diligent manual labour. In crude steel making, the material foundation was the rich resources of the Swedish *Stahlberg*, and in blister steel production, it was all about the high quality of Oreground iron, together with the selection of appropriate fuels. The process of transforming nature into iron and steel was in the hands of skilled craftsmen, belonging to the sphere of artisanal work, and our case also proves that localised metalworking practices often depended on wide patterns of workforce migration. Contemporary writers on the metal trades, like Emanuel Swedenborg, were well aware of these preconditions for making quality products. They could observe and describe, but never reached a full understanding of the manipulation of matter.

Towards mid-century, this static system began to crumble, when hybrid people like Sven Rinman and Bengt Qvist, entered the world of production in a completely new way. Rinman was indeed a prolific writer on iron and steel, but also a man actively engaged in everyday work. This is clearly exemplified by his dealings in blister

steel production, where he was involved in constructing new furnaces for the conversion of Swedish bar iron. The furnace test at Vissboda can be seen as the beginning of a process in which blister steel surpassed the production of crude steel, but it was also an early endeavour to scrutinise the relationship between nature and human work in a more systematic way. Not only did it affect ways to inspect the manipulation of natural resources, but it also pointed towards new ways of organising production. With Rinman's improved cementation technique, a new hierarchy was perceptible, one that was less dependent upon skilled craftsmen, and more suited to the Swedish *oeconomia*. Qvist's engagements in the making of crucible steel demonstrate this development even further, with technical expertise in a more pronounced position within the Swedish iron and steel trade.

Rinman and Qvist belonged to what Tony Wrigley has labelled «the advanced organic economy», in which a static society was gradually eroded by changes in the spheres of production, commerce, science, and politics; they thought about concrete improvements, but could not foresee a period of prolonged progress. This was to change towards the end of the century, when yet another generation of travelling *savants*, like Eric Thomas Svedenstierna, saw the full effects of the «mineral-based energy economy» in British iron- and steelmaking. Experiencing how these changes left Swedish ironworks struggling «on the outer edge», Svedenstierna did not frame potential solutions in the language of cameralism, as his predecessors, but instead viewed the British development, with an industrial production based on technical advancement, as something to emulate: it was only to «tirelessly [follow] the direction of the age and hence the improvements arising». It was up to a «hybrid expert» of a later generation, Gustaf Ekman, to accomplish what Svedenstierna had envisioned. After several journeys to Britain, Ekman came to lead the quest for improvements at Swedish ironworks, with the «Lancashire method» combining transfers of British technology with a continuous reliance on charcoal. With the new technology implemented, ironmaking expanded, and the British market became once again the main recipient of Swedish bars. The relationship established a century before, between makers of high-quality Swedish iron and English steelmakers, was strengthened, as the new varieties supplied a rising, industrial, British steel production. With Svedenstierna and Ekman, the focus on ways of refining iron into steel and metal wares that dominated among eighteenth-century cameralists, was replaced by an emphasis on pig and bar iron making. Ekman's mission was not to develop the production of steel and metal wares, but instead to adapt Swedish ironmaking to a context of industrial progress.

Notwithstanding the developments from mid-eighteenth century, from Rinman's improved steel furnaces to the Lancashire-method, it was clear that the daily production still relied on working people and their manual dexterity. In 1831, when commenting on the challenges with the Lancashire forging, Ekman highlighted the artisans' «motions» and «training», thus reinstating the balance between «*episteme*, *praxis*, and *technē*» that was missing from Svedenstierna's analysis.

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