

Russian steel production from the repeal of serfdom to the First World War

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ABSTRACT: This paper describes the development of Russian steel production over some 50 years from the repeal of serfdom in 1861 up to the First World War. The paper explains that steel output, initially from established ironworks in the Ural region which were early process innovators, increased after 1861 and grew further during the 1870s and 1880s as investments were made in the north-western, central and southern regions of the Empire including present-day eastern Ukraine. Massive increases in production then followed in the 1890s following the emergence of the southern region as the major steel producer, and crude steel production overtook that of bar iron in about 1895. Furthermore, a significant proportion of steel production was from integrated works also engaged in iron smelting; and several of the works in the south, established through foreign investment, were far larger and more modern than many of their counterparts elsewhere in Russia.

Introduction

This paper covers a period of substantial economic change and process development in the Russian ferrous metal industries commencing with the repeal of serfdom in 1861 (Esper 1982) and expansion of the Russian railway network later in the century. Associated government tariffs and financial premiums for the production of steel rails then created further incentives for investment in steelworks using new processes and large-scale production systems (Goldman 1956; Lyashchenko 1970; Blanchard 2000; 2005).

Use of the above-cited English-language sources has been supplemented by consultation of a range of sources in Russian. These include first-hand accounts of the operations and resources of iron- and steel-works in the Perm, Ufa and Orenburg provinces of the Ural region at the end of the 19th century, edited by Mendeleev (1900a); and production and process data provided by three Soviet historians, namely:

- Strumilin (1967) also cited by Esper and Blanchard, and Goldman who quoted from a previous edition of Strumilin's book published in 1935;

- Pokrovskii (1973), whose work appears in a collection of essays by researchers from the Institute of the History of Natural Sciences and Technology of the Academy of Sciences of the USSR;
- Tikhonov (1988), who provides a detailed account of the development of the Russian mineral fuel and ferrous metal industries during the second half of the 19th century.

These three texts, published by the Academy of Sciences of the USSR, have drawn on contemporary sources including state archives not usually available outside Russia; but the latter two have not been widely cited previously in the English language. Tikhonov (1988), in particular, focuses on geographical aspects of access to resources and markets for the various steelworks which he cites in his text, and that regional approach has been followed in this paper. The regions defined by Tikhonov are:

- the Ural region, situated some 1,600 km east of Moscow and covering an area of some 400,000-450,000 km² (Tikhonov 1988, 66-124).
- the central region containing Moscow, Nizhnii

Novgorod (an important centre for iron trading since the 18th century) and Bryansk (Tikhonov 1988, 191-227);

- the north-western region in and around St Petersburg (Tikhonov 1988, 227-40);
- the southern region, situated some 800km south west of Moscow and covering some 100,000km² (Westwood 1965 Tikhonov 1988, 125-190);
- eastern Poland and Finland, which were parts of the Russian Empire during the years covered by this research. Tikhonov gives less information on these regions, presumably because they were not subsequently integrated into the former USSR.

This paper also extends previous research on the Russian ferrous metal industry in the Russian pre-Revolutionary period (Hill 2016a), and contributes to an understanding of the subsequent development of the Soviet industrial base.

Social changes, market demand and process innovations

Steel output in Russia was tiny in 1860; only 1,600 tons, produced almost exclusively in the Ural region compared to 226,000 tons of bar iron, 75% of which was also produced in the Urals (Hill 2014). Although steel was a harder and tougher material than bar iron, its use had been restricted by the high costs of the cementation and crucible processes, but significant social, market and technological changes began to create a basis for expansion of Russian capacity after 1860, namely:

- the repeal of serfdom in 1861, hence providing a more mobile labour force than previously (Esper 1982);
- rapid expansion of markets for ferrous products, particularly for railway lines and equipment from 1856 (originally met chiefly by imports) following the introduction of plans for a national railway network, but increasingly from 1868 (approximately 1,000km per year of rails up to 1878) when a government subsidy was provided to encourage the rolling of rails in Russia. Many of those rails, however, were produced from imported pig iron and steel scrap but domestic production increased after the imposition of import tariffs on steel scrap and pig iron in 1881, with further increases to some 50% in 1887. Production then surged after further import tariffs on iron and steel in 1891 and the award of generous contracts for rail supplies (Lyashchenko 1970);
- technological innovation, namely the introduction of the Bessemer converter and the Siemens-Martin

open hearth furnace first patented outside Russia in 1856 and 1864, respectively (Pokrovskii 1973; Burnham and Hoskins 1943, 23-4, 35-6).

Process innovations and diffusion

Although some use of puddling, cementation and crucible processes would have continued after 1860, particularly in view of the high quality available from the latter method, they would have been expensive in terms of usage of materials, time and labour. Newer processes offered cost savings and experimental work on the Bessemer process was carried out in the Urals independently at works in Zlatoustovsk and Vsevolodovil'vensk during 1856 and 1857, and during 1863 at Verkhne-Turinsk and the long-established works in Nizhne-Tagil' where pig- and bar-iron had been produced since the early-18th century by the Demidov family (Hill 2006). The process was also introduced at the state-owned Votkinsk works in 1864, the site of the first successful implementation of the iron puddling process in Russia in 1843 (Hill 2014; 2016b).

Russian ironmasters were therefore early experimenters with the process and the large works at Nizhne-Tagil' installed a converter only some seven years after the first award of a patent for the process in Britain, subsequently displaying Bessemer steel at a Paris exhibition in 1867. Modifications to the process were subsequently introduced at Nizhne-Saldinskii (a long-established iron-works in the Ural region, also owned by the Demidovs), to compensate for the (presumably lower) silicon content of Uralian pig iron. A small Bessemer converter was also installed at Putilov's works in St Petersburg during the late 1860s, following his acquisition of the company in 1868, to supplement steel production from puddling furnaces used to manufacture steel-crowned iron rails, and another works in St Petersburg (Obukhovskii) installed a Bessemer converter in 1872. Those investments in the north-western region were followed by an installation at a works in Bryansk in the central region (south west of Moscow) in the mid-1870s. The process innovations in the Urals, St Petersburg and Bryansk therefore support Goldman's acknowledgement of Russian successes in the introduction of the Bessemer process, compared to his criticisms of the previous lack of introduction of mineral fuels and hot blast into the smelting processes in the Ural region (Goldman 1956). An innovation in flux composition (the Gilchrist-Thomas process, originally developed in 1878) to compensate for high phosphorus contents in some ores, was introduced later in 1899 (Strumilin 1967, 407), mainly in steelworks in the far south of Russia near to the Sea of Azov (Taganrog,

Kerch and Mariupol'). That technique was not widely used, however, because of brittleness in some of the resultant steel (Pokrovskii 1973).

The Siemens-Martin open hearth process (an adaptation of the Siemens puddling furnace already widely adopted in Russia for the production of bar iron; Hill 2016a) was first introduced into Russia in 1868 at the Ivano-Sergievskii works in the Urals, the Russian Society of Railways works in 1871-2 and at the Obukhovskii and Putilovskii works in Saint Petersburg in 1873-4 (Pokrovskii 1973). Although Goldman (1956) is critical of the slowness of adoption of the Siemens-Martin process, it is important to note that the first use of an open hearth furnace at a Russian works was only four years after a patent for the process was first granted outside Russia, and by 1886 open hearth furnaces were producing approximately 124,000 tons of steel, some 18,000 tons more than from Bessemer converters (Strumilin 1967, 387). Furthermore, between 1890 and 1900 the proportion of open hearth crude steel in total national steel production had reached 67% (some 1,360,000 tons), even though it was a slower process (eight hours for a batch of steel compared to two hours from a Bessemer converter). An open hearth furnace did, however, allow for better process control and consequent flexibility in production. In addition, as many of the Russian rail producers were engaged in the re-processing of iron rails to provide steel replacements (Tikhonov 1988 56-7, 227-8; Westwood 1965), and open hearth furnaces used scrap bar iron and/or steel as one of the feedstock materials in addition to pig iron, the open hearth process emerged as the preferred choice for those applications.

Although Uralian works were early adopters of both the Bessemer and open hearth processes, their volumes of steel production were low: only 16 tons in 1870 from Votkinsk and some 200-250 tons each from the works in Nizhne-Tagil' and Nizhne-Saldinsk. The largest output from any Uralian steelworks during that year was some 1,200 tons from a factory in Perm, which was lower than the production of 1,600 tons of puddled steel from Obukhovskii. By 1880, Obukhovskii had increased its production by four times following the installation of a Bessemer converter in 1872 and a gas-fired open hearth furnace in 1873 (Tikhonov 1988, 227-236; Pokrovskii 1973); the Bryanskii works in the central region was producing some 60,000 tons following the installation of a Bessemer converter and an open hearth furnace in the mid-1870s (Tikhonov 1988, 216); the Aleksandrovskii works in Saint Petersburg, which had installed an open hearth furnace in 1879, was producing more than 25,000 tons; and the Putilovskii works was achieving an out-

put of 80,000 tons following the installation of two Bessemer converters and an open hearth furnace in the second half of the 1870s to supplement production from a small Bessemer converter previously installed in the 1860s.

The outputs from the Aleksandrovskii, Putilovskii and Bryanskii works were far in excess of the 15,000 tons and 13,000 tons respectively from the two largest Uralian sites (Katav-Ivanovskii and Nizhne-Saldinskii) (Tikhonov 1988, 231), and illustrate that although some works in the Urals were relatively quick to experiment with both Bessemer converters and open hearth furnaces, one producer in the central region and two producers in Saint Petersburg had achieved far higher outputs from the processes in 1880. Furthermore, the north-western region was predominantly a user of coal as a fuel (originally imported from Britain and subsequently transported from coalfields in the south of the Empire), so mineral fuel had probably overtaken charcoal as the fuel of choice in steel production by 1880. The Putilovskii works in particular had also been a significant producer of puddled iron for rails, producing some 26,000 tons in 1870, compared to less than 9,000 tons from the two largest Uralian works (Verkhne- and Nizhne-Saldinskii). The Bryanskii works had produced some 12,000 tons of bar iron in 1875 which was also higher than production from the two largest Uralian works (Tikhonov 1988, 216, 231).

By 1890, there were ten Bessemer Converters over the whole of the Russian Empire producing some 115,000 tons of crude steel, increasing to 32 converters in 1900 producing some 674,400 tons. There was a particularly rapid growth in the south of the Empire: 21 converters in 1900 compared to only two in 1890. Although the Urals was the region with the most converters in 1890, and the second most in 1900, the quantities were relatively modest: four in 1890 (probably including Nizhne-Tagil'skii, Nizhne-Saldinskii, and Katav-Ivanovskii; Tikhonov 1988, 69) and only five in 1900. The quantities of Bessemer converters were even smaller in the other regions, namely three in the north-west, two in Poland, and only one in the central region (Tikhonov 1988 56-7; Strumilin 1967, 387; Pokrovskii 1973). Some 40% of the Empire's Bessemer Converters were therefore located in the Urals in 1890 and some 20% in the south, but by 1900 these proportions had changed to only 16% in the Urals but more than 66% in the south. By 1910, the total figure had decreased to 25 for the whole of the country, but production had increased to some 816,000 tons (Pokrovskii 1973) signifying major increases in unit capacity.

There were far higher numbers of open hearth furnaces operating than Bessemer converters, however, namely some 77 (including 19 in the southern region and 12 in the Urals) in 1890, increasing to 122 in 1895 (including 18 in the southern region and 29 in the Urals) and 159 in 1900 (including 44 in the southern region and 41 in the Urals). Those quantities were followed by the central region and Poland (31 and 29 respectively) and by the north-western region with 14. In every region, the numbers of open hearth furnaces far outstripped the number of Bessemer converters: by a factor of two in the south, almost five in the north-west, eight in the Urals, fourteen in Poland and thirty one in the central region. Furthermore, although the quantity of Bessemer converters in the southern region far outstripped those in the Urals by a factor of four in 1900, the quantities of open hearth furnaces in the two regions were approximately equal (Strumilin 1967, 387; Pokrovskii 1973).

It can also be inferred that although average output from a Bessemer converter in Russia during 1900 (some 21,000 tons) was more than twice the average output from an open hearth furnace (some 9,500 tons), the total production from the larger numbers of open hearth furnaces was far higher than from the smaller number of Bessemer converters in all regions, except the south where they were probably approximately equal. Furthermore it appears that larger steelmaking units (either converters or open hearth furnaces) were used in the south (almost 19,000 tons per unit), followed by Poland and the north-west (approximately 10,000 tons per unit, overwhelmingly from open hearth furnaces) and the Ural and central regions (approximately 6,000 tons per unit, also overwhelmingly from open hearth furnaces).

National and regional steel production (1860-1900)

As a consequence of the social, market and technological changes referred to above, Russian crude steel production increased by almost five times from its low base in 1860 to some 7,700 tons in 1870 (Strumilin 1967, 382; Tikhonov 1988, 56) although equivalent to only some 3% of bar iron output, with the Urals remaining as the largest regional crude steel producer at some 3,000 tons (Tikhonov 1988, 87; Hill 2016a). By 1880, total national production had reached almost 308,000 tons (including Poland and probably Finland) and the Ural region had been overtaken by the north-west and central regions (plus Poland) (Table 1).

The boom years for expansion of steel production, however, were 1893-1900 when demand for rail track increased to more than 3,000 km annually, accounting for some 50% of ferrous metal markets (Blanchard 2000). National production had increased by some 23% from 1880 to more than 378,000 tons in 1890, but then surged to almost 2,215,000 tons in 1900, probably surpassing bar iron production by about 1895 (Strumilin 1967, 376, 387) some five to ten years after steel production had surpassed that of bar iron in Great Britain (Burnham and Hoskins 1943, 27, 158). Growth in rail production then reduced sharply after 1900 as a result of the removal of government subsidy, but was followed some years later by a switch in demand to armaments (Blanchard 1999; 2000; 2005): production increased to 3,543,000 tons in 1910 before surging to 4,918,000 tons in 1913 just prior to the outbreak of World War 1 (Table 1).

The increases in national production outlined above occurred as a consequence of different growth rates

Table 1: Russian crude steel production by region, 1860-1913 (in tons)

Region	1860	1870	1880	1890	1900	1910	1913
Total	1,600 ^{1,2}	7,710 ²	307,756 ¹	378,147 ¹	2,214,861 ¹	3,543,000 ³	4,918,000 ³
Urals	1,600 ¹	na	38,240 ¹	44,289 ¹	307,965 ¹	na	na
South	na	na	15,000 ¹	115,000 ¹	1,226,113 ¹	na	na
Central	na	na	72,028 with Poland ¹	85,124 ¹	188,255 ¹	na	na
North and Northwest	na	na	111,316 ¹	75,502 ¹	189,892 ¹	na	na
Poland	na	na	na	55,568 ¹	294,666 ¹	na	na

Notes:

1 Tikhonov (1988, 56, 57, 178).

2 Strumilin (1967, 382).

3 Strumilin (1967, 353). Output data are provided for 'produktsiya' for bar iron and crude steel combined for 1860-1890. The proportions for 1870 are stated as 97% for bar iron and 3% for crude steel from a combined output of 257,009 tons. A combined output of bar iron and crude steel of 211,173 tons is provided for 1860, 600,000 tons for 1880, 851,000 tons for 1890, and 2,711,000 tons in 1900; these cited figures match the totals for bar iron and crude steel cited separately for the respective years in Tikhonov (1988, 56-7) and Strumilin (1967, 382). It is also likely that the data provided for output of crude steel from 1890 onwards also refers to both bar iron and steel in view of the large volumes cited for steel alone.

na = not available.

from the various regions over a range of decades, which in turn were affected by investment decisions in new production facilities. For example, although crude steel production in the traditional Uralian ironworking region increased by more than four times from about 8,000 tons in the mid-1870s (assuming that the Urals accounted for almost half of national production; Tikhonov 1988, 57-8) to more than 38,000 tons in 1880 (Table 1), the region only achieved some 12% (Table 2) of total national crude steel output, partly because Uralian ironworks continued to produce large amounts of high quality bar iron (Hill 2016a), and as mentioned previously the combined steel output from the two largest producers (Katav-Ivanovskii and Nizhne-Saldinskii) was only in the region of 25,000 tons (Tikhonov 1988, 91).

Larger quantities of crude steel were produced in 1880 in the north-west (Table 1): some 111,000 tons (using low-tariff imports of pig iron and coal) including (as previously mentioned) almost 80,000 tons from the Putilovskii works following installation of a Siemens-Martins furnace and the construction of two further Bessemer converters during 1877-8 (Tikhonov 1988, 56-7, 227-31; Blanchard 2000). The works was also the largest Russian steel producer during that year, achieving a production quantity only reached in 1893 by either John Hughes's Novorossiiskii works in Yuzovka (Bowen 1978; Edwards 1992; Thomas 2009) or the Dneprovskii plant, subsequently the country's two largest steel producers, both based in the southern region (Tikhonov 1988 140, 176, 228).

The second-largest producer in the north-west during 1880 was the Aleksandrovskii works (some 25,000 tons) which was the country's third largest steel producer at the time after the Bryanskii works, in the central region, which produced almost 60,000 tons in 1880 following the installation of a Bessemer converter in the 1870s (Tikhonov 1988, 207, 216, 228). Production also increased from the remainder of the central region and the Polish region to some 72,000 tons in 1880 (Tikhonov 1988, 56-7; Table 1), the Bryanskii works accounting

for some 80% of the region's output during that year.

The southern region meanwhile was laying the foundation for its subsequent major expansion producing almost 15,000 tons in 1880 (Table 1), the vast majority of which (some 14,000 tons) was produced at John Hughes's Novorossiiskii works, following its commencement of steel production in 1879 using an open hearth furnace (Tikhonov 1988, 56-7, 139-40). Hughes in particular gained from incentives provided by the Russian government as it sought to develop iron and steel production in present-day eastern Ukraine: those incentives included a concession for railway construction, grants of land, a generous loan, a large contract and a price premium for rail production. Although beset by early difficulties, particularly during smelting, Hughes persevered and demonstrated the commercial viability of iron smelting and steel production in the southern region (Goldman 1956; Westwood 1965; Friedgut 1989; Heather 2010).

As also mentioned previously, although most of Uralian pig iron production during the decade to 1890 continued to be used for bar iron production (more than 240,000 tons), the region's crude steel output (some 44,400 tons) had increased slightly from 1880 (38,200 tons) but was overtaken by all other regions by 1890. In the north-west, steel production had declined from some 111,000 tons to some 75,000 tons (Table 1) as a consequence of changes in import tariffs on iron and coal after 1885. Production from Aleksandrovskii fell by 60% over that decade and output from the Putilovskii works halved, although the latter works had increased its labour force in metallurgical production by some 10% compared to that of 1885 but had also doubled its number of engineering workers over the same time (Tikhonov 1988, 232). That change in labour force indicated a change in focus to higher added-value manufacture rather than just steel production.

Production continued to increase in the central region by some 20% during that decade and the Bryanskii works in

Table 2: Percentage of Russian crude steel production for each region, 1860-1913

Region	1860	1870	1880	1890	1900	1910	1913
Total	100	100	100	100	100	100	100
Urals	almost 100	na	12	12	14	na	na
South	na	na	5	30	55	na	na
Central	na	na	23 (with Poland)	23	8	na	na
North and Northwest	na	na	37	20	9	na	na
Poland	na	na	na	15	13	na	na

Note: Percentages are calculated from tonnages shown in Table 1. na = not available.

particular increased its production by a similar amount. In the southern region, however, steel production increased by almost eightfold from some 15,000 tons in 1880 to 115,000 tons in 1890 within a Russian total of 378,000 tons, surpassing all other Russian regions but still remaining second to the Ural region in the combined production of bar iron and steel (some 141,000 tons compared to 288,000 tons). The Novorossiiskii works in particular produced some 55,000 tons of steel in 1890, and the recently opened Dneprovskii works some 50,000 tons: the two works accounted for almost all of the region's output (Tikhonov 1988, 140, 178).

Uralian steel production then increased by almost sevenfold to some 308,000 tons in 1900 when the region's steel production surpassed that of its bar iron (257,000 tons: the country's highest regional production), overtook that of Poland (almost 295,000 tons), and was significantly higher than that from the north-western and central regions (some 188,000 tons each) (Tikhonov 1988, 56-7) (Table 1). Production from the south of the Empire, however, increased by more than tenfold to some 1,226,000 tons in 1900 within a Russian total of 2,215,000 tons (Tikhonov 1988, 56-57, 178) (Table 1) during a decade of rapid construction and extension of Russian railway networks and high import tariffs for ferrous products (Blanchard 2000). It is likely, therefore, that the southern region emerged as the Empire's majority crude steel producer during 1895-6 (Table 2), followed by the Urals, although the Ural region still probably matched the southern region in the combined production of crude steel and bar iron; and these majority and secondary positions for steel production were maintained during the remainder of the 19th century. By 1900, however, the southern region was producing more than four times as much steel as the Urals, and twice as much steel and bar iron combined, from a land area which was only a quarter of the size.

Steelworks' capacities and fuel selection in 1900

Introduction

Tikhonov (1988, 179) argues that the industrial revolution in the Russian iron and steel industry was virtually complete by 1900, as a high level of modern industrial capacity using advanced steelmaking techniques had been assimilated into the industry by that year. Furthermore the industry was predominantly fuelled by mineral fuels during the latter two decades of the 19th century, with the exception of works in the Ural region which still continued to harvest wood for direct use in steelmaking or to convert to charcoal for the production

of high quality pig iron. In addition the overwhelming majority of the industry was powered by steam engines, again with the exception of the Urals which continued to use the fast-flowing rivers in the region to drive either waterwheels or turbines for approximately half of its power requirements (Tikhonov 1988, 59-61). This section examines the scale of production in the various Russian regions, using the criterion used by Tikhonov (1988, 53) to define a large steelworks, namely whether it could have been classified as a 'millionaire' producer achieving an annual output exceeding one million poods (*pudy*), or more than 16,000 tons.

Ural region

In the Ural region, only two long-established steelworks produced more than one million poods in 1900 (Katav-Ivanovskii producing 16,000 tons and Nizhne-Saldinskii, some 32,000 tons) and both had been producing crude steel since the late 1870s; but of the seven steelworks built after 1890, one produced some 32,000 tons (Chusovoi, commencing steel production in 1895) and another exceeded 48,000 tons after commencing steel production in 1897 (Nadezhdinskii). Those four works, or 15% of the 27 Uralian steel producers, accounted for about 45% of total crude steel production from the Ural region (or some 6% of total national output), and some 30% of regional production was from Nadezhdinskii and Chusovoi together. Furthermore, three of the four works (Nizhne-Saldinskii, Katav-Ivanovskii and Nadezhdinskii) were also major producers of rails (Egorov 1900, 112-3; Vukolov 1900a, 183; Vukolov 1900b, 228; Tikhonov 1988, 96) and smelters of iron ore, producing some 32,000 tons, 16,000 tons and 40,000 tons of pig iron respectively (Tikhonov 1988, 87, 93), accounting for some 12% of the region's pig iron output. It appears, therefore, that a significant proportion of steel (a comparatively new material) was produced in newer and larger works, whereas pig iron (a traditional material) continued to be smelted in a long-established range of smaller works.

Furthermore, all of the millionaire works were well-resourced in terms of access to woodland (Mendelev 1900b, 40, 41), water power and pig iron (either from their own blast furnaces or local smelters using adjacent sources of good quality ore), although there would have been increased pressure on the availability of wood from 1895 when steel production expanded rapidly (Tikhonov 1988, 96). In addition, in comparison to the southern region, three quarters of the investments in the Uralian millionaire works appear to have come from Russian sources: landed or industrial aristocracy in the case of the older works (Egorov 1900, 112-15, Vukolov

1900a, 181-3) and either Russian (at Nadezhdinskii) or French (at Chusovoi) shareholders in the case of the newer (Vukolov 1900b, 222-35; Vukolov with Egorov 1900, 71-7).

Although coal production increased significantly within the region, from some 6,500 tons in 1860 to some 350,000 tons in 1900 (Tikhonov 1988, 32, 33), and some was suitable for use in copper smelting or coking for use in a mixture with wood or charcoal, the production of coke in the Urals was small: 10,000 tons in 1900 from Lun'evsk coal (which accounted for some 24% of the region's coal production) or less than 1% of the Russian total coke production. Its use within Uralian iron and steel production remained tiny: less than 3% (with hard coal) of regional fuel consumption in the region's ferrous metal industry in 1896, and less than 0.1% of fuel consumption in national iron smelting in 1900 (Mendelev 1900b, 46, 47; Tikhonov 1988, 76, 77, 110-12). This low level of consumption was a consequence of its volatility, high sulphur content and difficulty to extract because of its hardness, but also because of lack of rail communication between coalmines and steelworks (Tikhonov 1988, 76, 77, 110-12). At the large Nadezhdinskii steelworks, for example, even though established as late as the mid-1890s, charcoal was apparently selected as a fuel (Blanchard 2005) in 1896 presumably for smelting, and firewood to generate the requisite hot gases for open hearth furnaces and Bessemer converters (Mendelev 1900b, 40, 41; Vukolov 1900b, 222-35), although plans were afoot in 1899 for a railway to link the Kizelevsk coalfield with the Bogoslovsk group of works which included Nadezhdinskii (Vukolov 1900b, 227).

The only substantial use of coke and hard coal in the region was in the group of factories of the French-owned Kamsk Shareholding Society (*Kamskoe aktsionernoe obshchestvo*), which included the Chusovoi works. The Kamsk group burnt some 32,000 tons of hard coal and coke in 1896, within a regional total of some 56,000 tons, alongside some 45,000 tons of charcoal and 37,000 tons of firewood. The group was therefore by far the largest user of hard coal and coke in the region (Mendelev 1900b, 40, 41), probably mixing it with charcoal for smelting, or with firewood for steel production. In addition, two of the group's works (including Chusov) were linked to the Kizelevsk coalfield by a branch railway line built in 1879 to Lun'evsk and Berezinskii, which also joined the main line from Perm to Ekaterinburg (Vukolov with Egorov 1900, 71; Tikhonov 1988, 69-71, 104).

Subsequent development of the railway system in 1885

(Ekaterinburg-Tyumen') facilitated access to markets in Western Siberia for iron and steel from the Central Urals, and in 1892 the Southern Urals were also linked westwards by a line from Chelyabinsk extending from Ufa. Railway linkages between the Central and Southern Urals were not achieved until 1896, however, with the construction of a line from Ekaterinburg to Chelyabinsk which also continued eastwards to Western Siberia. Those railway systems were used mainly for distribution of ores (particularly those rich in manganese), pig iron, and crude and rolled steel (Tikhonov 1988, 69-71, 105-7).

Central region

Five millionaire steelworks were located in the central region in 1900, from a total of seven steel producers in the region: Bryanskii, some 300km south west of Moscow; Sormovskii in Nizhnii Novgorod, some 400km east of Moscow; Andronev'skii, also known as the Moscow Metals Factory; and Kulebaskii and Nizhne-Vyksunskii some 120km south-west from Nizhnii Novgorod. Those works used local ores sometimes mixed with supplies from the Urals, or imports of pig iron from Britain to the newer works through the well-connected railway network to and from Moscow; the major fuels were coal and coke from the Donbass or fuel oil (Tikhonov 1988, 202-7). The Bryanskii works produced almost 72,000 tons in 1890 but production had fallen to 55,100 tons in 1900; in that same year Kulebaskii was producing some 30,300 tons, Nizhne-Vyksunskii some 21,300 tons, Sormovskii some 34,400 tons, and Andronev'skii some 44,000 tons. The level of concentration was therefore particularly high in the largest steelworks in the central region as almost all of the region's steel output in 1900 was from those five millionaire works.

Three of the five works were also smelters of iron ore (in Bryansk, Kulebask and Vyksunsk), producing some 13,000 tons, 8,000 tons and 20,000 tons respectively of pig iron in 1900, although only accounting for 17% of the region's pig iron production of 234,100 tons during that year (Hill 2016a), compared to more than half of the region's steel production. As in the Urals, therefore, pig iron production in the central region appears to have been less concentrated than that of steel in the largest works. As also in the case of the Urals, the millionaire steel producers appear to have been mostly financed and owned by Russian shareholders.

The central region differed from the Urals in the existence of substantial railways before 1870 linking Moscow to two major steelworks, namely Nizhne-Novgorod (directly) and Bryansk (indirectly); and a further railway

was built in the 1870s linking Vyksunsk and Kulebask (indirectly) to Moscow (Tikhonov 1988, 202).

North-western region

Four millionaire steelworks (Aleksandrovskii, Izhorskii, Obukhovskii and Putilovskii, the largest of the north-western steelworks) were located in the north-western region in 1900, from five steel producers located there using pig iron, scrap and coal from outside the region, including significant imports from Britain. As previously mentioned, the latter works was purchased by Putilov in 1868 to produce iron rails with a fused steel crown for the Nikolaev railway, together with small quantities of engineering steels, and then expanded to larger-scale production using a Bessemer converter and open hearth furnaces (Tikhonov 1988, 228, 231). In 1900, the Putilovskii works alone produced some 93,600 tons (almost double the output from the largest Uralian steelworks) followed by Aleksandrovskii at some 24,700 tons, Izhorskii at some 20,348 tons and Obukhovskii at some 16,500 tons. The region's millionaire works consequently produced more than 80% of its steel output in 1900, or some 6% of total national production, and were owned entirely by either Russian steelmasters, merchants, or the government, apart from some French and long-standing British investment in the Aleksandrovskii plant.

Southern region

Of the twenty five iron and steel works operating in the southern region in 1900, eighteen had been established after 1896, three between 1891 and 1895, two between 1886 and 1890 (including the Dneprovskii works), and only two before 1885 (including the Novorossiiskii works established in 1871). Those enterprises benefited from the existence of a railway network between Taganrog and Yuzovka built in the 1870s, between Krivoi Rog and Yuzovka built in the 1880s, and a further Krivoi Rog link built in the 1890s.

Fifteen of the nineteen steelworks in the southern region were millionaire works in 1900 and accounted for 98% of the region's output of crude steel and 54% of national steel production (Tikhonov 1988, 140, 178). Eight of the works (Novorossiiskii, Donetsko-Yure'evskii, Druzhkovskii, Petrovskii, Sulinskii, Konstantinovskii, Mateevskii and Russkoe obshchestvo mashinostroitel'nogo zavodov Gartmana) were in the Donbass area, three (Aleksandrovskii, Dneprovskii, Ekaterinoslavskoe obshchestvo Russkikh truboprokatnykh zavodov) were near to the northern reaches of the river Dniepr (*pridnepr*), three (Nikopol-Mariupol'skii, 'Russkii Providans', Taganrovskii) were

near to the north and south coasts of the Sea of Azov (*priazovsk*) and one (Ural'skoe-Volzhskoe) in the Lower Volga (*Nizhne-Volzhskoe*) area. Six (Novorossiiskii, Dneprovskii, Aleksandrovskii, Petrovskii, Druzhkovskii, and Taganrog) of the nineteen millionaire works produced more than five million poods each (some 80,000 tons) and together accounted for some two thirds of southern output, or some one third of national production. Two (Novorossiiskii and Dneprovskii) of those six each produced more than 10 million poods annually (some 160,000 tons): 173,000 tons in the case of the former, and 218,000 tons in the case of the latter, and together accounted for one third of southern output, or more than 15% of national production.

Most of the millionaire steel works in the south appear to have been wholly owned by foreign companies, with the exception of the Silunskii and Aleksandrovskii works which were Russian-owned, and the Nikopol'-Mariupol'skii, Taganrog and Ural'sko-Volzhskii works established as joint ventures between Russian and Belgian companies. The levels of foreign investment in Russian mining and metallurgy increased rapidly over the last decade of the 19th century, accounting for 65% of total investment in 1890 and 72% in 1900, and approximately half of total foreign investment in Russian enterprises during the 1890s went into southern mining and metallurgical operations, possibly accounting for 90% of total capital investment there in 1900 (Falkus 1972, 70, 72).

The seven largest steelworks located in the Donbass produced collectively some 550,000 tons of steel in 1900, accounting for some 45% of the southern region's steel production; and three of those works (Novorossiiskii, Druzhkovskii and Petrovskii) were also major producers of rails accounting for more than 250,000 tons in total or more than two thirds of their steel production. The remainder of works in the area, however, appear to have had a more diverse product range including engineering (eg the Gartman works). The three works located near to the Dniepr produced some 470,000 tons of steel in total accounting for almost 40% of the southern region's production, and two of those works (Aleksandrovskii and Dneprovskii) were significant rail producers; although the proportion of rails in their output was lower than for those steelworks in the Donbass, and the third works appears to have specialised in the production of steel tubes (Ekaterinoslavskoe obshchestvo Russkikh truboprokatnykh zavodov). The four remaining works in the Priazov and Nizhnyi Volzhsk regions were smaller than the larger ones in the areas referred to above, with a product range not dominated by rail production.

The Novorossiiskii works was also the largest smelter of pig iron (272,000 tons) in the country and the Dneprovskii works was the second largest (almost 213,000 tons) (Tikhonov 1988, 140, 152, 156, 171-3, 178); those two works accounted for almost one third of the region's pig iron production. Four other large producers of steel (Aleksandrovskii, Petrovskii, Druzhkovskii, and Taganrog) were also significant smelters of iron ore, producing some 156,000 tons, 152,00 tons, 96,000 tons and 80,000 tons of pig iron respectively, accounting for more than another third of the region's pig iron production. Of the fifteen millionaire steelworks in 1900, eleven of them were also millionaire smelters of iron ore, producing some 87% of the region's pig iron and almost 45% of national production. The levels of production and concentration for both pig iron and steel production in the southern region in 1900 therefore reflected the large scale of investment of modern equipment for both smelting and steelmaking, combined with high levels of integration. Furthermore, all of the steel output from the southern region was coal-fuelled; the Donbass region was a large coal producer in 1860 (about 100,000 tons), overtaking the Dombrovsk region in Poland by 1870 and reaching almost 10 million tons in 1900 (Tikhonov 1988, 32-3), a significant proportion of which was converted to coke for use by iron and steel producers (Tikhonov 1988, 150, 156).

Power and productivity: Regional comparisons in 1900

In 1900, some 308,000 tons of crude steel were produced in the Ural region in 17 steelworks employing some 4,700 direct workers, whilst in the southern region the corresponding figures were some 1,226,000 tons from 14 steelworks employing some 11,360 direct workers (Tikhonov 1988, 62). The output from the average southern steelworks was therefore almost five times that of its Uralian counterpart, and the average tonnage per direct worker some 65% higher (108 tons per worker per year compared to 65 tons) as an average southern works employed about three times as many direct workers as its Uralian counterpart. The Uralian figure was higher than that of the central region (41 tons per worker, from 4,656 direct workers) which shared similarities in the sizes of works, and almost identical to that of the north-west (66 tons per worker from 3,191 direct workers, which may have been influenced by similarities in product mix), but lower than that of Poland (95 tons per worker from 3,354 direct workers) which approached the performance of the southern region (Tikhonov 1988, 62). The output per worker becomes even more marked, however, when auxiliary (or indirect) workers are included (108,283

in the Urals but only 4,151 in the south) although the Uralian figure would have included those engaged in charcoal production, whereas coal mining and coking in the south would have taken place in separate enterprises from steelmaking (Tikhonov 1988, 62, 63).

It is difficult, however, to estimate the differences in power per worker in steelworks as available data on horsepower refer to metallurgical enterprises including smelters, bar iron fineries and puddling furnaces, as well as Bessemer converters and open hearth furnaces. Higher levels of power would certainly have been demanded for bellows at the newer iron- and steel-works, thereby usually requiring steam engines (which in their turn needed abundant fuel supplies) rather than relying on water wheels. The average power used at a Uralian metallurgical works was of the order of 550 hp, some 20% lower than in the central and Polish regions (some 700-800 hp), and far lower than in the north-western and southern regions (some 4,500 hp and 9,000 hp respectively). In addition, the ratio between steam power and water power was completely different in the Urals than in the other regions; steam power and water power were approximately equal in the Ural region in 1900 including a higher proportion from water turbines compared to 1890, whereas steam power was some 25 times higher than that from water in the central and Polish regions in 1900, some 250 times higher in the north-west and some 400 times higher in the south (Tikhonov 1988, 62).

Steel production, 1900-14

As explained above, Tikhonov (1988, 179) argues that the industrial revolution in the Russian iron and steel industry was virtually complete by 1900, as a high level of modern industrial capacity using advanced steelmaking techniques had been assimilated into the industry by that year. In the early 20th century, however, government support for railways ceased abruptly, causing over-capacity in many works, although the Ural region was partially exempted as the steelworks there tended to produce high-quality engineering steels, and works in the north-western region continued to supply to a range of local engineering companies and shipyards. The southern steelworks attempted to solve the crisis by means of cartelisation and sales allocation, until government support for railways was replaced by urgent requirements for steel to increase production in the arms industry (Blanchard 2000; Falkus 1972, 75-84) as a consequence of worsening international relations with Japan in 1904 and Germany in 1914. Steel production consequently increased to some 3.5 million

tons in 1910 and almost 5 million tons in 1913 (Table 1). This growth in production after 1900, however, was obtained from consolidation and expansion of existing works rather than the creation of any new major sites (Tikhonov 1988, 179).

Production of crude steel continued apace in Russia until the outbreak of the First World War, but its level of steel production in 1914 lagged behind USA, Germany and Great Britain, approximating to that of France although exceeding that of Belgium. Nevertheless, by the outbreak of the First World War, a modern industry existed in the south of the Empire and a longer-established industry continued to produce in the central region and the north-west, but particularly in the Urals – a strategically important location far from possible foreign incursion. The rate of expansion of Russian steel production between 1860 and the eve of the Bolshevik Revolution had therefore been very high, with the majority produced in fairly modern furnaces and mills.

Conclusions

The changes in industrial technology in Russian steel production, and its location, from 1861 to 1914 can be summarised as:

- introduction of the Bessemer process in the early 1860s and the Siemens-Martin open hearth furnace later in the decade which facilitated large scale production of crude steel directly from pig iron, rather than from bar iron on a smaller scale as previously. Two of the earliest adopters of the Bessemer converter and Siemens-Martin open hearth process (within one year and four years respectively of the granting of the processes' patents) were long-established works in the Urals region. In addition, two other steelworks in St Petersburg also began to use Bessemer technologies during the late 1860s followed by the implementation of open hearth furnaces from the 1870s. Another two works, one in the central region and the other in the north-west, were also early adopters of the open hearth process in the 1870s. Those latter four works demonstrated innovation in scale of production as well as process, and by the mid-1880s the north-western and central regions had achieved larger quantities of steel production than the Urals which continued to produce large quantities of bar iron.
- relatively faster adoption of steelmaking processes by Russian works compared to the previous 50 year lag behind their English counterparts in the diffusion of puddling from 1843; and the even longer lags for the adoption of mineral fuels and the use of hot

blast in the smelting process, although Uralian coal was difficult to mine and the hot blast process was not always the best for Uralian ores (Hill 2016a). Those steelmaking innovations in both process and scale during the 1860s to the 1880s were then followed by massive foreign investment in the southern region during the 1890s, encouraged by government incentives through tariffs and prices. Those investments focused on even larger scales of production than previously, through transfer of West European techniques and organisation.

- increasing use of coal as a fuel for steelmaking and iron smelting, commencing in the north-west from the late 1870s using the region's geographical advantage for imports of pig iron, scrap and coal; but especially in the southern region from the 1880s as rich resources of coking coal began to be exploited. The use of wood as a fuel continued to be dominant at works in the Ural region, which produced large quantities of bar iron as well as steel. The exception to the non-use of coal in the Urals was a French-owned group (Kamsk Shareholding Society).
- almost exclusive use of steam engines to provide power for air blasts in Bessemer converters and open hearth furnaces throughout the Empire by 1900, except in the Urals. In view of its widespread availability, water power continued to be used there to produce approximately half of the requisite power, albeit by increasing use of the more efficient water turbines rather than waterwheels; although it is likely that steam power was introduced in most of the larger Uralian works to achieve the requisite scales of production.
- production by 1900 of almost 70% of the total national steel output from works manufacturing more than 16,000 tons per year, including almost 50% from works in the south of the Empire. Many of these steelworks were also integrated with iron smelters accounting for approximately 50% of national pig iron production in 1900, including some 45% from the south.
- dominance of the southern region as a producer of steel rails, particularly at three works in the Donbass although three of the four largest Uralian works were also significant rail producers. Many established works in the north-western and Ural regions, however, produced steels for a wider application or converted their steel to higher-value engineering production.

This research has also highlighted that the mid-1890s emerged as the years in which revolutionary changes occurred in the industry. In the first place, there was a

major change in the mix of products manufactured, with the production of crude steel outstripping that of bar iron in about 1895. Secondly, production from investments in integrated iron smelters and steel furnaces in the south of the Empire, funded mainly by West European capital and supplied by railway networks which enabled ore and coal to be easily moved from source to furnace, had overtaken those from all other regions and accounted for more than 50% of total national production in 1900. In addition, almost all of the southern iron- and steel-works were based on the process configurations of Western European iron- and steel-masters using coal-based technologies for smelting, steel production and power. The production from the southern region continued to increase as new iron- and steel-works built in the 1890s had a higher output than many of the producers in other regions.

As well as being a period of rapid advances in technology, the time interval covered by this paper was also a period of major changes in location of capacity in the industry, even more massive in scale than that of the previous eastward shift in the 18th century from the central and north-western regions to exploit Uralian availabilities of good quality ores, abundant forests and water power. In the late 19th century, however, although the Urals remained as an important region of steel production, there were major investments in the central and north western regions during the 1870s and 1880s, and then in the south of the Empire to exploit resources of good quality coking coal in the Donbass and ores in Krivoi Rog from the 1880s and 1890s.

That investment in steel furnaces and iron smelters in the south was also paralleled, particularly after 1890, by the development of railway networks linking ironworks to coalfields and ore supplies, as well as to markets; the growth in railway networks in its turn also continued to drive demand for steel rails and rolling stock. Steelworks in the south of the Empire were generally much bigger and their furnaces and converters far larger than those in other regions (excepting Poland), and their output per direct worker was significantly higher. Furthermore, there were also differences in crude steel production processes between the south and the other regions; open hearth furnaces were preferred by far in the Urals, central and Polish regions, whereas the differences in output between the two processes were less in the northwest and far smaller in the south of the Empire.

Although distant from major iron consumers in European Russia, the Ural region maintained its militarily strategic advantage of being far removed from potential invading

armies. Uralian ironmasters enlarged their production capacities, maintained their large scale systems of water- and land-transport from ironworks to customers previously established in the 18th century, and were able to access railway connections in the late-19th century. By 1900, the Urals had emerged as the second most important regional major steel producer whilst continuing as the largest regional producer of bar iron, although its position had changed from producing some 80% of ferrous materials to some 20% as a consequence of rapid expansion of ironworks and railways in the south of the Empire.

Production of crude steel continued apace in Russia until the outbreak of the First World War, but its level of steel production in 1914 lagged behind USA, Germany and Great Britain. Nevertheless, by the outbreak of the First World War, a modern industry existed in the south of the Empire following rapid expansion, and a longer-established industry continued to produce in the central region and the north-west, but particularly in the Urals. Although suffering widespread destruction during the four year Civil War after the Bolshevik Revolution, sufficient of the infrastructure remained to enable subsequent rapid expansion by the Soviet government after 1929 (Cooper 1977).

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Note on transliteration: all published sources in the Russian language cited in this paper, as well as references to places and individuals, have been transliterated from the Cyrillic script in conformance with British Standard BS2979:1958 (*Transliteration of Cyrillic and Greek characters*). In works published before 1917, attempts have been made to approximate the older script to the modern version of Cyrillic before transliteration. In addition, most of the names of works referred to are usually linked to their location (eg Nizhne-Tagil'skii based in Nizhne-Tagil', and Bryanskii based in Bryansk). The major exceptions are the two Aleksandrovskii works in the north western and southern regions named after Tsar Alexander, and some other works named after their owners (eg the Obukhovskii and Putilovskii works owned by Obukhov and Putilov). The famous Novorossiiskii works established by John Hughes in Yuzovka (now Donetsk) relates to its establishment in the then 'New Russia' area of present day eastern Ukraine.

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