Leapfrogging or Path Dependence? Water Mills and Long-Run Growth in the Scottish Industrial Revolution*

Malte Hinrichs†

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Abstract

Does technological change favour agile entrants or adaptable incumbents? I examine this using Scotland's industrialisation, testing whether steam power allowed new locations to "leapfrog" centres of water power. Using a newly constructed dataset linking over 1,200 pre-industrial mills to parish-level outcomes, and an instrumental variable strategy based on geographic endowments, I reject the leapfrogging hypothesis. An additional mill in 1755 caused 8% higher long-run population growth (driven by migration), with effects intensifying precisely when steam power became abundant. Micro-evidence reveals that hydraulically advantaged mill sites largely survived, transitioned to industrial production and avoided obsolescence by integrating steam power as a complementary technology. The findings demonstrate that proto-industrial water power provided the critical infrastructure and human capital for the steam age, challenging the view that coal endowments alone determined the industrial map.

Keywords: Industrial Revolution, path dependence, human capital, migration, energy transition

JEL Classification Codes: N13, O33, J24, R11, N73

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†Department of Economics, Queen's University Belfast and Centre for Economics, Policy and History. Email: mhinrichs01@qub.ac.uk

"The entire history of the development of machinery can be traced in the history of the grain mill. The factory in English is still called a mill.*"*

— Karl Marx: *Das Kapital* (1867)[1]

1 Introduction

Why did some regions flourish during the Industrial Revolution while others languished? A dominant narrative, powerfully summarised by Sidney Pollard, argues that "the map of the British Industrial Revolution […] is simply the map of the coalfields" (1981, p. 4). This view, supported by influential scholars who see coal as a necessary condition for sustained growth (Wrigley, 1959; Allen, 2009; Fernihough and O'Rourke, 2021), posits that access to this novel energy source was the primary determinant of industrial geography.

This coal-centric perspective, however, overlooks the kinetic energy source that powered early mechanisation and shaped economic activity for centuries prior: water. Scholars like Reynolds (1983), Mokyr (1992), and Crafts (2004) have long emphasised that the roots of the Industrial Revolution lie in the application of water power, a technology that was widespread and sophisticated in Europe long before the advent of steam. This established proto-industrial base raises a fundamental question about the nature of technological transitions: path dependence versus leapfrogging.

At the heart of this inquiry lies a tension between two economic forces: Did early advantages, such as an abundance of water mills, create self-reinforcing patterns of development that persisted through technological change? Or did the advent of steam power as a new general-purpose technology allow other regions to bypass, or "leapfrog", established centres, rendering their initial advantages obsolete? The latter view suggests a process of creative destruction, where incumbents become "locked in" to older technology while agile entrants in new locations seize the advantage.

[1] Translation from German: "Die ganze Entwicklungsgeschichte der Maschinerie lässt sich verfolgen an der Geschichte der Getreidemühlen. Die Fabrik heisst im Englischen immer noch *mill*." (Marx, 1867, p. 332)

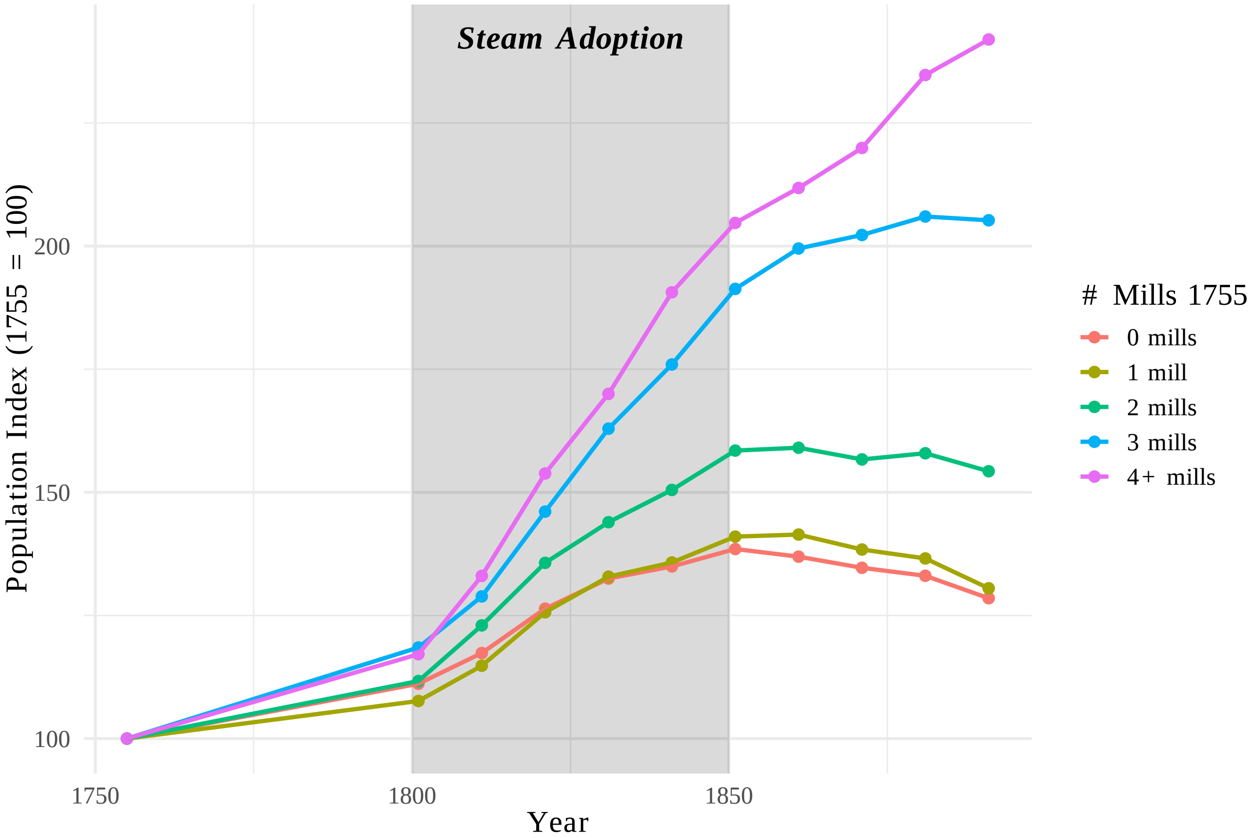
A focus on Scotland helps fill a notable gap in the economic history of the Industrial Revolution. While the English case has been extensively documented, Scotland's industrialisation and its foundations remain far less studied. As a centre of the Scottish Enlightenment, the nation produced thinkers like Adam Smith who theorised the new economic age. It was also the birthplace of key technological innovations, most famously the improvements James Watt made to the steam engine. This combination of an innovative intellectual climate and foundational technological advances makes Scotland an ideal setting to investigate how the critical transition in power sources unfolded in a country that both generated new technologies and proved unusually ready to adopt them.

Scotland's rugged topography offered abundant water power potential, which was harnessed by over 1,200 mills dotting the landscape by 1755, on the eve of industrialisation. The country then experienced a dramatic transformation as one of the birthplaces of the Industrial Revolution. A preliminary look at the data reveals a striking pattern. As shown in Figure 1, parishes with a greater number of water mills in 1755 experienced substantially faster and more sustained population growth over the subsequent 140 years. This powerful descriptive evidence motivates the central hypothesis of this study: that pre-industrial water mills were not relics of a bygone era but foundational pillars of Scotland's economic transformation.

This paper provides robust causal evidence for industrial path dependence using a comprehensive dataset that combines newly digitised mill locations from old maps with parish-level demographic and economic data spanning nearly 150 years. The main findings demonstrate that pre-industrial water mills were powerful engines of long-term development. By the end of the nineteenth century, a parish with one additional water mill in 1755 had experienced approximately 8% greater cumulative population growth than an otherwise similar parish. This effect became statistically significant in the 1820s and 1830s, precisely during Scotland's period of rapid industrial expansion, indicating that these sites became focal points for mechanised production during the critical transition period.

Crucially, the Scottish evidence directly contradicts the "incumbent lock-in and entrant leapfrogging" dynamic documented by Hornbeck et al. (2024) for the United States. Instead of becoming technological dead ends, Scotland's water-powered parishes successfully adapted to become centres of steam adoption and industrial diversification. By 1800, around six additional

Figure 1: Time Series Plot of Population Growth by Water Mills in 1755



Notes: The plot illustrates the evolution of population indices for parishes categorised by the number of water mills present in 1755 (0 mills, 1 mill, 2 mills, 3 mills, or 4+ mills). Each category begins with a base index of 100 in 1755. For subsequent periods, the index is cumulatively updated using the average population growth rate calculated across parishes within each category. Points represent the index values at each observed year, connected by lines to show trends over time.

Sources: As described in the text.

pre-industrial mills were associated with the installation of one additional steam engine outside of collieries. By 1850, two additional 1755 mills were associated with one additional textile mill. The effect further extended to wood, paper, metal, and chemical mills, showcasing broad industrial diversification rooted in the original mill sites. This reveals a story of path dependence where pre-industrial mill sites first evolved into water-powered factories and were then augmented by complementary steam engines.

The analysis of the demographic mechanisms driving this growth uncovers that population increases in mill-intensive parishes resulted primarily from migration rather than fertility changes. The 7.5% population growth effect between 1801 and 1851 can be decomposed into three main channels: a bit less than half of that growth derives from reduced emigration from these thriving parishes, while the remaining effect comes from in-migration, split roughly equally between short-distance migrants from within 50 km and foreign migrants, overwhelmingly from Ireland.

Occupational data from the 1851 census reveals that these parishes also developed distinct labour market profiles. Locations with more pre-industrial mills hosted significantly higher shares of millwrights and machinery manufacturers. This relationship also holds when examining workers by their parish of birth, suggesting that these sites facilitated the local accumulation of mechanical skills.

To conduct this analysis, I constructed a comprehensive dataset that unifies previously disparate sources at the Scottish parish level. This combines newly digitised mill locations from the Roy Military Survey of Scotland (1747–1755) and the First and Second Ordnance Surveys (c. 1850 and 1900), with demographic data from Webster's census of 1755 and each decennial census from 1801 to 1891. The dataset further incorporates geographic variables including water power potential, land capability, terrain ruggedness, distances to coal deposits and historical ports, as well as historical institutional factors such as Royal burgh status or religious composition, and transportation infrastructure including canals and railways. Additionally, I unified industrial data from Factory Returns and early steam engine records at the Scottish parish level, and derived migration patterns from the 1851 census. This provides unprecedented spatial and temporal coverage for Scotland during its Industrial Revolution, made robust by the remarkable stability of Scottish civil parish boundaries throughout the period.

The empirical analysis employs an instrumental variable (IV) strategy to isolate the causal effect of water mills from unobserved confounding factors. I exploit the fact that pre-industrial mills required both a suitable power source and local economic demand. The instrument is therefore the interaction between a parish's water power potential (supply of energy) and its agricultural land capability (proxy for grain milling demand). This approach is valid for two reasons. First, the instrument is highly relevant: the interaction between high water potential and good grain suitability is a strong predictor of historical mill placement, confirmed by a first-stage F-statistic of over 200. Second, it satisfies the exclusion restriction: while water potential or land quality alone could affect growth through multiple channels, their specific interaction is uniquely tied to the feasibility of mill construction in the pre-industrial era. By simultaneously controlling for the individual effects of both interacted variables, the strategy isolates the variation in mill presence that is plausibly exogenous to other drivers of industrialisation.

In addition to providing a valuable new database for future research, my study makes several distinct contributions to the literature. First, it establishes a causal link between pre-industrial water mills and long-run industrial development, demonstrating that the geography of the Scottish Industrial Revolution was deeply rooted in its proto-industrial past (Reynolds, 1983; Mokyr, 1992; Whatley, 1997).

Second, it provides a clear counterexample to the leapfrogging narrative in technological transitions (Franck and Galor, 2021; Fritzsche and Wolf, 2023; Hornbeck et al., 2024), showing how incumbents can successfully adapt when new technologies emerge. This suggests that the high costs and initial unreliability of steam made its adoption most logical as a complement to existing water power installations – a dynamic of technological succession rather than displacement.

Third, my study adds crucial nuance to the debate over coal's primacy in industrialisation (Pollard, 1981; Allen, 2009; Fernihough and O'Rourke, 2021). The findings suggest that coal's benefits were most effectively exploited in regions that already possessed a proto-industrial base built on water power, which provided the infrastructure, skills, and agglomeration economies necessary to leverage the new energy source effectively.

Fourth, my study contributes to the literature on the origins of industrial human capital (Mokyr, 1992; Mokyr et al., 2022; Kelly et al., 2023) and the effects of industrialisation on skill levels (Feldman and van der Beek, 2016; de Pleijt et al., 2020; Diebolt et al., 2021). I provide new evidence for the human capital dimension of path dependence by linking 1755 mills to the location of mechanical trades in 1851. This finding supports the argument that proto-industrial facilities served as training grounds for the technical expertise that underpinned the Industrial Revolution.

Finally, by detailing the migration channels underlying demographic change, the paper underscores the importance of labour mobility as an enabling condition for industrialisation, which, as Houston and Withers (1990) notes, was particularly high in Scotland, facilitating the reallocation of workers to emerging industrial centres.

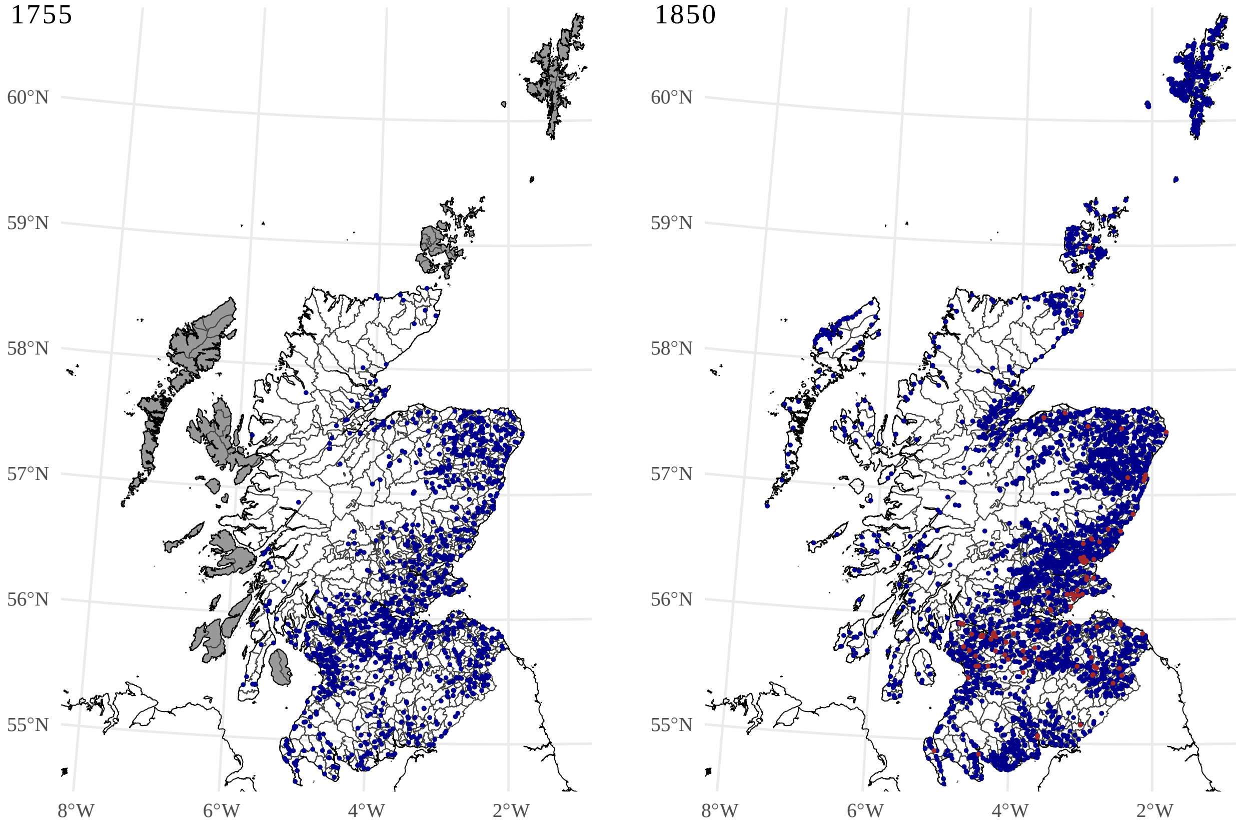
2 Historical Background

2.1 Water Mills and Early Industrialisation in Scotland

Scotland entered the Industrial Revolution with a long tradition of water power use. Present in Europe since Roman times and with a notable surge in the Middle Ages, water mills were an important part of pre-industrial production (Curwen, 1944; Wilson, 2002; Langdon, 2004). They were used for a wide range of productive activities: grain grinding, sawing, weaving, metal processing, bone milling and many more (Reynolds, 1983; Lucas, 2006). As Reynolds (1983, p. 5) summarises: "Because of its ability to reduce dependence on human labour, to increase productivity, and to carry out tasks nearly impossible with animate power sources, the water wheel became the power source of first choice in European heavy industry by the end of the medieval period."

Scotland was no exception to the success of water mills in pre-industrial Europe. Its rugged geography provided almost ideal conditions for the use of water power, so that prior to 1750, small water mills dotted large parts of Scotland (Jonell et al., 2024). The central Lowlands are punctuated by fast-flowing rivers (Clyde, Forth, Tay) that drop sharply from uplands, providing strong head for water wheels. The Highlands offered even greater potential for water power, as Jonell et al. (2023) note, but their sparse population, poor roads and unsuitability for most crops limited the demand for mills. Thus, most mills were situated in the agriculturally suitable part of the country along the east coast and in the Lowlands as shown in Figure 2. In 1755, there were 1200 water mills on the Scottish mainland as depicted on the Roy Military Survey of Scotland (Jonell et al., 2024).

Figure 2: Mills in 1755 and 1850



Notes: The figure consists of two maps depicting the locations of mills in Scotland for the years 1755 (left) and 1850 (right). In both maps, blue dots indicate the positions of water mills. For the 1850 map, brown dots additionally mark the locations of steam mills. Parish boundaries are outlined in black. In the 1755 map, the outer islands are shaded in grey, as they were not included in the Roy Military Survey of Scotland (1747–1755).
Sources: As described in the text.

Mill owners had a range of power sources available, each with advantages and disadvantages. Up until the nineteenth century, water power was dominant in agriculture and industry until steam gradually became a viable alternative (National Library of Scotland, 2021). Wind mills never played a major role in Scotland with only 25 out of around 4,000 mills in 1850 being wind-powered (National Library of Scotland, 2021). Water mills themselves existed in various forms that competed with each other: floating mills on larger rivers, tidal or sea mills, Norse (horizontal) mills, and vertical water wheels (National Library of Scotland, 2021). Horizontal mills were common in the Highlands and islands and “fared best on small, steeply falling water courses” (Grano and Bishop, 2017). They were mechanically simpler and thus cheaper and easier to build but limited in power compared to vertical-wheeled designs. The latter technology was better suited for larger industrial applications and could reach efficiencies of up to 80 percent (Reynolds, 1983).

The start of Scotland’s Industrial Revolution is commonly dated to the 1770s (Whatley, 1997). From a comparative backwater in Britain, Scotland largely industrialised parallel to England, leaving Ireland behind. It quickly caught up to English wage levels (Gibson and Smout, 1995). Harnessing water power for textile production was central to Scotland’s early industrial success: Linen weaving in Fife and Perthshire expanded with water-powered flax mills and the textile towns of Ayrshire, and the industrial belt along the Clyde and Forth owed their initial growth to water-powered cotton spinning and weaving mills (Whatley, 1997). In the early 1800s, more than 250,000 individuals were employed in the textile industry (Whatley, 1997).

According to Whatley (1997, p. 52), the “great age of water power in Scotland” lasted from around 1730 to 1830, though the actual power produced by water continued to climb until at least the mid-nineteenth century. The number of water mills more than tripled from 1,200 in 1755 to almost 3,900 in 1850 (National Library of Scotland, 2021; Jonell et al., 2024). Based on my classification using the object name books accompanying the First Ordnance Survey, about half of the mills in 1850 were used to grind grain followed by around 650 mills in wood processing and 600 in the textile industry.

Jonell et al. (2024) have quantified Britain’s water power potential at a high resolution and found that across Britain, access to water power was abundant in most counties. Only in the Mersey Basin, local water capacity was quickly reached (Jonell et al., 2024). Scotland’s industrial regions had relatively plentiful water. However, as Malm (2014) points out, British manufacturers during the 1820s and 1830s stood at an energy crossroads. They had to decide between further investments in water power and switching to coal for their continued growth. Despite various proposals to build large reservoir systems that would boost water power capacity in core manufacturing areas, the most significant of these plans never materialised. Instead, most manufacturers switched to steam power. As Whatley (1997) notes, “the Scottish industry remained significantly more heavily dependent on water power than the north of England". By 1835, water still generated 43.6 percent of Scottish industrial power, whereas it provided only 18.6 percent in northern England. Nonetheless, steam also took the lead around the middle of the nineteenth century in Scotland (Whatley, 1997).

2.2 Water Power, Institutions, and Demography

The newly built industrial mills urgently required a growing workforce. Due to high fertility rates and the so-called Scottish Agricultural Revolution leading to a better food supply, Scotland's population grew from 1.3 million in 1755 to 1.6 million by 1801 and over 4 million by 1891 (Lythe and Butt, 1975; National Records of Scotland, 2022). Both permanent and temporary (seasonal) migration levels were high by European standards in Scotland, allowing people to move to the newly built factories (Houston and Withers, 1990). Cities like Glasgow and Paisley already more than doubled their populations between 1755 and 1801 (National Records of Scotland, 2022). These rapid population changes were facilitated by the fact that, as Houston and Withers (1990) notes, "legal and institutional constraints on movement were slight".

Urban expansion, however, was just one element of a broader demographic shift in which the central Lowlands increasingly absorbed population away from the Highlands and, in the nineteenth century, also the Borders (Whatley, 1997). The Highland Clearances that lasted from roughly 1750 to 1860, in which Highland landlords in parts forcibly cleared tenants for sheep pasture, accelerated rural depopulation and mass migration to Lowland towns or overseas (Gibson, 2006). The Highland Potato Famine from 1846 onwards accelerated this development but was tackled more effectively and proved far less severe than the Irish famine at the same time (Devine, 2018). Scottish aggregate demographic statistics were hardly affected (Mokyr, 1980). On the other hand, across the sea, the Irish famine caused many Irish to flee to Scotland (Whatley, 1997). By 1851, over 200,000 Irish-born people lived in Scotland, a 90 percent increase since 1841 (Whatley, 1997; Schürer et al., 2024). It is to be expected that this exodus from the Highlands and Ireland also supplied labour to emerging water-powered mills.

The Central Belt was the major profiting area: In the mid-eighteenth century, it accounted for only a third of the country's population; by 1821 its share of population had already risen to about half of the Scottish population, almost completely at the expense of the north (Lythe and Butt, 1975). The western Lowlands, in particular, drew in a constantly growing share of the population, with nearly a third of all Scots living there by 1851 (Whatley, 1997). Substantial parts of this increase came from the Highlands and Ireland, but the general consensus is that short-distance migration was more important: As Whatley (1997, p. 66) notes, "the main source of Lowland growth was Lowlanders". Paisley, for example, obtained most of its 15,000–18,000 immigrants between 1760 and 1800 from the neighbouring rural counties of Ayrshire and Renfrewshire (Houston and Withers, 1990).

The legal framework for water rights was complex and evolved over time. As the use of water-powered mills increased in the eighteenth century, the lack of a coherent legal system regulating the use of water power led to frequent court cases between mill owners. The need for a defined system of water rights quickly became apparent (Robbie, 2013). Thus, the doctrinal foundation of common interest evolved as courts experimented with different legal theories to resolve these disputes. While the laws generally emphasised the rights of landowners to use the water naturally occurring on their property (Feris and Gibson, 2013), this doctrine also included the right of downstream landowners to have the water transmitted to them "undiminished in quantity, unpolluted in quality, and unaffected in force and natural direction and current" (*Morris v Bicket*, 1864).

In practice, this meant that building a larger mill always required negotiations with upstream and downstream landowners, unless the entire stream was held by a single proprietor (Robbie, 2013). In many cases, negotiations succeeded, but disputes such as *Morris v Bicket* (1864) suggest that these regulations constrained the expansion of water power. This was especially true for larger projects in the mid-nineteenth century, as more competing interests became involved. Turner (1958) provides an example where a mill owner sought a higher power output, but water rights upstream were already controlled by other mills. The only solution was to move the entire mill 100 metres downstream to increase the hydraulic head.

2.3 The Importance of Water Power vs. Coal

It is widely accepted that Scotland's early mechanisation relied primarily on human and water power as "prime movers". Mokyr (1992), Crafts (2004) and Clark (2014) have all emphasised that the roots of Europe's Industrial Revolution lie in the application of water power. Reynolds (1983) and van Bavel et al. (2018) argue that medieval Europe's vast water power grid was a key comparative advantage over societies like China and the Middle East. In Scotland this was no exception. As Whatley (1997, p. 51) puts it: "Traditional agents, human beings, animals, wind and water were the main sources of kinetic energy during the first decades of Scottish industrialisation." Technological change in the 1760s–1780s (e.g., Hargreaves's spinning jenny, Arkwright's water frame) was quickly applied to water-driven Scottish mills, enabling larger factory production.

However, economists and historians alike debate how essential water power and coal were for the establishment of self-sustaining economic growth. Wrigley (1959), Landes (2003) or Allen (2009) see the adoption of coal as a necessary condition for the Industrial Revolution. Malanima (2006) argues that only increased coal exploitation enabled sustainable increases in energy consumption and output per capita. Goldstone (2002, p. 379) concludes from his data that "the major bottleneck to self-sustaining and accelerating growth lay in the volume and concentration of energy available for mechanical work" and that "the major breakthrough of this bottleneck only came with the creation of (steam) engines". Geographically, Pollard (1981, p. 4) writes that "the map of the British Industrial Revolution [...] is simply the map of the coalfields". More recently, Fernihough and O'Rourke (2021) have shown that access to nearby coal was crucial for industrial siting.

On the other hand, Clark and Jacks (2007) estimate that Britain could have replaced coal with Baltic wood at a modest GDP cost (<4% by 1860), implying coal scarcity was not catastrophic. Mokyr (1992) and Mokyr et al. (2022) argue that the ingenuity of the age was the important driver of growth and water remained a viable primary mover for many industries. Quantifying its importance, Guilfoos (2025) shows that in the United States, the hypothetical loss of half of all water power endowments by 1880 would have reduced land values as much as eliminating the entire railroad network. Cameron (1985) points out that water power had not reached a technological dead end in the early Industrial Revolution and would have allowed for further substantial increases in power output: the water wheel reached its peak technical efficiency after 1850 and new inventions like the hydraulic turbine and water-column engine further opened new possibilities. Crafts (2004) concludes from growth accounting that "steam's impact on the annual rate of growth was modest" and Clark (2014, p. 222) that "advances in textiles and agriculture explain the majority of the Industrial Revolution".

In any case, water power was relied upon in industry long into the Scottish Industrial Revolution. Some horizontal mills in the Highlands still operated in 1900, and large Lowland mills used steam pumps to boost water flow (Whatley, 1997). Kanefsky (1979) estimates that in 1800, 70 percent of British industrial power came from water, and by 1830, coal and water still contributed roughly equal amounts of power. In Scotland, steam surpassed water even later (Whatley, 1997). Water power simply lacked the exponential growth of steam engines.

However, water power had several advantages that allowed it to be a viable alternative to steam throughout most of the nineteenth century: Most importantly, Chapman (1970) calculated that installing water power around 1790 was only a quarter of the cost of steam per horsepower. Furthermore, iron water wheels had a lifetime of several decades, whereas earlier steam engines typically only lasted for a few years (Kelly et al., 2023). This leads Kelly et al. (2023) to conclude that "Steam was adopted [...] only when the reliability and efficiency of the engines was improved [...] and suitable sites for water power were becoming scarce." Thus, the Scottish case exemplifies a flexible transition: water power shaped the early industrial geography, but steam eventually eroded the location and power constraints.

Comparing Scotland's experience helps highlight general patterns. Across the British Isles, Ireland presents a contrast. Like Scotland, Ireland had large and easily accessible water power potential but relatively little coal; it fell behind in industrialisation and remained extremely poor in European perspective pre- and post-famine (Mokyr, 1980). Making use of water power alone thus does not necessarily lead to successful industrialisation. English textile centres like Lancashire and West Riding are known for exploiting both water and coal (Jonell et al., 2024). Allen (2009) emphasises that England's cheap coal and high wages gave an extra push to capital-intensive technology, but Mokyr et al. (2022) and others stress that prior water power laid the groundwork. In many parts of Germany, the first factories were also water-powered. Later German industrialisation with its heavy industry in the Ruhr area did hinge on coal, but by then water power had already been crucial in proto-industrialising small towns and mechanically skilling the German population (Hinrichs, 2026).

2.4 Path Dependence versus Leapfrogging

This study investigates two aspects of path dependence in relation to water power during the Scottish Industrial Revolution. First, it examines whether pre-industrial use of water power in mills helped these areas industrialise more quickly and successfully, leading to migration to these locations. Second, given the importance of water power as a prime mover in the early Industrial Revolution in Scotland and its gradual loss of significance in the nineteenth century, the study asks how enduring these positive growth effects were when steam engines were widely adopted.

The first aspect concerning path dependence of proto-industrial clusters appears likely, as there was no change in power source. Early industrial water mills were larger and more powerful than their pre-industrial predecessors but technologically not fundamentally different (Reynolds, 1983). Path dependence thus makes sense for several reasons: First, it was possible to use existing mills to flexibly change the production and switch from grain grinding, for example, to powering textile machinery with relatively little effort (Radkau, 2008). As Chapman (1970, p. 237) notes: "In all the textile regions there is evidence of existing water mills being converted for cotton-spinning". Second, when building a new mill it made sense to do so in place of a pre-existing one as the infrastructure (dams, lades etc.) could be reused National Library of Scotland (2021). Third, it has been argued by Mokyr et al. (2022) and Hinrichs (2026) that pre-industrial mills led to skill accumulation in millwrights and other craftsmen, which provided a local supply of skilled artisans for industrial mill construction and operation.

The second aspect of path dependence is theoretically more ambiguous. At the heart of the literature lies a debate over *path dependence* of early industrial geography versus creative *leapfrogging* by new technologies. One view is that initial advantages – a river system here, a coal seam there – create self-reinforcing patterns of development. These patterns reflect a broader hypothesis: initial endowments have lasting effects. If water mills spurred early factory formation, those places might maintain their growth advantage. Leapfrogging behaviour would suggest that by the 1850s, entrepreneurs unconstrained by outdated water wheels – willing to build steam engines and railways – could establish factories in more convenient locations (ports, flat land near workers), bypassing older water-mill towns.

By demonstrating that water flow and rugged terrain were main determinants of cotton textile factory location in England in 1838, Crafts and Wolf (2014) have provided evidence for at least short-run path dependence. There are good theoretical reasons for expecting industrial path dependence: Ample evidence suggests that steam engines, because of their high costs, were initially often used as backups during water-deficient periods – either mechanically or by pumping water back up – creating strong incentives for steam engine adoption in water-powered factories (Reynolds, 1983; Whatley, 1997). In other cases, steam took over permanently but the engine simply replaced the water wheel in an existing mill building (Chapman, 1970).

Reinforcing this view, a county-level analysis for Britain by Nuvolari et al. (2011) found a positive and significant relationship between the number of water wheels and the subsequent installation of Newcomen steam engines. Furthermore, Mokyr et al. (2022) have demonstrated long-run path dependence of skills and mill locations in pre-industrial times, suggesting this effect may have extended into the age of steam, making the transition easier by drawing on existing expertise. Hinrichs (2026) has shown that water mills in Prussia functioned as catalysts of skill accumulation and population growth, but only until 1850 when the effect on population growth disappeared but was not reversed.

The alternative possibility is leapfrogging: established water-mill centres might have entered relative decline if they became "locked in" to water power while places with poorer water power potential but nearby coal deposits experienced rapid growth. New industrial areas could then rapidly industrialise using steam, offsetting the head start of rural water-powered towns. In this context, Jonell et al. (2024) have shown that limited water power potential in the Mersey Basin accelerated the adoption of steam engines and thereby facilitated the industrial rise of Greater Manchester.

Hornbeck et al. (2024) have examined this phenomenon for the United States: studying lumber and flour mills in New England and the American Midwest, they show that as steam costs fell, counties with less water power potential grew faster (due to steam-powered entrants) while counties rich in water power experienced slower growth (as incumbents faced sunk-cost lock-in). They term this dynamic "incumbent lock-in and entrant leapfrogging": water-powered firms hesitated to abandon their costly waterworks, allowing new entrepreneurs to leapfrog them using steam power. Similar developments have been observed for the later power transition from coal and steam to oil and electricity by Franck and Galor (2021) and Fritzsche and Wolf (2023).

Which effect dominated in Scotland? This study answers this question using data spanning almost 150 years from pre-industrial Scotland to the height of coal, steel, shipbuilding and heavy engineering (Lythe and Butt, 1975). Both the beneficial effect of pre-industrial water power usage in mills and the long-run consequences of water-powered industrialisation over the course of the Industrial Revolution are evaluated in the following sections. Ultimately, evidence for both effects can be found in the case of Scotland's industrialisation.

3 Data

This study draws upon a new comprehensive dataset that combines historical mill locations, demographic data, and geographical characteristics across Scotland, spanning from the pre-industrial period through the height of the Industrial Revolution. It contributes to economic history research by unifying previously disparate datasets and augmenting them through new digitisation of historical maps and census data. The resulting database provides unprecedented spatial and temporal coverage of Scotland's industrial transformation, enabling analysis at at both the individual mill level and the civil parish level over more than a century.

3.1 Historical Mill and Industrial Data

Roy Military Survey of Scotland The foundation of my analysis rests upon mill locations derived from the Roy Military Survey of Scotland (1747–1755), known to its contemporaries as the 'Great Map' (National Library of Scotland, 2025). This survey provides an invaluable historical snapshot of Scotland's landscape at the very dawn of industrialisation, representing the only comprehensive topographic mapping in the UK predating the nineteenth-century Ordnance Survey. The Roy Military Survey covers the entirety of the Scottish mainland and offers a crucial baseline for understanding the distribution of economic activity before the Industrial Revolution.

The mill locations from this historic survey have been digitised by Jonell et al. (2024), who also identified mills within 275 metres of the nearest river, providing a precise measure of water-powered proto-industrial infrastructure. Their digitisation effort represents a significant advancement in making eighteenth-century cartographic data accessible for quantitative analysis, transforming hand-drawn historical maps into spatially-referenced datasets suitable for modern geographic information systems (GIS).

Ordnance Surveys 1st and 2nd Edition A temporal perspective on industrial development is provided by mill locations mapped in the Ordnance Survey's First and Second Editions, conducted around 1850 and 1900, respectively. These surveys captured Scotland's industrial landscape at the height of its transformation, offering detailed cartographic evidence of the expansion and diversification of mill-based production throughout the nineteenth century. The digitised mill locations, available through the Scottish Water Mills Website, represent a comprehensive spatial resource derived from these surveys (National Library of Scotland, 2021).

Of particular value beyond the mill locations are the Object Name Books that accompanied these surveys. These books contain detailed textual descriptions of mills and their specific functions, providing rich qualitative information. I have systematically reorganised the Scottish Water Mills Project's text-based classification system, which identifies approximately 350 different mill type combinations such as "Grain Mill, Textile Mill, Water Mill" into a comprehensive taxonomy. This reclassification effort involved creating a dual classification scheme: first by power source (water, wind, steam, or water infrastructure) and second by production type (grain, wood, metal, textiles, paper, tobacco, alcohol, building materials, chemicals). This classification system enables analysis of both technological adoption patterns and industrial specialisation trends across different regions and time periods.

Early Steam Engines and Factory Returns In addition to the data on mills, the technological dimension of Scottish industrialisation is captured through multiple complementary sources. Data on early steam engine adoption comes from Kanefsky (2025), documenting the number of steam engines in use before 1800 at the parish level. This provides insight into the early adoption of steam technology, which would eventually complement and often replace water power in Scottish industry.

Textile factory development is documented through the 1838 Factory Returns, processed by Jonell et al. (2024). These returns provide detailed information on textile factory power usage, reporting both water and steam power in horsepower terms. This data enables analysis of the transition from water to steam power in textile production, one of the most important sectors of Scottish industrialisation.

3.2 Demographic Foundation

The demographic dimension of this study is supported by an exceptionally detailed and consistent population dataset spanning from Webster's pioneering census of 1755 through each decennial census from 1801 to 1891. This longitudinal demographic data, made available in digital form by the National Records of Scotland (2022), provides the analytical foundation for understanding the relationship between industrial development and population change over nearly 140 years.

The particular strength of this demographic data lies in its spatial consistency. Scottish civil parish boundaries remained remarkably stable from the late eighteenth century until the 1950s, contrasting sharply with the frequent boundary changes that complicate longitudinal analysis in England and Wales. This stability enables confident comparison of demographic and industrial changes within consistent geographic units over the entire study period. The dataset includes parish areas as reported in the 1881 census and calculated population densities, all linked to GIS polygons. These spatial units are used to aggregate mill counts and other geographically referenced data at the parish level.

The demographic data extends beyond simple population counts to include social and economic characteristics. I have digitised data on religious affiliation from Webster's original analysis of population in 1755, as reported in Kyd (1952). Additionally, I draw on the earliest surviving complete census for Scotland from 1851 from Schürer et al. (2024), alongside lookup tables from Rhodes (2024), to calculate a wide array of socio-economic variables at the parish level. These include measures of migration, fertility, and occupational structure, offering deeper insight into the demographic dimensions of industrialisation. Population data from National Records of Scotland (2022) and Kelly et al. (2023) is also used to compute a measure of market potential, using the Harris market potential methodology with geodesic distances and an exponential decay parameter of 20 kilometres.

3.3 Instrument and Control Variables

The analysis incorporates a comprehensive set of geographic and environmental variables to control for natural advantages and constraints on industrial development. Central to the identification strategy is water power potential, derived from rasterised data from Jonell et al. (2024) based on the 1891–1940 moisture balance and corrected for post-industrial barriers. Additional variables, such as terrain ruggedness[2], are derived directly from Ordnance Survey (2013).

Complementing this hydrological measure is land capability data derived from 1950s–1980s soil surveys (Soil Survey of Scotland Staff, 1981), which quantifies the share of land suitable for growing at least a narrow range of crops. Together, an interaction between water power potential and land capability serves as an instrument to obtain an exogenous source of variation in the number of water mills. The agricultural potential measure additionally captures the opportunity cost of labour movement from agriculture to industry.

The dataset further includes measures of transportation infrastructure and access to coal. In addition to a variable for coastal location or proximity to navigable rivers, canal access is documented using digitised maps from the Royal Commission on Canals and Waterways (1907), while railway development is captured through data from Satchell et al. (2018) showing railway line presence in 1851. Distance measures to coal deposits, based on Fernihough and O'Rourke (2021), and ports, based on digitised maps from McNeill and MacQueen (1996), capture access to essential inputs and export opportunities.

Finally, as additional control variables, Royal burgh status, also derived from McNeill and MacQueen (1996), identifies parishes with special privileges that may have affected industrial development. Highland Clearances are identified through digitised maps from Gibson (2006), capturing regions affected by these significant demographic disruptions and major battles fought between 1500 and 1750 are identified through Historic Environment Scotland (2020) data, potentially indicating regions affected by political instability.

A detailed list of all variables with their respective definitions and sources is available in Appendix A.1.1.

[2] Ruggedness in this paper is constructed following Riley et al. (1999), who define the Terrain Ruggedness Index (TRI) as the square root of the summed squared elevation differences between each raster cell and its eight immediate neighbours.

4 Empirical Analysis

4.1 Identification Strategy

The empirical strategy employed to estimate the causal effect of water mills on population growth and other outcomes of industrialisation builds upon ordinary least squares (OLS) and instrumental variable (IV) approaches, with the latter addressing potential endogeneity concerns that could bias naive correlational estimates. The baseline specifications regress parish-level outcomes like population growth rates, the number of textile factories or child–woman ratios on the number of water mills in the parish in 1755, 1850 or 1900. The fundamental regression equation in the case of population growth as the dependent variable with panel data from 1755 to 1891 takes the form:

$$\Delta \log(Pop_{i,t}) = \alpha_t + \beta_t \cdot Mills_{i,1755} + \gamma_t X_i' + \epsilon_{i,t} \tag{1}$$

where $\Delta \log(Pop_{i,t})$ represents the log population change in parish i from period $t-1$ to period t. The analysis considers both decadal growth and cumulative growth since 1755.[3] $Mills_{i,1755}$ denotes the number of water mills in parish i in 1755. The key parameters of interest are the year-specific coefficients β_t, which trace the dynamic effect of pre-industrial mills over time. The model includes a full set of year fixed effects (α_t) and a vector of parish-level control variables (X_i') whose effects (γ_t) are also allowed to vary by year. $\epsilon_{i,t}$ is the error term.

The temporal structure of this specification addresses immediate concerns about reverse causality. Since mill locations are measured from historical maps predating the demographic outcomes by decades, and given that most water mills represented long-standing infrastructure often dating back centuries, direct reverse causation from industrial outcomes to pre-industrial mill construction is implausible within the study's timeframe.

However, more subtle forms of endogeneity remain concerning. Omitted parish characteristics that influenced both historical mill placement and subsequent demographic development could bias the estimates. For instance, parishes with entrepreneurial cultures or superior local

[3] In the case of decadal population growth, growth rates over varying census intervals are standardised as $\Delta^{dec} \log(Pop_{i,t}) = 10 \times \frac{\log(Pop_{i,t}) - \log(Pop_{i,t-1})}{t - t_{-1}}$. In the case of cumulative population growth, the dependent variable is $\Delta^{cum} \log(Pop_{i,t}) = \log(Pop_{i,t}) - \log(Pop_{i,1755})$.

institutional arrangements might have developed both mill infrastructure and advantages for subsequent industrialisation.

To address these endogeneity concerns, I employ an instrumental variable approach. I use the fact that, as Jonell et al. (2023) write, since water mills were considerable investments of physical capital "their careful siting often took into account local hydrology, topography, and economic demand". Thus, I exploit exogenous geographical variation in parishes' suitability and demand for water mills in pre-industrial times. Following the methodology established by Mokyr et al. (2022) in the analysis of Domesday Book water mills in England, the identification strategy centres on the interaction between water power potential and agricultural land capability as an instrument for the prevalence of water mills.

The construction of water mills required a reliable flow of water and sufficient elevation change to generate the hydraulic head necessary for mill operation. Up to a certain point, steeper terrain and greater water flow improved the feasibility and efficiency of harnessing water power. To capture this dimension, one component of the instrument is a measure of water power potential, calculated from raster cells as the logarithmic sum – accounting for diminishing returns – of local physical water power potential (in Watts). This measure is based on historical moisture balance data and adjusted for post-industrial infrastructure barriers.

However, as Mokyr et al. (2022) emphasise, demand for milling services in the pre-industrial period only arose where grain was available to be milled. Given the high cost of overland transportation in pre-industrial times, it was rarely economical to move grain to remote locations with better water power potential and then transport the flour back for consumption. Accordingly, the instrument combines two components: water power potential and land capability. The latter is based on historical soil surveys quantifying the share of land suitable for crop cultivation. The interaction between these two variables captures exogenous variation in mill suitability, while separately controlling for their independent effects on economic development.

The first-stage regression takes the form:

$$Mills_{i,1755} = \phi + \rho \cdot (WaterPowerPotential_i \times LandCapability_i) + \theta X_i' + \nu_i \tag{2}$$

where the interaction term $WaterPowerPotential_i \times LandCapability_i$ serves as the excluded instrument, and X_i' includes all exogenous controls from the main specification.

The second-stage equation then becomes:

$$\Delta \log(Pop_{i,t}) = \alpha_t + \beta_t \cdot \widehat{Mills}_{i,1755} + \gamma_t X_i' + \epsilon_{i,t} \tag{3}$$

The validity of this instrumental variable approach rests on two critical assumptions: relevance and exogeneity. The relevance condition requires that the instrument strongly predicts water mill density, which can be tested empirically through first-stage F-statistics and examination of the relationship between geographical suitability and historical mill construction patterns.

The relevance of the instrument is confirmed by the first-stage regression results, presented in Table 1. The table shows that the interaction term, $WaterPowerPotential_i \times LandCapability_i$, is a strong and highly significant predictor of the number of water mills in a parish in 1755. The coefficient for the instrument is positive and statistically significant at the 1% level across all specifications. This relationship remains robust even after including the extensive set of controls (Columns 2–6). Crucially, the model controls for water power potential and land capability as separate variables, indicating that it is the specific interaction between the supply of potential energy and the demand for milling services that predicts mill placement. The preferred specification, corresponding to the IV models in the main analysis, yields a first-stage F-statistic of over 200, as reported in Table 2. This value is substantially larger than the conventional thresholds for weak instruments, providing strong support for the relevance condition.

The exogeneity assumption is more challenging to verify but is the most critical component of this identification strategy. The instrument must affect population growth only through its impact on water mill development, not through alternative channels. This exclusion restriction is plausible given the specific nature of the interaction term. While water power potential and agricultural capability could individually affect economic development through multiple pathways (which I control for), their interaction specifically captures the technological feasibility and demand for water mills in the pre-industrial period.

However, this assumption is not without potential problems. A valid criticism is that the instrument might be correlated with unobserved factors affecting population growth. For instance, parishes with both high water power potential and good farmland might have possessed

Table 1: First-Stage Regression Analysis

Dependent Variable:	Water Mills 1755					
Method:	OLS					
	(1)	(2)	(3)	(4)	(5)	(6)
Water Power Pot. × Land Cap.	0.655***	0.771***	0.838***	0.828***	0.827***	0.835***
	(0.054)	(0.059)	(0.087)	(0.091)	(0.111)	(0.092)
Geographic and Environmental Controls	No	Yes	Yes	Yes	Yes	Yes
Agricultural and Economic Base Controls	No	No	Yes	Yes	Yes	Yes
Transportation and Infrastructure Controls	No	No	No	Yes	Yes	Yes
Institutional and Cultural Controls	No	No	No	No	Yes	Yes
Latitude-Longitude	No	No	No	No	No	Yes
Num. Obs.	795	795	787	787	787	787
R2	0.208	0.281	0.317	0.323	0.330	0.334
R2 Adj.	0.207	0.274	0.307	0.312	0.315	0.317

Notes: This table reports results from the first-stage regression specification for the following analyses in this paper. The number of water mills in 1755 is regressed on the instrument (water power potential interacted with land capability) and a vector of control variables. Controls are grouped into different categories for better readability. A full table with all control variables reported individually can be found in the Appendix in Table A.3. Robust standard errors adjusted for spatial correlation are reported in parentheses; *** denotes statistical significance at the 0.01 level, ** at the 0.05 level, and * at the 0.1 level, all for two-sided hypothesis tests. All regressions include a constant.

other latent advantages like a topography well suited for agriculture and water transport that independently drove population growth, thus violating the exclusion restriction.

This fundamental challenge is addressed in several ways. First, the analysis incorporates an extensive set of control variables to isolate the effect of water mills from these other potential drivers. These variables include Geographic and Environmental Controls, Agricultural and Economic Base Controls, Transportation and Infrastructure Controls, and Institutional and Cultural Controls as specified in Section A.1.2.

Second, and more decisively, in Section A.3.1, a direct test of the exclusion restriction is conducted. The reduced-form regression is run on the subsample of parishes that had zero water mills in 1755. As theory would predict, if the instrument's effect flows only through mills, it should have no power in this 'no-mills' sample. The findings confirm this: the instrument's coefficient is statistically indistinguishable from zero, strongly mitigating concerns about unobserved channels.

Third, in Section A.3.4, placebo tests confirm the instrument's uniqueness. This test shows that other plausible interaction terms like Water Power Potential interacted with Port Access are not significant predictors of mill placement. This reinforces the argument that the chosen instrument specifically captures the conditions for pre-industrial milling, not just general economic potential.

Taken together, these tests provide robust empirical evidence supporting the identification strategy. To also address concerns about potential spatial correlation in both mill prevalence as well as in the demographic and industrial outcomes, the empirical implementation employs spatial clustering corrections as proposed by Conley (1999) that account for potential correlation within geographic regions. Section A.4.1 demonstrates the robustness of the main results to alternative standard error specifications.

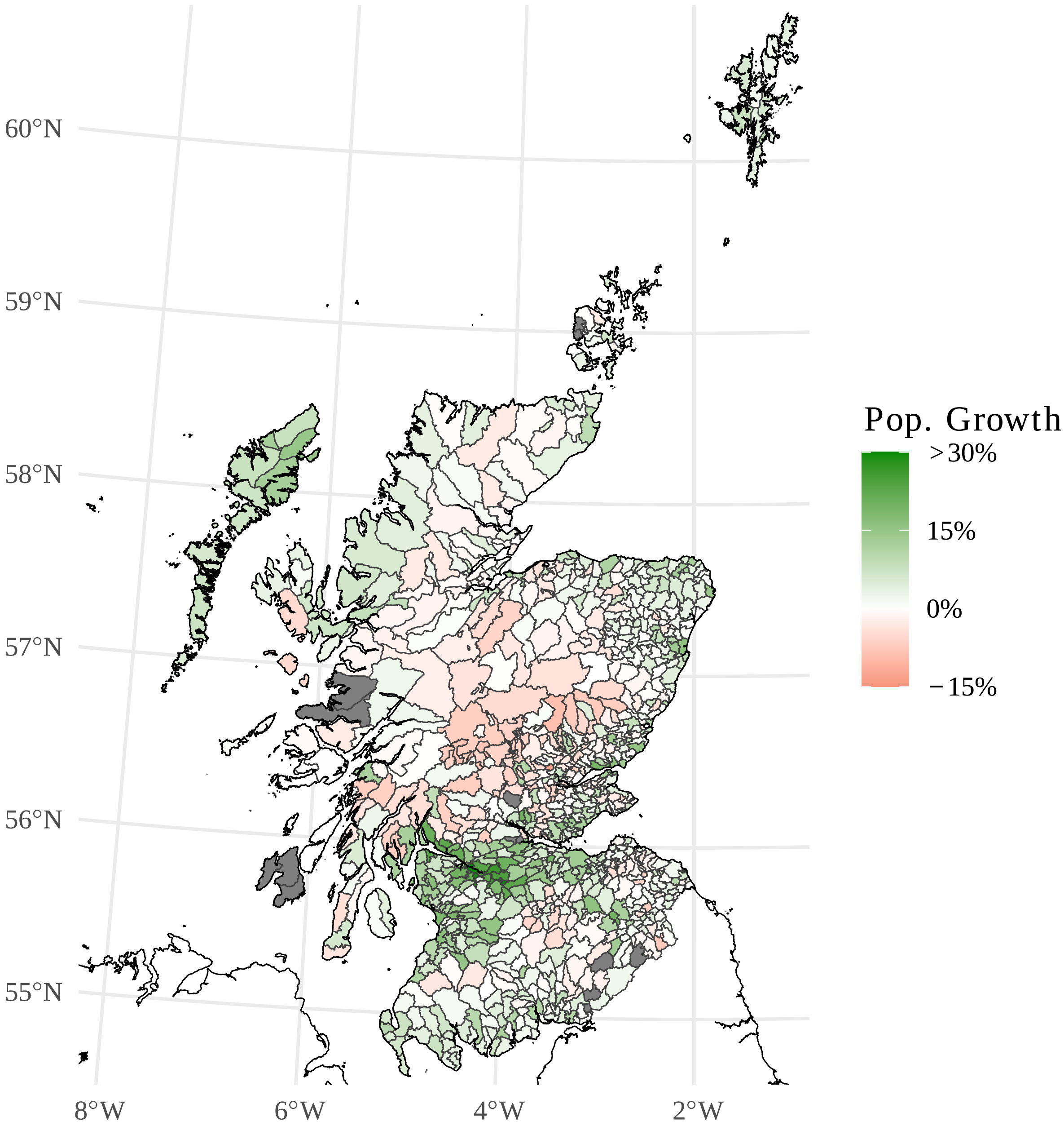
4.2 Population Growth

The relationship between water mills and population growth forms the first empirical focus of this analysis. In eighteenth and nineteenth-century Scotland, growing population is arguably the most reliable indicator of general economic growth, given the lack of consistent regional data on output or income. In contrast to England for example, Scotland is particularly well suited to this kind of demographic analysis, thanks to the remarkable stability of its civil parish boundaries from the eighteenth century through the 1950s. This geographic consistency at a granular administrative level allows for accurate tracking of demographic changes over time.

Scotland's demographic transformation during the study period was both dramatic and spatially heterogeneous. The country's population more than tripled from approximately 1.3 million in 1755 to over 4 million by 1891, but this growth was far from uniform. As illustrated in Figure 3, while many Highland parishes saw a population decline due to the Highland Clearances and emigration, the industrialising regions of the Central Belt and coastal areas experienced dramatic population increases. Numerous parishes within the Central Belt sustained average decadal growth rates exceeding 15%, and Glasgow, along with several surrounding parishes, recorded rates above 30% per decade over the 140-year span – amounting to cumulative growth of over 3,500%.

Beyond this general trend of urbanisation, Figure 3 also reveals considerable variation in population change outside the Central Belt. In many areas, substantial population gains occurred in close proximity to parishes experiencing population decline, highlighting the highly localised nature of demographic change. This spatial heterogeneity provides crucial identifying

Figure 3: Decadal Population Growth in Scotland 1755–1891



Notes: The map illustrates the average decadal population growth rates in Scottish parishes from 1755 to 1891, calculated as the geometric mean over the entire period and expressed in percent. The colour scale is designed to highlight variations, with growth rates capped at 30% in the positive direction to improve visibility for the majority of parishes exhibiting lower growth levels.
Sources: As described in the text.

variation for the analysis. Parishes with comparable geographic and cultural characteristics experienced vastly different demographic trajectories depending on their industrial development patterns. The timing of demographic changes also varied but is not represented in Figure 3.

The results of the main empirical analysis, presented in Table 2, confirm a strong and persistent causal link between the pre-industrial presence of water mills and subsequent population growth. The table displays estimates from both Ordinary Least Squares (OLS) and Instrumental Variable (IV) models, with the analysis focusing on the interaction between the number of water mills in a parish in 1755 and dummy variables for each subsequent census decade to examine the evolving impact of these early mills over time.

Columns 3 and 4 report estimates for cumulative population growth since 1755. Both OLS and IV models yield highly consistent results, as illustrated in Figure Figure 4. A positive effect of pre-industrial water mills emerges in the early nineteenth century, becoming statistically highly significant by the 1820 and 1830s, respectively. The effect continues to strengthen through the mid-century, although the upward trend appears to level off after 1850. The IV coefficient for one additional water mill in 1755 increases to 0.042 by 1831 and 0.078 by 1891, indicating that by the late nineteenth century, a parish with one additional water mill in 1755 had experienced approximately 8% greater cumulative population growth than an otherwise similar parish.

The coefficients for water mills with decadal population growth as the dependent variable (Columns 1 and 2) show that the most pronounced short-term growth occurred between roughly 1811 and 1841, precisely when Scotland witnessed rapid industrial expansion, particularly in textiles, and accelerating urbanisation. This temporal alignment suggests parishes with many water mills were not simply continuing historical trends, but rather benefited from a structural transformation: they became focal points for industrial activity and population in-migration. It is important to note that the slowing of the rate of growth in the second half of the nineteenth century does not imply a disappearing advantage; rather, as Figure 4 and the cumulative coefficients show, it represents the "locking-in" of a new, persistently higher level of economic activity and population.

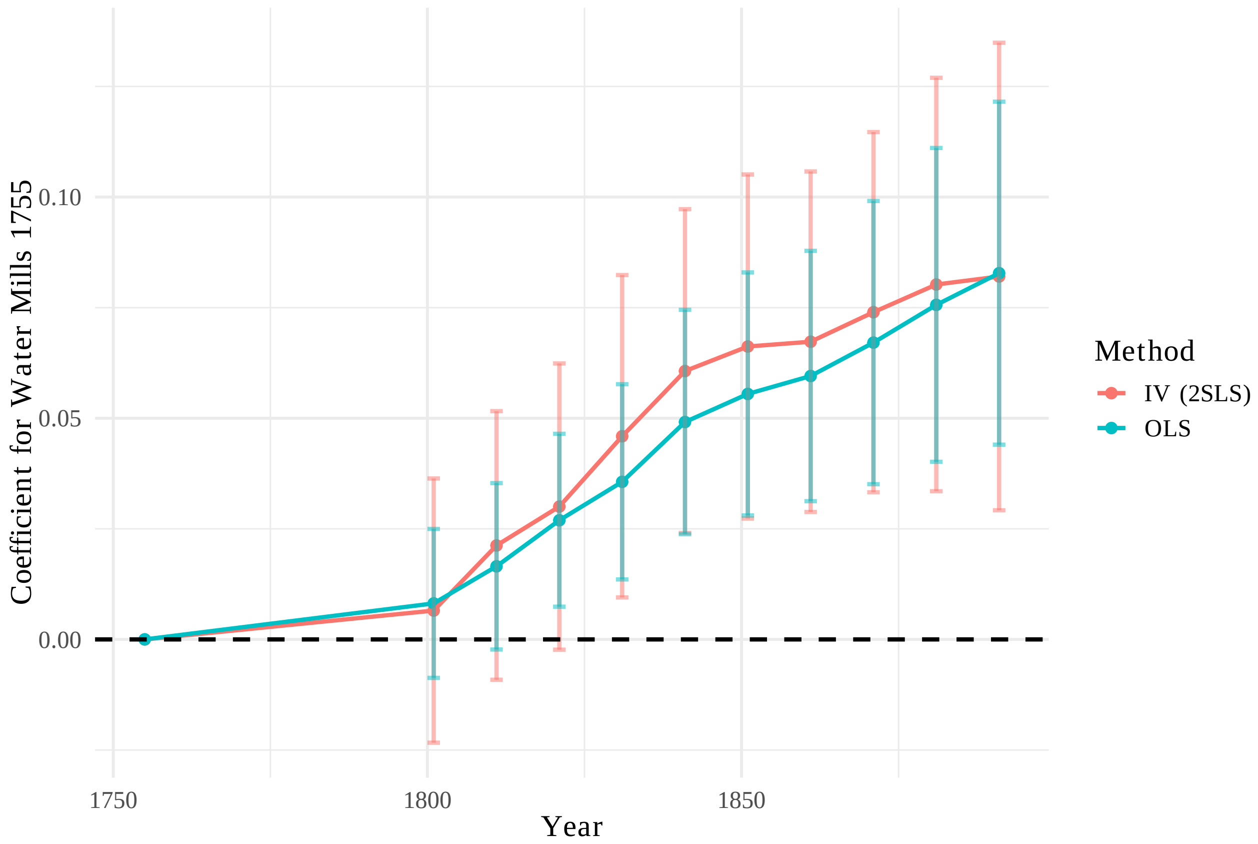
The results align with both forms of path dependence identified in the literature, providing strong empirical support to the idea that industrial development in Scotland was shaped by a

Table 2: Regression Analysis of Water Mills and Population Growth

Dependent Variable:	Decadal Pop. Growth		Cumulative Pop. Growth	
Method:	OLS	IV (2SLS)	OLS	IV (2SLS)
	(1)	(2)	(3)	(4)
Water Mills 1755 × Factor (1801)	0.002	0.001	0.008	0.007
	(0.003)	(0.004)	(0.009)	(0.015)
Water Mills 1755 × Factor (1811)	0.008*	0.015**	0.017*	0.021
	(0.004)	(0.007)	(0.010)	(0.015)
Water Mills 1755 × Factor (1821)	0.010***	0.009	0.027***	0.030*
	(0.004)	(0.008)	(0.010)	(0.017)
Water Mills 1755 × Factor (1831)	0.009**	0.016**	0.036***	0.046**
	(0.004)	(0.007)	(0.011)	(0.019)
Water Mills 1755 × Factor (1841)	0.014***	0.015**	0.049***	0.061***
	(0.005)	(0.007)	(0.013)	(0.019)
Water Mills 1755 × Factor (1851)	0.006*	0.006	0.055***	0.066***
	(0.004)	(0.007)	(0.014)	(0.020)
Water Mills 1755 × Factor (1861)	0.004	0.001	0.060***	0.067***
	(0.004)	(0.008)	(0.014)	(0.020)
Water Mills 1755 × Factor (1871)	0.008*	0.007	0.067***	0.074***
	(0.004)	(0.008)	(0.016)	(0.021)
Water Mills 1755 × Factor (1881)	0.009**	0.006	0.076***	0.080***
	(0.004)	(0.007)	(0.018)	(0.024)
Water Mills 1755 × Factor (1891)	0.007*	0.002	0.083***	0.082***
	(0.004)	(0.007)	(0.020)	(0.027)
Geographic and Environmental Controls	Yes	Yes	Yes	Yes
Agricultural and Economic Base Controls	Yes	Yes	Yes	Yes
Transportation and Infrastructure Controls	Yes	Yes	Yes	Yes
Institutional and Cultural Controls	Yes	Yes	Yes	Yes
Latitude-Longitude	Yes	Yes	Yes	Yes
Num. Obs.	7870	7870	7870	7870
R2	0.219	0.213	0.316	0.301
R2 Adj.	0.199	0.192	0.298	0.283

Notes: This table reports coefficients from a panel regression specification, where the number of water mills in 1755 is interacted with year dummies. Columns 1 and 2 use the decadal change in log population since the previous census year as the dependent variable. For the period 1755–1801, the decadal growth rate is calculated as the average change per decade in log population over 46 years. Columns 3 and 4 use the cumulative change in log population since 1755 as the dependent variable. Subject to rounding and the conversion for 1755–1801, coefficients for decadal growth rates can be summed up to obtain their counterparts for cumulative growth up to that year. Controls are grouped into different categories for better readability. Robust standard errors adjusted for spatial correlation are reported in parentheses; *** denotes statistical significance at the 0.01 level, ** at the 0.05 level, and * at the 0.1 level, all for two-sided hypothesis tests. All regressions include a constant.

Figure 4: Coefficient Plot for Cumulative Population Growth 1755-1891



Notes: The plot displays the estimated coefficients from a panel regression where the number of water mills in 1755 is interacted with year dummies. The dependent variable is the cumulative change in log population for each census year relative to the base year 1755. The coefficients represent the estimated marginal effect of one additional pre-industrial water mill on cumulative population growth over time. All standard controls (geographic, economic, transportation, and institutional) are included in the specification. The lines compare estimates from the Ordinary Least Squares (OLS) specification with those from the Instrumental Variable (IV) specification. Error bars indicate 95% confidence intervals based on robust standard errors adjusted for spatial correlation.

Sources: Regression analysis based on data sources described in the text.

dual path dependence: first, through early industrial clustering around water mills, and second, through the successful adaptation of these clusters during the transition to steam.

First, the evidence confirms that water mills acted as early industrial nuclei. As Whatley (1997), Mokyr et al. (2022), and others have argued, water power remained viable well into the nineteenth century, while the infrastructure of pre-industrial mills – dams, channels, and associated workshops – could be readily adapted for mechanised production. Chapman (1970) and Radkau (2008) note that conversion from grain milling to textile spinning or weaving often required minimal investment. The regression results suggest that these adaptations of pre-industrial milling sites into larger industrial water-powered factories translated into measurable demographic effects.

Second, and more strikingly, the evidence contradicts the leapfrogging dynamic documented by Hornbeck et al. (2024) for the United States. The timing is particularly revealing: the cumulative impact of water mills on population growth becomes statistically significant from the 1830s onward – precisely at the end of what Whatley (1997) terms the "great age of water power" and during steam power's rise to prominence. This implies that the early industrial clusters retained their advantage, likely through several mechanisms: the accumulation of skilled labour, sunk infrastructure costs, and the early adoption of steam engines as supplemental power in established water-powered mills. Rather than being overtaken by steam-powered entrants in more flexible locations, early water-powered parishes in Scotland maintained and even deepened their advantage.

This challenges conventional notions of "incumbent lock-in". Instead of being hampered by outdated infrastructure, many of these sites successfully transitioned to steam. As Reynolds (1983) and Whatley (1997) note, water-powered mills often integrated steam engines – first as auxiliary power, then as full replacements – without the need to relocate. The legacy of the water mill thus provided a flexible foundation rather than a technological dead end. Some leapfrogging may still have occurred, as the effect of water mills appears to flatten in the latter half of the nineteenth century, but clearly leapfrogging did not dominate. Instead, early advantages from water power were consolidated, establishing lasting foundations for economic growth.

Table 3: Regression Analysis of Water Mills and Early Industrialisation

Dependent Variable:	Total Steam Engines 1800		Non-Colliery Engines 1800		Textile Power 1838 (log x+1)	
Method:	OLS	IV (2SLS)	OLS	IV (2SLS)	OLS	IV (2SLS)
	(1)	(2)	(3)	(4)	(5)	(6)
Water Mills 1755	0.223	0.176	0.125***	0.170**	0.092**	0.272**
	(0.161)	(0.276)	(0.046)	(0.083)	(0.042)	(0.123)
Geographic and Environmental Controls	Yes	Yes	Yes	Yes	Yes	Yes
Agricultural and Economic Base Controls	Yes	Yes	Yes	Yes	Yes	Yes
Transportation and Infrastructure Controls	Yes	Yes	Yes	Yes	Yes	Yes
Institutional and Cultural Controls	Yes	Yes	Yes	Yes	Yes	Yes
Latitude-Longitude	Yes	Yes	Yes	Yes	Yes	Yes
Num. Obs.	787	787	787	787	787	787
R2	0.126	0.118	0.185	0.167	0.190	0.202
R2 Adj.	0.105	0.098	0.166	0.148	0.171	0.183

Notes: This table reports results from OLS and IV regressions of the number of steam engines before 1800 and combined total power output (water and steam) in textile factories in 1838 on the number of water mills in 1755. Controls are grouped into different categories for better readability. A full table with all control variables reported individually can be found in the Appendix in Table A.4. Robust standard errors adjusted for spatial correlation are reported in parentheses; *** denotes statistical significance at the 0.01 level, ** at the 0.05 level, and * at the 0.1 level, all for two-sided hypothesis tests. All regressions include a constant.

4.3 Industrialisation

While population growth provides evidence of economic dynamism, understanding the mechanisms behind differences in population growth over the course of the Industrial Revolution requires examining Scotland's industrial development directly. This section investigates whether pre-industrial water mills served as springboards for subsequent technological adoption and factory expansion, testing whether early water-powered locations became hubs for steam engines, textile factories, and diversified manufacturing.

The transition from water to steam created a quasi-natural experiment. Would areas with abundant water power adapt successfully to steam, or would they be leapfrogged by new entrants in more flexible locations, as Hornbeck et al. (2024) document for the United States? The Scottish evidence points strongly to the first outcome: parishes with pre-industrial water-power advantages were significantly more likely to become centres of steam-powered industry and broader manufacturing expansion.

Table 3 presents regression results for two core indicators of industrial transformation: the number of steam engines installed by 1800 and the total power capacity of textile factories by 1838. The IV estimates, supported by first-stage F-statistics above 200, address endogeneity concerns and reveal clear evidence of industrial path dependence.

Parishes with more water mills in 1755 were significantly more likely to adopt steam technology in locations away from coalfields. While the effect on the total number of steam engines is not statistically significant, the OLS and IV estimates for steam engines used outside of collieries are positive and significant. A coefficient of 0.17 implies that around six additional pre-industrial mills were associated with one additional steam engine outside of collieries by 1800.

This finding directly contradicts a simple substitution model where steam would have been adopted first in areas lacking water power. Instead, it supports the historical accounts of Chapman (1970) and Whatley (1997), who describe steam engines initially serving as auxiliary power during dry spells or as pumps to recirculate water to mill wheels, a practice which Nuvolari et al. (2011) found to be a significant factor in the adoption of early steam technology across Britain. Rather than being competing technologies, it seems that in Scotland water and steam were initially complementary.

The effect on textile power capacity is even more striking. An additional water mill in 1755 was associated with a 9-27% increase in total horsepower (combining water and steam sources) in textile factories by 1838. The magnitude suggests that pre-industrial mill sites became the centres of Scotland's textile revolution, leveraging both their established infrastructure and their accumulated mechanical expertise to build larger, more powerful industrial complexes.

Table 4 examines how pre-industrial advantages translated into industrial diversification by 1850, breaking down mill development across eight major sectors. The textile sector shows a strong response, with a coefficient of almost 0.5 for the IV specification, indicating that two additional 1755 mills were associated with one additional textile mill by 1850. This confirms textiles as the primary transmission mechanism from proto-industrial to industrial Scotland, consistent with Whatley's (1997) emphasis on water-powered cotton spinning as the foundation of Scottish industrialisation.

Table 4: Regression Analysis of Water Mills in 1755 and Industrial Mills in 1850

Dependent Variable (Mills in 1850):	Metal and Machinery		Textiles		Chemicals		Wood and Paper		Alcohol and Tobacco	
Method:	OLS	IV (2SLS)	OLS	IV (2SLS)	OLS	IV (2SLS)	OLS	IV (2SLS)	OLS	IV (2SLS)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Water Mills 1755	0.018**	0.034**	0.254***	0.540***	0.032***	0.070	0.180***	0.582***	0.035***	0.061*
	(0.007)	(0.013)	(0.091)	(0.110)	(0.009)	(0.045)	(0.047)	(0.093)	(0.011)	(0.031)
Geographic and Environmental Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Agricultural and Economic Base Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Transportation and Infrastructure Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Institutional and Cultural Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Latitude-Longitude	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Num. Obs.	787	787	787	787	787	787	787	787	787	787
R2	0.139	0.137	0.116	0.117	0.110	0.111	0.174	0.251	0.246	0.231
R2 Adj.	0.117	0.116	0.094	0.095	0.088	0.089	0.153	0.232	0.227	0.212

Notes: This table reports results from OLS and IV regressions of various classes of industrial mills in 1850 on the number of water mills in 1755. Controls are grouped into different categories for better readability. In contrast to the other tables, economic base controls exclude steam engines. A full table with all control variables reported individually can be found in the Appendix in Table A.5. Robust standard errors adjusted for spatial correlation are reported in parentheses; *** denotes statistical significance at the 0.01 level, ** at the 0.05 level, and * at the 0.1 level, all for two-sided hypothesis tests. All regressions include a constant.

Wood and paper mills display an even larger IV coefficient of 0.58. This reflects both the continuity of water-power-intensive processing activities and the growing demand for input goods with wood for construction and shipbuilding, and paper for education and administration. The results also reveal significant spillovers into newer industrial sectors: metal and machinery mills, chemical mills and even in alcohol and tobacco mills by 1850 exhibit small but mostly significant coefficients. This suggests that early mill sites became platforms for industrial experimentation and diversification, even in sectors with no direct technological connection to traditional milling.

Overall, the findings add crucial nuance to the debate over the relative importance of water versus coal. While scholars like Allen (2009) and Fernihough and O'Rourke (2021) have rightly emphasised the transformative role of coal, this analysis shows that the Industrial Revolution's geography was not written on a blank slate. The results challenge a strongly deterministic view, such as Pollard's (1981) claim that the industrial map was simply the map of the coalfields. In Scotland, the pre-industrial map of water power was a critical precursor. The locations best suited for water mills became the beachheads for the steam-powered economy. This suggests that access to coal was a necessary, but not sufficient, condition; its benefits were most effectively exploited in regions that already possessed a proto-industrial base built on water.

The Scottish evidence provides a striking contrast to the "incumbent lock-in and entrant leapfrogging" dynamic documented by Hornbeck et al. (2024) for the United States. Rather than being overtaken by steam-powered entrants in more flexible locations, Scottish water-powered parishes maintained and amplified their industrial advantages. Several factors could explain this difference: As the birthplace of James Watt, Scotland adopted steam earlier than the United States, creating incentives to experiment with it within existing production sites before investing in purely steam-powered factories. Scotland's compact geography and abundant water resources also meant that most industrial regions had access to both water power and coal, reducing trade-offs between energy sources. This gradual, complementary adoption of steam allowed incumbents to build on sunk investments, while accumulated human capital and agglomeration economies reinforced the competitive advantages of established industrial centres.

4.4 Micro-Evidence: Mill Survival and Transformation

The parish-level analysis establishes that locations with more pre-industrial water mills experienced faster population growth and industrialisation. This causal link, robust to instrumental variable estimation, rules out simple geographic sorting. However, aggregate data cannot reveal the precise economic mechanism: Did the path dependence arise because the physical capital of the old mills (dams, lades, and buildings) was directly reused? Or did these locations simply develop superior market access and human capital, while the original mill sites themselves were abandoned in favour of modern factories built within the same parish?

Distinguishing between these possibilities is crucial for understanding the nature of the transition. If the sunk costs of hydraulic infrastructure provided a valuable foundation for early industry, we should observe high rates of incumbent survival and adaptation. Conversely, if the shift to steam power rendered water-based infrastructure obsolete or "locked in" owners to inefficient technologies we would expect to see leapfrogging, where new entrants in locations with good coal access replaced the old sites.

To test the role of physical capital directly, this section shifts the unit of analysis to the individual mill, tracing the fate of the 1,200 water mills identified in the 1755 Roy Military Survey. I examine three sequential outcomes: survival, technological adoption, and industrial transformation. Matching each 1755 mill to the 1850 Ordnance Survey data, a 1755 mill is considered to have 'survived' if any mill structure is found within a 500-metre radius of its original location in the 1850 survey. This threshold accounts for map inaccuracies and the possibility that mills may have been relocated slightly, as documented by Turner (1958) in his study of Perthshire water mills. For surviving sites, I then identify if they adopted steam power or transitioned from grain milling to manufacturing of industrial goods like textiles, metal parts or paper.

I estimate the determinants of these outcomes using a Probit model:

$$\Pr(Y_{i,p} = 1 | X_i, Z_p) = \Phi(\beta_0 + \beta_1 X'i + \beta_2 Z'p + \epsilon_{i,p}) \tag{4}$$

where $Y_{i,p}$ is a binary variable indicating the outcome (survival, steam adoption, or industrialisation) for mill i located in parish p. The model includes a vector of mill-level geographic and economic characteristics, $X'i$, such as local water power potential, local mill density within 5 km (which may capture both competition effects and agglomeration benefits), and distances to coalfields. It also includes a vector of parish-level controls, $Z'p$, to account for the broader economic context, including 1755 population density and market potential. Φ represents the cumulative distribution function of the standard normal distribution. For ease of interpretation, the results are presented as Average Marginal Effects (AMEs), which quantify the change in probability for a one-unit change in a given explanatory variable.

The results from these probit models are presented in Table 5. Columns 1 and 2 show that of the nearly 1,200 mills present in 1755, approximately 62% (746 sites) were still in use a century later. The most powerful predictor of a mill site's survival to 1850 was its local water power potential. A one-unit increase in water power potential within a 1 km radius – roughly the difference between the worst and the best-endowed mill – was associated with a 42 percentage point higher probability of that site surviving. This large effect underscores the enduring economic value of water power. Better endowed sites were far more likely to be maintained, rebuilt, or repurposed over the century, consistent with Reynolds's (1983) argument that they represented valuable fixed capital.

Though economically small[4], the positive and significant coefficient on log distance to coal in Column 2 indicates that mills farther from coalfields had a higher probability of survival. A plausible explanation is that proximity to coalfields intensified the process of creative destruction. In coal-rich areas, new, large-scale steam-powered factories may have emerged and out-competed older, smaller water mills for land, labour, and capital. This pattern points towards localised leapfrogging in coal-rich areas, whereas in distant regions, expensive coal made existing water mills more valuable for continued production and thus more likely to be maintained. This finding suggests that while the aggregate pattern at the regional level reflects path dependence, elements of technological displacement were present in areas where steam power was most cost-competitive.

On the other hand, the analysis of surviving mills reveals evidence of complementary adaptation rather than widespread displacement. Columns 3 and 4 show that steam adoption

[4]The Average Marginal Effect (AME) of log distance to coal is 0.026. Because the variable is log-transformed, a doubling of the distance to coal is associated with an increase in the probability of survival of approximately 1.8 percentage points, calculated as $\Delta\text{Pr}(\text{Survival}) = 0.026 \times \ln(2) \approx 0.018$.

Table 5: Analysis of Mill Survival and Transformation 1755–1850

Dependent variable (1850):	Mill Survival		Switched to Steam		Industrialised	
Method:			Probit (AMEs)			
	(1)	(2)	(3)	(4)	(5)	(6)
Water Power Potential (1 km Radius)	0.381***	0.419***	−0.055	−0.074	0.183*	0.233*
	(0.080)	(0.076)	(0.061)	(0.061)	(0.094)	(0.126)
Ruggedness (1 km Avg.)	−0.002	−0.002	0.000	0.000	0.008**	0.006*
	(0.003)	(0.004)	(0.001)	(0.001)	(0.004)	(0.004)
Land Capability (5 km Avg.)	0.109	−0.014	−0.026	−0.025	−0.028	−0.091
	(0.071)	(0.086)	(0.038)	(0.035)	(0.118)	(0.137)
Altitude	0.000	0.000	0.000	0.000**	−0.001	−0.001
	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.001)
Mill Density (5 km Radius)	0.006	0.005	0.003	0.004	0.004	0.000
	(0.005)	(0.008)	(0.002)	(0.002)	(0.008)	(0.006)
Distance to Coalfield (log + 1)	0.012	0.026**	−0.012***	−0.012**	−0.005	0.006
	(0.011)	(0.011)	(0.004)	(0.005)	(0.015)	(0.018)
Distance to Coast or River (log)	−0.005	−0.007	−0.005	−0.004	0.000	−0.002
	(0.017)	(0.018)	(0.006)	(0.007)	(0.025)	(0.031)
Distance to Port (log)	−0.016	−0.005	0.001	−0.001	−0.037	−0.019
	(0.013)	(0.018)	(0.011)	(0.011)	(0.047)	(0.049)
Distance to Burgh (log)	−0.020**	−0.009	0.003	0.004	0.012	0.012
	(0.010)	(0.014)	(0.006)	(0.007)	(0.026)	(0.036)
Parish-Level Controls	No	Yes	No	Yes	No	Yes
Num. Obs.	1199	1187	746	737	746	737
Mean Dep. Var.	0.622	0.621	0.034	0.033	0.303	0.300
Pseudo R2	0.025	0.033	0.083	0.167	0.018	0.037

Notes: This table reports the Average Marginal Effects (AMEs) from Probit models examining the determinants of mill survival and transformation between 1755 and 1850. The unit of analysis is the individual water mill from the 1755 Roy Military Survey. Columns 1–2 model the probability of a mill site surviving to 1850, where survival is defined as the presence of any mill structure within a 500-metre radius of the original site in the 1850 Ordnance Survey. Columns 3–4 and 5–6 are estimated on the subsample of surviving mills, modelling the probability of adopting steam power and transitioning to industrial production, respectively. 'Switched to steam' indicates the presence of a steam-powered mill, while 'industrialised' refers to a transition to non-grain production. Parish-level controls, included in even-numbered columns, consist of 1755 population density, market potential, percentage of Catholics, and dummies for canal access, railway presence by 1851, Highland Clearances, and historical battles. A full table with all control variables reported individually can be found in the Appendix in Table A.7. Robust standard errors adjusted for spatial correlation (50 km cutoff) are reported in parentheses; *** denotes statistical significance at the 0.01 level, ** at the 0.05 level, and * at the 0.1 level, all for two-sided hypothesis tests. All regressions include a constant.

was driven by coal proximity, confirming transport cost constraints. Crucially, local water power potential has no significant effect on steam adoption, refuting a simple substitution narrative and aligning with accounts of technological complementarity (Chapman, 1970; Whatley, 1997). Conversely, Columns 5 and 6 show that the site's water power potential best predicted transformation from a traditional grain mill to industrial production. It not only increased survival probability by around 40 percentage points but also, conditional on survival, raised the probability of industrial transformation by 23 percentage points relative to a mean of 30% (Column 6). The positive coefficient on ruggedness may further reflect the importance of hydraulic head for power-intensive industrial processes. By contrast, the coefficient on distance to coal is statistically insignificant.

These findings reinforce the arguments of Reynolds (1983), Mokyr (1992), and Crafts (2004) regarding water power's foundational role in early industrialisation, though they contrast with Crafts and Wolf (2014) who found coal determined English textile locations in 1838. This divergence likely reflects Scotland's abundant water power potential (Jonell et al., 2024) or suggests coal operated at the extensive (regional) rather than intensive (site-specific) margin. Consistent with classic accounts of steam adoption (Pollard, 1981; Allen, 2009; Fernihough and O'Rourke, 2021), proximity to coal facilitated the transition to steam technology, but it did not drive industrial transformation at incumbent sites. Instead, industrialisation occurred disproportionately at locations with superior water power potential. While areas close to coalfields show signs of localised displacement through lower survival rates, the dominant pattern is one of sequential complementarity: hydraulically advantaged sites survived and industrialised, and where coal was cheap, steam power augmented capacity rather than replaced existing capital.

4.5 Migration and Fertility

Having established that pre-industrial water mills generated sustained population growth and facilitated industrial development, this section examines the demographic mechanisms underlying these effects. The evidence indicates that migration, rather than fertility changes, was the primary driver of population growth in mill-intensive parishes.

The demographic transition theory articulated by Galor (2012) proposes that improvements in economic conditions during early industrialisation typically manifested through rising fertility – driven by improved living standards and falling mortality due to better nutrition and living conditions. Over time, however, fertility declined as the opportunity cost of childbearing increased (Galor, 2011). For Prussia, Becker et al. (2010) date this fertility transition to the late nineteenth century. At the micro level, Horrell and Humphries (1995) show that employment in textile mills provided new economic opportunities for women, reshaping marriage patterns and family formation decisions. In principle, then, mills could have influenced fertility in two opposing directions: raising fertility through improved living standards, or reducing it through a child quality–quantity tradeoff and increased female labour market participation.

Despite these theoretical considerations, the analysis in Table 6 reveals little evidence of a fertility response. By 1851, there is virtually no relationship between pre-industrial water mills and demographic outcomes. The coefficients for fertility, measured by the child–woman ratio, are positive but statistically insignificant and very small: one additional mill corresponds to less than 0.01 additional children per woman. Similarly, household size and the elderly population share show only marginal differences, though they become statistically significant in the IV specification.

Overall, these findings suggest that water mill–based industrialisation had no meaningful effect on fertility, household structure, or age composition. One interpretation is that parishes industrialising from a pre-industrial water mill base were not socioeconomically different enough from others to generate distinct fertility patterns. Alternatively, mid-century may have been a period when positive and negative effects of industrialisation on fertility offset one another.

Since neither fertility nor mortality shifts can explain the observed population increases, migration must have been the dominant demographic mechanism. Scotland was not a country of large-scale immigration during this period, although over 300,000 of its 1851 population of 2.9 million were born outside the country. Internal migration accounted for most of the growth in industrialising parishes between 1820 and 1870 and was substantial: almost 1.4 million people resided outside their parish of birth in 1851. This figure highlights the high degree of labour mobility within Scotland. Declining transport costs, both within Europe and overseas, facilitated movement towards areas offering better employment opportunities and higher wages

Table 6: Regression Analysis of Water Mills and Fertility

Dependent Variable (1851):	Child-Woman Ratio		Avg. Household Size		Pct. 60+ Years Old	
Method:	OLS	IV (2SLS)	OLS	IV (2SLS)	OLS	IV (2SLS)
	(1)	(2)	(3)	(4)	(5)	(6)
Water Mills 1755	0.004	0.007	0.016	0.038	−0.022	0.143*
	(0.004)	(0.007)	(0.016)	(0.025)	(0.059)	(0.079)
Geographic and Environmental Controls	Yes	Yes	Yes	Yes	Yes	Yes
Agricultural and Economic Base Controls	Yes	Yes	Yes	Yes	Yes	Yes
Transportation and Infrastructure Controls	Yes	Yes	Yes	Yes	Yes	Yes
Institutional and Cultural Controls	Yes	Yes	Yes	Yes	Yes	Yes
Latitude-Longitude	Yes	Yes	Yes	Yes	Yes	Yes
Num. Obs.	785	785	785	785	785	785
R2	0.154	0.153	0.317	0.317	0.327	0.330
R2 Adj.	0.133	0.132	0.300	0.300	0.311	0.314

Notes: This table reports results from OLS and IV regressions of demographic variables on the number of water mills in 1755. A full table with all control variables reported individually can be found in the Appendix in Table A.8. Robust standard errors adjusted for spatial correlation are reported in parentheses; *** denotes statistical significance at the 0.01 level, ** at the 0.05 level, and * at the 0.1 level, all for two-sided hypothesis tests. All regressions include a constant.

(Hatton and Williamson, 1998). The rapid expansion of transportation networks, particularly canals and railways, further reduced migration costs and allowed labour to respond swiftly to industrial demand.

Ideally, the role of migration could be assessed by tracking the growth or shrinking of different subgroups across time. Since 1851 provides the earliest complete census with detailed individual birthplace information, however, I employ an alternative strategy to approximate the contribution of different channels to population growth between 1801 and 1851. I begin by defining a population composition identity for a parish in year t:

$$P_t = SDM_t + LDM_t + For_t + Loc_t \tag{5}$$

where the total population P_t consists of short-distance migrants, long-distance migrants, foreign-born individuals, and locally born individuals.

Population growth between 1801 and 1851 $\frac{P_{1851}}{P_{1801}}$ can then be expressed as:

$$\frac{P_{1851}}{P_{1801}} = \frac{SDM_{1851}}{P_{1801}} + \frac{LDM_{1851}}{P_{1801}} + \frac{For_{1851}}{P_{1801}} + \frac{Loc_{1851}}{P_{1801}} \tag{6}$$

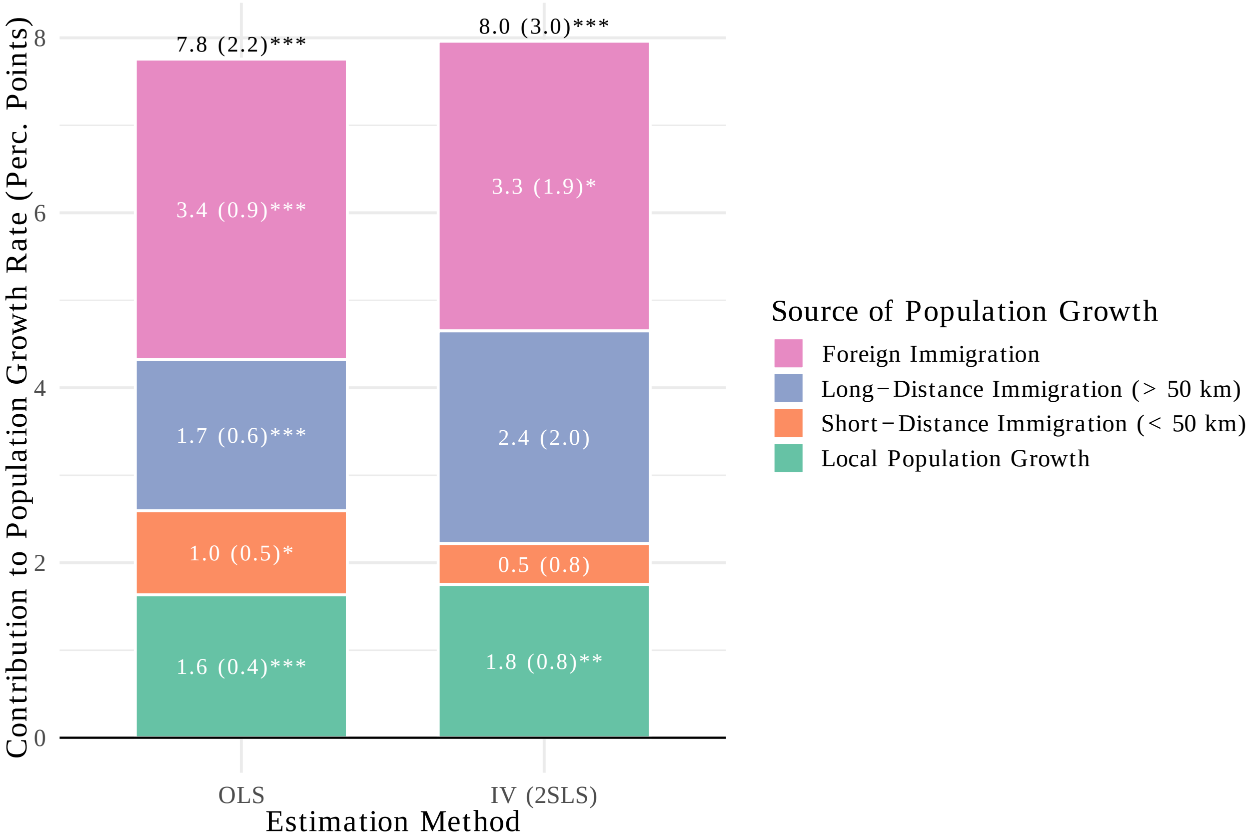
Under the assumption that immigrants present in 1801 were no longer alive in 1851, this identity decomposes parish-level population growth into short-distance immigration, long-distance immigration, foreign immigration, and a local growth component. I define short-distance immigrants as those born outside the parish but within 50 km, long-distance immigrants as those born elsewhere in Scotland beyond 50 km, and foreigners as those born outside Scotland. The local growth component measures the size of the locally born population in 1851 relative to total population in 1801. By nature, this reflects the balance of births, deaths, and emigration among the locally born. Since Table 6 shows no relationship between water mills and fertility or mortality, variation in the local growth component should largely reflect differences in emigration. A positive coefficient here indicates a lower emigration rate.

Figure 5 visualises the results of a regression of the individual population growth components between 1801 and 1851 on the number of water mills in 1755. One additional water mill in 1755 is associated with a 7.5% increase in parish population between 1801 and 1851. Of this, about 3% derives from the local growth component, which primarily reflects reduced emigration. The remaining increase of more than 4% is roughly equally split between foreign immigration and short distance immigration from within 50 km. Long-distance internal migration within Scotland appears to play only a minor role in the population growth of industrialising areas.

The dominance of short-distance over long-distance migration is consistent with Hatton and Williamson (1998) emphasising the role of falling transport costs and local wage differentials. Industrial growth around water mills created strong localised labour markets that drew in workers from nearby parishes rather than redistributing population across Scotland. This aligns with Whatley (1997, p. 66), who observed that “the main source of Lowland growth was Lowlanders.” The pattern also reflects Ravenstein’s (1889) notion of “step migration,” in which rural populations moved gradually towards industrial centres rather than undertaking long-distance relocations.

The limited role of long-distance internal migration within Scotland may seem surprising in light of the Highland Clearances, which Gibson (2006) date to roughly 1750 to 1860. Yet, recent scholarship suggests that while the Clearances were locally devastating, they had relatively modest aggregate demographic effects on Scotland’s industrialising regions (Devine, 2018).

Figure 5: Decomposition of Population Growth Effect (1801–1851)



Notes: The figure graphically presents the results of OLS and IV regressions of total relative population growth between 1801 and 1851, as well as its components, on the number of water mills in 1755. The height of each column represents the coefficient for total population growth, which is displayed at the top. The figure decomposes this total effect into its underlying components, which are stacked to show their relative contributions; by construction, the sum of the component coefficients equals the total coefficient. All population growth measures are expressed in percentage terms. The decomposition of total population growth follows the approach described in the main text. A corresponding regression table can be found in the Appendix in Table A.9. Robust standard errors adjusted for spatial correlation are reported in parentheses; *** denotes statistical significance at the 0.01 level, ** at the 0.05 level, and * at the 0.1 level, all for two-sided hypothesis tests.

Sources: As described in the text.

Foreign immigration, by contrast, was heavily concentrated in parishes with many water mills in 1755. Table A.10 in the appendix shows that Irish migrants account for nearly all of this inflow. Their numbers rose by more than 90% between 1841 and 1851 to around 200,000 individuals by 1851, reflecting mass famine-driven migration (Whatley, 1997; Schürer et al., 2024). By comparison, roughly 50,000 migrants from England and Wales did not disproportionately settle in mill-rich areas, and immigration from elsewhere remained too small to matter. The concentration of Irish migrants in industrial parishes underscores that these areas offered superior economic opportunities, consistent with the industrial path dependence highlighted above.

These demographic patterns suggest that successful industrialisation in Scotland required more than technological innovation or capital accumulation: it also depended on the ability to attract and absorb labour. Scotland's relatively open internal migration regime, with minimal legal or institutional constraints on movement, may have been an enabling condition for the success of mill-based industrialisation (Houston and Withers, 1990). Migration also helps explain the self-reinforcing nature of industrial path dependence. Parishes that attracted early waves of migrants from nearby areas likely developed larger and more diversified labour forces, which in turn sustained further industrial growth and continued in-migration. In this way, the demographic foundations of industrial Scotland were built as much on mobility as on machinery.

4.6 Occupations

Having established that pre-industrial water mills generated sustained population growth through migration rather than fertility changes, and that these locations successfully industrialised on water power and through complementary adoption of steam power, this section examines the occupational structure of mill-intensive parishes to understand the types of economic activities and skills that emerged in these locations. The analysis draws on individual-level census data from 1851, the earliest complete census with detailed occupational information, to test whether water mills shaped not only aggregate demographic outcomes but also the specific composition of the local workforce.

Table 7 examines broad sectoral employment shares. The coefficients for agriculture are negative although statistically insignificant. In contrast, pre-industrial water mills had a positive and statistically significant effect on manufacturing employment, where in the IV specification one additional 1755 mill is associated with a 0.8 percentage point increase in the share of the population employed in manufacturing. Given that the mean manufacturing share was approximately 6% in 1851, this represents a substantial 13% increase relative to the mean.

The decomposition by manufacturing sub-sector reveals that this effect was present in industries that could benefit from spillovers generated by pre-industrial mills, such as an accumulated supply of mechanical skills, existing power infrastructure, or established transport links. The coefficient for metal manufacturing is statistically significant with a 10% increase relative to the mean. Agricultural manufacturing, which includes milling, refining, baking etc., shows a large, significant coefficient, showing that while agricultural employment tended to decline, food processing industries concentrated in mill-rich areas. The coefficient for textile manufacturing is positive and significant, but modest in absolute terms. Steam and coal availability seem to be better predictors of textile employment by 1851, indicating a declining relative importance of historical water power sites for textiles as steam became the dominant technology. This result aligns with the findings of Crafts and Wolf (2014) for England, who demonstrate that by 1838, proximity to coal and steam power had become a primary determinant of textile factory location.

Table 7: Regression Analysis of Water Mills and Occupations in 1851

Dependent Variable (1851):	Pct. Agriculture		Pct. Manufacturing		Pct. Metal Mf.		Pct. Agricultural Mf.		Pct. Textile Mf.	
Method:	OLS	IV (2SLS)	OLS	IV (2SLS)	OLS	IV (2SLS)	OLS	IV (2SLS)	OLS	IV (2SLS)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Water Mills 1755	−0.314	−0.219	0.281***	0.795*	0.011*	0.014***	0.235***	0.791*	0.043***	0.053**
	(0.195)	(0.272)	(0.104)	(0.468)	(0.006)	(0.005)	(0.085)	(0.455)	(0.014)	(0.023)
Distance to Coal (log x+1)	1.197***	1.206***	−1.156***	−1.107***	0.041**	0.042**	−0.964***	−0.911***	−0.062***	−0.061***
	(0.461)	(0.445)	(0.297)	(0.327)	(0.021)	(0.021)	(0.254)	(0.280)	(0.024)	(0.023)
Steam Engines 1800	0.035	0.031	0.003	−0.020	−0.002	−0.002	−0.009	−0.033	0.008	0.007
	(0.060)	(0.060)	(0.146)	(0.152)	(0.002)	(0.002)	(0.132)	(0.151)	(0.007)	(0.007)
Geographic and Environmental Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Agricultural and Economic Base Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Transportation and Infrastructure Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Institutional and Cultural Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Latitude-Longitude	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Num. Obs.	785	785	785	785	785	785	785	785	785	785
R2	0.474	0.472	0.305	0.308	0.121	0.118	0.268	0.272	0.171	0.156
R2 Adj.	0.461	0.458	0.288	0.291	0.099	0.096	0.250	0.254	0.150	0.135

Notes: This table reports results from OLS and IV regressions of occupational shares in 1851 on the number of water mills in 1755. The dependent variables are derived from the 1851 census, classified using EA17 and EA51 codes (e.g., EA17=1 for Agriculture, EA51=7 for Metal Manufacturing). Each occupational share represents the percentage of the total resident population of that parish in 1851 employed in that sector. Controls are grouped for readability. A full table with all control variables reported individually can be found in the Appendix in Table A.11. Robust standard errors adjusted for spatial correlation are reported in parentheses; *** denotes statistical significance at the 0.01 level, ** at the 0.05 level, and * at the 0.1 level, all for two-sided hypothesis tests. All regressions include a constant.

An important interpretive caution is warranted regarding the magnitude of these effects. While statistically significant, the coefficients on occupational shares are modest compared to the large population growth effects documented earlier. This is a mechanical consequence of using shares, which must sum to 100%. Factory workers needed food, housing, and services, creating derived demand for shopkeepers, bakers, publicans, carters, and construction workers. Thus, even as the manufacturing workforce grew substantially in absolute numbers, the percentage share of manufacturing was diluted by the simultaneous growth of this supporting non-tradeable sector. The results show the compositional tilt towards manufacturing, not the full absolute scale of industrial employment growth.

The relationship between employment shares and coal access also merits attention. Distance to coal is positively associated with agricultural employment and negatively associated with manufacturing employment, confirming that proximity to coalfields was a powerful driver of structural transformation. This is consistent with the findings of Fernihough and O'Rourke (2021) regarding coal's importance for industrial siting. However, the continued significance of the water mills coefficient after controlling for coal access demonstrates that proto-industrial foundations mattered independently. The coefficient on early steam engines before 1800 (log x+1) in the manufacturing regressions is negative in the OLS specification but insignificant or negative in IV, suggesting that switching to steam very early was not necessarily advantageous.

Table 8: Regression Analysis of Water Mills and Skills in 1851

Dependent Variable (1851):	Pct. Millwrights		Pct. Machinery Mf.		Pct. Tools Mf.		Pct. Skilled		Pct. Unskilled	
Method:	OLS	IV (2SLS)	OLS	IV (2SLS)	OLS	IV (2SLS)	OLS	IV (2SLS)	OLS	IV (2SLS)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Water Mills 1755	0.028***	0.040**	0.035***	0.035*	0.005**	0.014	0.112**	0.185*	−0.316	−0.166
	(0.010)	(0.017)	(0.012)	(0.021)	(0.002)	(0.009)	(0.048)	(0.099)	(0.229)	(0.258)
Distance to Coal (log x+1)	0.000	0.002	−0.005	−0.005	0.001	0.002	−0.209	−0.202	1.428***	1.442***
	(0.009)	(0.009)	(0.010)	(0.010)	(0.002)	(0.003)	(0.142)	(0.140)	(0.428)	(0.422)
Steam Engines 1800	−0.001	−0.001	−0.001	−0.001	0.000	−0.001	0.029	0.025	−0.006	−0.012
	(0.002)	(0.003)	(0.002)	(0.003)	(0.000)	(0.001)	(0.033)	(0.033)	(0.052)	(0.049)
Geographic and Environmental Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Agricultural and Economic Base Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Transportation and Infrastructure Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Institutional and Cultural Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Latitude-Longitude	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Num. Obs.	785	785	785	785	785	785	785	785	785	785
R2	0.180	0.131	0.190	0.159	0.038	0.043	0.314	0.312	0.412	0.408
R2 Adj.	0.160	0.110	0.170	0.138	0.015	0.019	0.297	0.295	0.397	0.394

Notes: This table reports results from OLS and IV regressions of skilled and unskilled occupational shares in 1851 on the number of water mills in 1755. The dependent variables are derived from the 1851 census. 'Pct. Skilled' and 'Pct. Unskilled' are classified using HISCLASS codes (6/7 and 11/12/13, respectively), while specific manufacturing skills use Occode and EA51 codes. All shares are calculated as the percentage of the total resident population of that parish in 1851. Controls are grouped for readability. A full table with all control variables reported individually can be found in the Appendix in Table A.12. Robust standard errors adjusted for spatial correlation are reported in parentheses; *** denotes statistical significance at the 0.01 level, ** at the 0.05 level, and * at the 0.1 level, all for two-sided hypothesis tests. All regressions include a constant.

Table 9: Regression Analysis of Water Mills and Birthplace Skills in 1851

Dependent Variable (1851):	BP Pct. Millwrights		BP Pct. Machinery Mf.		BP Pct. Tools Mf.		BP Pct. Metal Mf.		BP Pct. Textile Mf.	
Method:	OLS	IV (2SLS)	OLS	IV (2SLS)	OLS	IV (2SLS)	OLS	IV (2SLS)	OLS	IV (2SLS)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Water Mills 1755	0.116***	0.133**	0.124***	0.148***	0.004*	0.006**	0.032**	0.035**	0.288**	0.765*
	(0.037)	(0.054)	(0.035)	(0.043)	(0.002)	(0.002)	(0.013)	(0.017)	(0.136)	(0.456)
Distance to Coal (log x+1)	−0.002	−0.001	−0.009	−0.007	0.006***	0.007***	−0.059**	−0.059**	−1.011***	−0.969***
	(0.012)	(0.013)	(0.013)	(0.014)	(0.002)	(0.002)	(0.028)	(0.029)	(0.378)	(0.363)
Steam Engines 1800	−0.004	−0.005	−0.009***	−0.010**	−0.001	−0.001	0.001	0.001	−0.037	−0.058
	(0.005)	(0.006)	(0.003)	(0.005)	(0.000)	(0.001)	(0.003)	(0.003)	(0.093)	(0.118)
Geographic and Environmental Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Agricultural and Economic Base Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Transportation and Infrastructure Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Institutional and Cultural Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Latitude-Longitude	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Num. Obs.	787	787	787	787	787	787	787	787	787	787
R2	0.317	0.127	0.292	0.186	0.043	0.039	0.205	0.194	0.337	0.339
R2 Adj.	0.300	0.106	0.275	0.166	0.019	0.016	0.185	0.174	0.320	0.323

Notes: This table reports results from OLS and IV regressions of birthplace-based skilled occupational shares (for individuals aged 30+) in 1851 on the number of water mills in 1755. This methodology groups all individuals in the 1851 census by their parish of birth. The dependent variable is the share of individuals born in a given parish (and aged 30 or older) who held a specific skilled occupation, classified by Occode or EA51 codes. This percentage is calculated relative to the total population born in that parish aged 30 or older, regardless of where they resided in 1851. Controls are grouped for readability. A full table with all control variables reported individually can be found in the Appendix in Table A.13. Robust standard errors adjusted for spatial correlation are reported in parentheses; *** denotes statistical significance at the 0.01 level, ** at the 0.05 level, and * at the 0.1 level, all for two-sided hypothesis tests. All regressions include a constant.

Table 8 shifts the focus to specific skilled occupations. This tests the argument that proto-industrial activity fostered localised human capital, a key theme in Mokyr's work (1992; 2022; 2023), who emphasises the importance of pre-existing technical skills and mechanical ingenuity as foundations for the Industrial Revolution. Pre-industrial mills, in particular, required a specialised workforce: millwrights. They were the craftsmen responsible for building and maintaining mill machinery and key figures in the mechanical knowledge networks emphasised by Mokyr (1992). This analysis tests if these artisanal skills, clustered around the 1755 mills, persisted locally.

The results show a positive association between 1755 mills and skills in 1851. Most notably, the coefficient for millwrights is positive and highly significant. One additional mill is associated with a 0.04 percentage point increase in the millwright share, a 40% increase relative to the mean (0.1). Their concentration in historically mill-rich areas suggests persistent, localised accumulation of mechanical expertise. This is further supported by positive findings for machinery and tool manufacturing workers, aligning with Mokyr et al. (2022) and Hinrichs (2026).

The broader measure of skilled workers classified by HISCLASS codes 6 and 7 also exhibits a positive, significant relationship. The coefficients, between 0.1 and 0.2, are quite small relative to the 5% mean, however. In contrast, the coefficient on unskilled workers is negative and statistically insignificant. This provides weak evidence for a compositional shift in mill-rich parishes to skilled labour and no evidence for an increased use of unskilled labour. This contrasts with broad narratives of technological change being either purely 'deskilling' (replacing artisans with machines) or 'skilling'. The historical literature itself is ambiguous, suggesting that industrialisation had complex effects, eliminating some craft skills while creating new demands for technical and mechanical expertise, alongside a massive new demand for unskilled operatives (Mokyr, 1992; Horrell and Humphries, 1995; Feldman and van der Beek, 2016; de Pleijt et al., 2020; Diebolt et al., 2021). The modest effects here may reflect these opposing forces, or the fact that both skilled and unskilled labour were needed in expanding industrial economies.

These skill effects can be the result of different mechanisms: sorting and skill development. One possibility is that the observed correlation between mills and skilled workers reflects sorting: individuals with mechanical skills may have migrated to mill-intensive parishes because opportunities there better matched their pre-existing skills. The migration decomposition showed that parishes with more mills attracted substantial in-migration, making this sorting mechanism plausible. The argument made by Mokyr et al. (2022) and Hinrichs (2026) however is skill development within and besides water mills over time.

To address this question and get more insights into skill formation a few decades prior to 1851 when the "great age of water power in Scotland" was not yet over (Whatley, 1997, p. 52), Table 9 employs an alternative approach by analysing occupations based on birthplace rather than residence. Instead of examining where skilled workers lived in 1851, this specification groups individuals by their parish of birth and measures the share of natives from each parish (aged 30 or older) who held skilled occupations in 1851, regardless of where they resided by that year. This birthplace-based measure better captures the skill formation function of a parish, as it includes individuals who acquired skills locally but subsequently migrated elsewhere.

The results are remarkably consistent with the residence-based analysis. The coefficients for millwrights, machinery manufacturing, and metal manufacturing remain positive and are now all significant across OLS and IV specifications. This indicates that individuals born in mill-rich parishes were more likely to enter these skilled mechanical trades even if they later moved away. The coefficient for textile manufacturing is substantially larger in the birthplace specification than in the employment shares in 1851, suggesting skill formation in water-mill-rich parishes but also subsequent outmigration of textile-skilled workers from their birth parishes, when water power started to lose importance.

The control variables in Table 9 add further nuance. Proximity to coalfields is a strong negative predictor of "being born" with textile skills, reinforcing the link between textiles and coal-based steam power by the mid-nineteenth century. However, coal access is uncorrelated with the mechanical skills of millwrights and machinery makers, which remain strongly associated with the 1755 water mills. Conversely, the presence of early steam engines (before 1800) is a positive predictor for metal-working skills, but not for millwright or textile skills, pointing to distinct skill-formation pathways. Together, these results suggest that Scotland's industrial geography was shaped by the interaction of proto-industrial foundations (water mills) and access to modern energy sources (coal), with both influencing the specific technological and occupational trajectories different locations followed.

In sum, the occupational analysis provides evidence consistent with the aggregate story of industrial path dependence. Parishes with more pre-industrial water mills not only attracted larger populations and more factories, but also developed distinctive skill profiles characterised by concentrations of millwrights, machinery workers, and textile artisans. The findings support the interpretation that pre-industrial mills served as platforms for skill accumulation and industrial diversification, as emphasised by Mokyr et al. (2022) for England and Hinrichs (2026) for Prussia. The results are, however, subject to limitations. The 1851 census provides a snapshot late in the water-to-steam transition. Furthermore, the birthplace analysis assumes skills are acquired locally before migration, which, while plausible for apprenticeships, cannot be directly observed due to a lack of data for earlier periods.

5 Conclusion

This paper demonstrates that Scotland's Industrial Revolution was fundamentally shaped by path dependence rooted in pre-industrial water power infrastructure. Using a comprehensive dataset spanning nearly 150 years and employing instrumental variable techniques to address endogeneity concerns, the analysis reveals that parishes with more water mills in 1755 experienced substantially greater population growth, industrial development, and technological adoption throughout the nineteenth century.

The findings make three distinct contributions to our understanding of early industrialisation. First, they provide robust causal evidence for industrial path dependence in a major European economy. Parishes with one additional water mill in 1755 experienced approximately 8% greater cumulative population growth by 1891, with effects becoming statistically significant precisely during Scotland's period of rapid industrial expansion between 1820 and 1850. This timing suggests that pre-industrial mill sites became focal points for mechanised production during the critical transition period, providing causal support for the long-run importance of proto-industrial foundations (Mokyr et al., 2022).

Second, the paper challenges prevailing narratives about technological displacement during the Industrial Revolution. Rather than experiencing "incumbent lock-in" as steam power emerged, water-powered parishes successfully adapted to become centres of steam adoption and industrial diversification. By 1800, areas with more pre-industrial mills were significantly more likely to have installed steam engines, and by 1838 they hosted substantially more textile factory capacity. This contradicts the leapfrogging dynamics documented in other contexts (Hornbeck et al., 2024) and reveals complementarity between water and steam technologies during Scotland's industrial transition.

Third, the demographic analysis illuminates the mechanisms underlying industrial growth. Population increases in mill-intensive parishes resulted primarily from migration rather than fertility changes, with roughly equal contributions from reduced emigration, short-distance internal migration, and Irish immigration following the potato famine. This pattern underscores the importance of labour mobility in facilitating industrial development and suggests that Scotland's relatively open internal migration regime was a crucial enabling condition for successful industrialisation (Houston and Withers, 1990).

Fourth, the analysis of occupations in the 1851 census provides new evidence for the human capital dimension of path dependence. It shows that pre-industrial mill locations evolved into specialised labour markets with significantly higher shares of mechanically-skilled workers, such as millwrights. Birthplace analysis confirms these sites facilitated the local formation of technical skills, supporting the view of proto-industry as a training ground for mechanical expertise (Mokyr, 1992; Mokyr et al., 2022; Hinrichs, 2026).

These findings have broader implications for understanding the geography of economic development. While coal access undoubtedly mattered for industrialisation, the pre-industrial distribution of water power created lasting advantages that persisted well into the steam age. The Industrial Revolution's map was not simply written by coalfields (Pollard, 1981) but reflected the complex interaction between new energy sources and existing proto-industrial foundations. Scotland's experience thus exemplifies how technological transitions can reinforce rather than eliminate historical advantages, with early industrial clusters successfully adapting to maintain their competitive edge across fundamental technological shifts.

The Scottish case also demonstrates the value of examining industrialisation through multiple lenses simultaneously. By analysing population growth, technological adoption, industrial diversification, and demographic mechanisms within a unified framework, this study reveals the interconnected nature of economic transformation during the Industrial Revolution. Future research might profitably extend this approach to other regions and time periods, examining how different institutional contexts and geographic endowments shaped the relationship between proto-industrial foundations and subsequent industrial development.

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A Appendix

A.1 Data and Measurement

A.1.1 Variable Definitions

The dataset used in this study comprises a collection of variables related to geographical, economic, institutional and demographic factors. These variables are sourced from a variety of archival and secondary materials and are all measured at the parish level. The final dataset is the results of a combination of existing datasets as well as new digitisation of historical maps and census data. A complete list of all variables, including their exact definitions and sources, is provided in Table A.1.

To analyse the structure of the labour force in Section 4.6, I rely on individual-level data from the 1851 census (Schürer et al., 2024). Transforming raw occupational descriptions into quantitative variables required a multi-step standardisation process using three distinct classification systems:

Sectoral Classification (EA Codes): To measure industrial composition (e.g., Pct. Manufacturing, Pct. Textile Mf.), occupations were classified according to the Economic Area (EA) scheme developed by Bennett et al. (2017). Using the numeric Occupation Codes (Occodes) provided in the Integrated Census Microdata (I-CeM), individuals were mapped to the EA17 (broad sectoral) and EA51 (detailed sub-sectoral) classifications. For instance, the broad manufacturing share is derived from EA17, while specific industries like metal and machinery are identified using EA51 codes. Complete tables including all EA17 and EA51 categories and further details on these classifications can be found in Bennett et al. (2017).

Skill and Social Class (HISCLASS): To proxy for human capital and skill levels (Pct. Skilled, Pct. Unskilled), occupations were mapped to the Historical International Social Class Scheme (HISCLASS). This construction followed a two-stage crosswalk procedure: first, the OCCHISCO codes in the census were converted to standard HISCO codes (Historical International Standard Classification of Occupations) using a crosswalk table provided by Zijdeman (2014). Second, these HISCO codes were translated into the 12-category HISCLASS system using the coding algorithms provided by Sandström (2015). In the regression analysis, “Skilled” workers are defined as those falling into HISCLASS categories 6 and 7 (foremen and medium-skilled workers), while “Unskilled” workers correspond to categories 11, 12, and 13 (unskilled farm and non-farm workers).

Specific Trades: specialised mechanical trades, such as millwrights, were identified directly using specific Occode identifiers to ensure precision in tracking the persistence of water-mill-related human capital.

A.1.2 Control Variables

The empirical analysis includes a wide range of control variables at the parish level to isolate the causal effect of water mills from other factors that might simultaneously influence both pre-industrial mill placement and long-run economic development. These controls are grouped into four main categories:

Geographic and Environmental Controls account for a parish’s natural endowments. Crucially, they include Water Power Potential and Terrain Ruggedness as standalone variables. By controlling for these main effects, the identification strategy ensures that the instrumental variable (the interaction of Water Power Potential with Land Capability) isolates the specific suitability for milling, rather than just general geographic advantage. This category also includes Distance to Coal, which is essential for distinguishing the effect of water power from the dominant alternative energy narrative (Pollard, 1981; Fernihough and O’Rourke, 2021). Variables for Parish Area, Coastal or Navigable River access, and Distance to Port capture basic geographic scale and natural access to transport infrastructure, which could independently drive economic activity.

Agricultural and Economic Base Controls account for the pre-industrial economic structure. They include Land Capability (the share of land suitable for grain cultivation), which serves as the demand-side component of the instrument. By controlling for these variables separately, the analysis isolates the instrument’s interaction from the general effect of agricultural productivity. Initial economic conditions are captured by Population Density in 1755 and Market Potential in 1755, which control for pre-existing levels of agglomeration and economic activity. The number of Steam Engines by 1800 is also included to control for the earliest adoption of the alternative technology, ensuring the water mill effect is not simply proxying for general technological precociousness.

Table A.1: Variable Definitions and Sources

Variable	Definition	Source
Water Mills 1755	Number of mills at most 275m away from nearest river	Jonell et al. (2024) based on Roy Military Survey of Scotland (1747-1755)
Mills 1850 or 1900	Number of mills classified by power source and function	Own classification based on mill locations from Ordnance Surveys digitized by National Library of Scotland (2021)
Water Power Potential	Sum of rasterized logarithmic average waterpower potential (in W) based on 1891-1940 moisture balance and corrected for post-industrial barriers (divided by 1,000 for better readability)	Own computations based on Jonell et al. (2024)
Ruggedness	Mean of rasterized Terrain Ruggedness Index (TRI) constructed following Riley et al. (1999) as the square root of summed squared elevation differences with neighboring cells	Own computations based on Ordnance Survey (2013)
Land Capability	Share of land suitable for at least a moderate (factor 1, classes 1-3) or narrow (factor 0.5, class 4) range of crops (1950s-1980s)	Own Computations based on Soil Survey of Scotland Staff (1981)
Population 1755	Total parish population in 1755	National Records of Scotland (2022) based on Webster's analysis of population 1755
Population 1801 to 1891	Total parish population in 1801 to 1891	National Records of Scotland (2022) based on decennial official censuses
Population Density 1755	Total population divided by total parish area in sq km	National Records of Scotland (2022)
Percentage of Catholics 1755	Number of Catholics ('Papists') divided by total population (in percent)	Digitized from Kyd (1952) reporting data from Webster's analysis of population 1755
Market Potential 1755	Harris market potential computed using population in 1755 (1761 for England) and geodesic distance with an exponential decay parameter of 10 km	Own computations based on National Records of Scotland (2022) and Kelly et al. (2023)

Variable	Definition	Source
Distance to Coal	Distance from parish border to nearest coal field in km, 0 if coal field and parish overlap	Own computations based on Fernihough and O'Rourke (2021)
Distance to Port	Distance from parish border to nearest port in 1700 in km, 0 if port in parish	Own computations based on digitized map from McNeill and MacQueen (1996)
Royal Burgh	Dummy = 1 if the parish contained a Royal burgh in 1700	Own assignment based on digitized map from McNeill and MacQueen (1996)
Highland Clearances	Dummy = 1 if the parish was affected by the Highland Clearances	Own assignment based on digitized map from Gibson (2006)
Battle 1500-1750	Dummy = 1 if a major battle was fought on the grounds of the parish between 1500 and 1750	Own assignment based on Historic Environment Scotland (2020)
Coast or Navigable River	Dummy = 1 if the parish had access to the coast or a navigable river	Own assignment based on digitized map from Royal Commission on Canals and Waterways (1907)
Canal	Dummy = 1 if a manmade canal ran through the parish	Own assignment based on digitized map from Royal Commission on Canals and Waterways (1907)
Railway Line 1851	Dummy = 1 if a railway line ran through the parish in 1851	Own assignment based on Satchell et al. (2018)
Steam Engines 1800	Number of steam engines used in the parish before 1800	Kanefsky (2025)
Non-Colliery Steam Engines 1800	Number of steam engines used before 1800 excluding engines in collieries	Kanefsky (2025)
Parish Area	Size of the parish in sq km	National Records of Scotland (2022)
Textile Factory Power 1838	Sum of reported power usage (water and steam) from 1838 Factory Return in hp	Own computations based on Jonell et al. (2024)
Percentage of Foreigners 1851	Percentage of parish population not born in Scotland	Own computations based on Schürer et al. (2024)
Child-Woman Ratio 1851	Number of children aged 0–7 in parish divided by number of women aged 15–45	Own computations based on Schürer et al. (2024)
Average Household Size 1851	Average number of persons per household	Own computations based on Schürer et al. (2024)
Percentage Over 60 Years 1851	Percentage of parish population aged 60 years and older	Own computations based on Schürer et al. (2024)
Longitude / Latitude	Easting and Northing of parish centroid according to British National Grid	Own computations based on National Records of Scotland (2022)

Variable	Definition	Source
Short-Distance Immigration (under 50 km)	Number of people in 1851 born outside parish but within 5–50 km in Scotland divided by total population in 1801 (in percent)	Own computations based on Schürer et al. (2024)
Long-Distance Immigration (over 50 km)	Number of people in 1851 born more than 50 km away in Scotland divided by total population in 1801 (in percent)	Own computations based on Schürer et al. (2024)
Foreign Immigration	Number of people in 1851 born outside Scotland divided by total population in 1801 (in percent)	Own computations based on Schürer et al. (2024)
Local Population Growth	Number of people in 1851 born in the same parish divided by total population in 1801 (in percent)	Own computations based on Schürer et al. (2024)
Irish Immigration	Number of people in 1851 born in Ireland divided by total population in 1801 (in percent)	Own computations based on Schürer et al. (2024)
English and Welsh	Number of people in 1851 born in England or Wales divided by total population in 1801 (in percent)	Own computations based on Schürer et al. (2024)
Other European	Number of people in 1851 born in continental Europe (excluding Britain and Ireland) divided by total population in 1801 (in percent)	Own computations based on Schürer et al. (2024)
From Rest of World	Number of people in 1851 born outside Europe divided by total population in 1801 (in percent)	Own computations based on Schürer et al. (2024)
Pct. Agriculture 1851	Percentage of resident population employed in Agriculture, classified using EA17 code 1	Own computations based on Schürer et al. (2024) and Bennett et al. (2017)
Pct. Manufacturing 1851	Percentage of resident population employed in Manufacturing, classified using EA17 code 10	Own computations based on Schürer et al. (2024) and Bennett et al. (2017)
Pct. Metal Mf. 1851	Percentage of resident population employed in Metal Manufacturing, classified using EA51 code 7	Own computations based on Schürer et al. (2024) and Bennett et al. (2017)
Pct. Agricultural Mf. 1851	Percentage of resident population employed in Agricultural Manufacturing, classified using EA51 code 23	Own computations based on Schürer et al. (2024) and Bennett et al. (2017)

Variable	Definition	Source
Pct. Textile Mf. 1851	Percentage of resident population employed in Textile Manufacturing, classified using EA51 code 9	Own computations based on Schürer et al. (2024) and Bennett et al. (2017)
Pct. Millwrights 1851	Percentage of resident population employed as Millwrights, identified by specific Occodes	Own computations based on Schürer et al. (2024)
Pct. Machinery Mf. 1851	Percentage of resident population employed in Machinery Manufacturing, classified using Occode or EA51 codes	Own computations based on Schürer et al. (2024)
Pct. Tools Mf. 1851	Percentage of resident population employed in Tools Manufacturing, classified using Occode or EA51 codes	Own computations based on Schürer et al. (2024)
Pct. Skilled 1851	Percentage of resident population classified as Skilled (Foremen and Medium-Skilled) corresponding to HISCLASS codes 6 and 7	Own computations based on Schürer et al. (2024), Zijdeman (2014) and Sandström (2015)
Pct. Unskilled 1851	Percentage of resident population classified as Unskilled (Farm and Non-Farm) corresponding to HISCLASS codes 11, 12, and 13	Own computations based on Schürer et al. (2024), Zijdeman (2014) and Sandström (2015)
BP Pct. Millwrights (30+)	Percentage of individuals born in the parish (aged 30+) employed as Millwrights anywhere in Scotland in 1851	Own computations based on Schürer et al. (2024)
BP Pct. Machinery Mf. (30+)	Percentage of individuals born in the parish (aged 30+) employed in Machinery Manufacturing anywhere in Scotland in 1851	Own computations based on Schürer et al. (2024)
BP Pct. Tools Mf. (30+)	Percentage of individuals born in the parish (aged 30+) employed in Tools Manufacturing anywhere in Scotland in 1851	Own computations based on Schürer et al. (2024)
BP Pct. Metal Mf. (30+)	Percentage of individuals born in the parish (aged 30+) employed in Metal Manufacturing anywhere in Scotland in 1851	Own computations based on Schürer et al. (2024)
BP Pct. Textile Mf. (30+)	Percentage of individuals born in the parish (aged 30+) employed in Textile Manufacturing anywhere in Scotland in 1851	Own computations based on Schürer et al. (2024)

Transportation and Infrastructure Controls are particularly important given that improved transportation could independently drive both mill prevalence and economic growth. This group captures investments in man-made infrastructure. Specifically, the analysis includes dummies for Canal access and the Railway Line Presence by 1851. These controls account for the impact of new transport networks, which dramatically lowered inland transport costs.

Institutional and Cultural Controls account for historical and institutional factors that could create divergent development paths. Royal Burgh status is included to control for parishes with special historical privileges that may have aided or hindered industrial development. Religious composition (Percentage of Catholics in 1755) and the history of major battles fought between 1500 and 1750 serve as proxies for deep-seated cultural differences or political instability. Finally, a dummy variable for parishes affected by the Highland Clearances is included. This is essential to control for a major, exogenous demographic shock that led to a depopulation in parts of Scotland.

A.1.3 Descriptive Statistics

Table A.2 provides descriptive statistics for all variables used in this study, summarising their central tendencies and variability. The table presents the total number of observations, the count of unique observations, mean, standard deviation, minimum, median, and maximum of each variable, rounded to at least two significant figures.

A.1.4 Data Quality

Population Data: Webster's Account and the Decennial Censuses Pre-statistical population estimates for Scotland are inherently imprecise, and Webster's *Account of the Number of People in Scotland in the Year 1755* is no exception. The Account survives in at least six manuscript versions and was assembled in multiple phases across 1755–56, with data for some parishes plausibly pre-dating the nominal reference year by more than a decade (Youngson, 1961; Anderson, 2011). Ministers' returns ranged from careful house-to-house lists to frank guesses: the minister of Kilmallie, for instance, wrote that "the precise Number of young and old in the parish would be impossible for me to make out in the time limited," submitting an estimate of "about Four Thousand and Two Hundred" (Anderson, 2011, p. 32). Anderson (2011) concludes that at the parish level, a majority of Webster's figures are accurate

Table A.2: Descriptive Statistics

	N	Sum	Mean	SD	Min	Median	Max
Water Mills 1755	795	1198	1.5	1.7	0	1	16
Water Power Potential	851	3856	4.5	6	0	2.7	54
Ruggedness	851	11 067	13	7.8	2.2	11	52
Parish Area	851	78 563	92	136	0.26	45	1140
Coast or Navigable River	851	339	0.4	0.49	0	0	1
Distance to Port	851	21 083	25	29	0	16	218
Distance to Coal	851	55 045	65	83	0	31	503
Land Capability	851	459	0.54	0.36	0	0.57	1
Population Density 1755	838	31 454	38	97	1.5	24	2365
Market Potential 1755	851	12 549	15	9.6	0.089	13	83
Total Steam Engines 1800	851	431	0.51	3.7	0	0	66
Canal	851	30	0.035	0.18	0	0	1
Railway Line 1851	851	251	0.29	0.46	0	0	1
Percentage of Catholics 1755	838	8	0.0091	0.062	0	0	0.96
Royal Burgh	851	72	0.085	0.28	0	0	1
Highland Clearances	851	102	0.12	0.32	0	0	1
Battle 1500-1750	851	70	0.082	0.27	0	0	1
Latitude	851	6.2×10^8	729 349	115 196	537 381	705 376	1 208 718
Longitude	851	2.6×10^8	305 074	62 133	66 509	313 728	461 003
Population 1755	838	1 250 398	1492	2649	80	1117	64 244
Population 1801	849	1 608 744	1895	4504	138	1227	90 768
Population 1811	847	1 799 416	2124	5641	154	1346	112 962
Population 1821	849	2 091 901	2464	7346	139	1481	150 674
Population 1831	849	2 364 732	2785	9176	122	1551	175 407
Population 1841	849	2 620 631	3087	10 975	120	1625	226 258
Population 1851	850	2 889 320	3399	13 264	127	1642	284 399
Population 1861	851	3 062 991	3599	15 196	134	1647	335 436
Population 1871	851	3 360 583	3949	18 566	105	1598	4×10^5
Population 1881	851	3 736 176	4390	21 431	106	1531	430 637
Population 1891	851	4×10^6	4731	24 394	85	1486	486 636
Total Steam Engines 1800	851	431	0.51	3.7	0	0	66
Non-Colliery Steam Engines 1800	851	105	0.12	1.1	0	0	19
Total Textile Power 1838	851	14 741	17	148	0	0	3630
Metal Mills 1850	851	33	0.039	0.26	0	0	4
Textile Mills 1850	851	614	0.72	3.2	0	0	71
Chemical Mills 1850	851	101	0.12	0.6	0	0	13
Wood Mills 1850	851	658	0.77	1.1	0	0	6
Paper Mills 1850	851	74	0.087	0.53	0	0	8
Alcohol Mills 1850	851	17	0.02	0.15	0	0	2
Tobacco Mills 1850	851	6	0.0071	0.17	0	0	5

	N	Sum	Mean	SD	Min	Median	Max
Metal Mills 1900	851	49	0.058	0.39	0	0	6
Textile Mills 1900	851	542	0.64	2.6	0	0	45
Chemical Mills 1900	851	83	0.098	0.59	0	0	12
Wood Mills 1900	851	906	1.1	1.4	0	1	13
Paper Mills 1900	851	78	0.092	0.47	0	0	7
Alcohol Mills 1900	851	21	0.025	0.18	0	0	3
Tobacco Mills 1900	851	3	0.0035	0.077	0	0	2
Child-Woman Ratio 1851	846	648	0.77	0.13	0.38	0.76	1.3
Average Household Size 1851	846	5018	5.9	0.54	4.4	5.9	8.6
Percentage 60+ Years Old 1851	846	6497	7.7	2	2.2	7.6	14
Short-Distance Immigration (under 50 km)	846	1 162 838	1375	6213	20	603	153 850
Long-Distance Immigration (over 50 km)	846	352 532	417	2402	2	110	44 420
Foreign Immigration	846	272 243	322	2499	0	38	62 462
Local Population Growth	846	1 083 359	1281	3566	0	706	90 508
Irish Immigration	846	2×10^5	236	2041	0	10	53 454
English and Welsh Immigration	846	50 060	59	420	0	12	9553
Other European Immigration	846	3296	3.9	36	0	0	828
Immigration From Rest of World	846	6923	8.2	70	0	2	1770
Pct. Agriculture 1851	846	17 648	21	9.7	1.1	22	55
Pct. Manufacturing 1851	846	5130	6.1	7.7	0	2.6	39
Pct. Metal Mf. 1851	846	108	0.13	0.59	0	0	11
Pct. Agricultural Mf. 1851	846	192	0.23	0.24	0	0.18	2.5
Pct. Textile Mf. 1851	846	5112	6	7.2	0	2.9	38
Pct. Millwrights 1851	846	85	0.1	0.14	0	0.054	0.78
Pct. Machinery Mf. 1851	846	184	0.22	0.27	0	0.15	3.4
Pct. Tools Mf. 1851	846	16	0.019	0.095	0	0	2.5
Pct. Skilled 1851	846	4263	5	2.5	0.48	4.6	24
Pct. Unskilled 1851	846	20 882	25	8.2	5	25	53
BP Pct. Millwrights (30+)	851	154	0.18	0.34	0	0	2.7
BP Pct. Machinery Mf. (30+)	851	392	0.46	0.49	0	0.32	3.3
BP Pct. Tools Mf. (30+)	851	27	0.031	0.079	0	0	0.86
BP Pct. Metal Mf. (30+)	851	205	0.24	0.55	0	0.11	11
BP Pct. Textile Mf. (30+)	851	7811	9.2	7.1	0	6.5	47

to no better than ±5 percent, with many potentially in error by 10 percent or more; the national total likely falls somewhere between 1.15 and 1.35 million.

On the other hand, Youngson (1961, p. 200), reviewing the same material, judges the Account "obviously thoroughly done" and considers the national total broadly credible. Taken together, these assessments suggest Webster provides a reasonable order-of-magnitude baseline: noisy at the parish level, but not systematically biased in a direction that would confound the empirical strategy here.

Crucially, any measurement error in the 1755 population baseline has limited bearing on the main findings. As Figure 4 shows, the estimated effect of pre-industrial mills on population growth is statistically indistinguishable from zero throughout the first five decades after 1755. It is only from the 1820s onward – when the mill effect intensifies alongside steam adoption – that the estimates become significant. This temporal pattern cannot be generated by noise or misreporting in the 1755 baseline; if anything, classical measurement error in the dependent variable attenuates coefficients towards zero, making the results conservative. By contrast, the decennial censuses from 1801 onward are administrative records of increasing quality and coverage (National Records of Scotland, 2022), and it is this part of the data that carries the weight of the long-run estimates.

Roy Military Survey Mill Data As a rapid military reconnaissance survey, the Roy map was not a precision instrument. Roy acknowledged it himself: "a magnificent military sketch, rather than a very accurate map" in which "no geometrical exactness is to be expected" (Fleet and Kowal, 2007, pp. 195–196). For the purposes of this analysis, however, geometric precision matters far less than the completeness and accuracy of mill representation as discrete point features. On this narrower question, the evidence is reassuring.

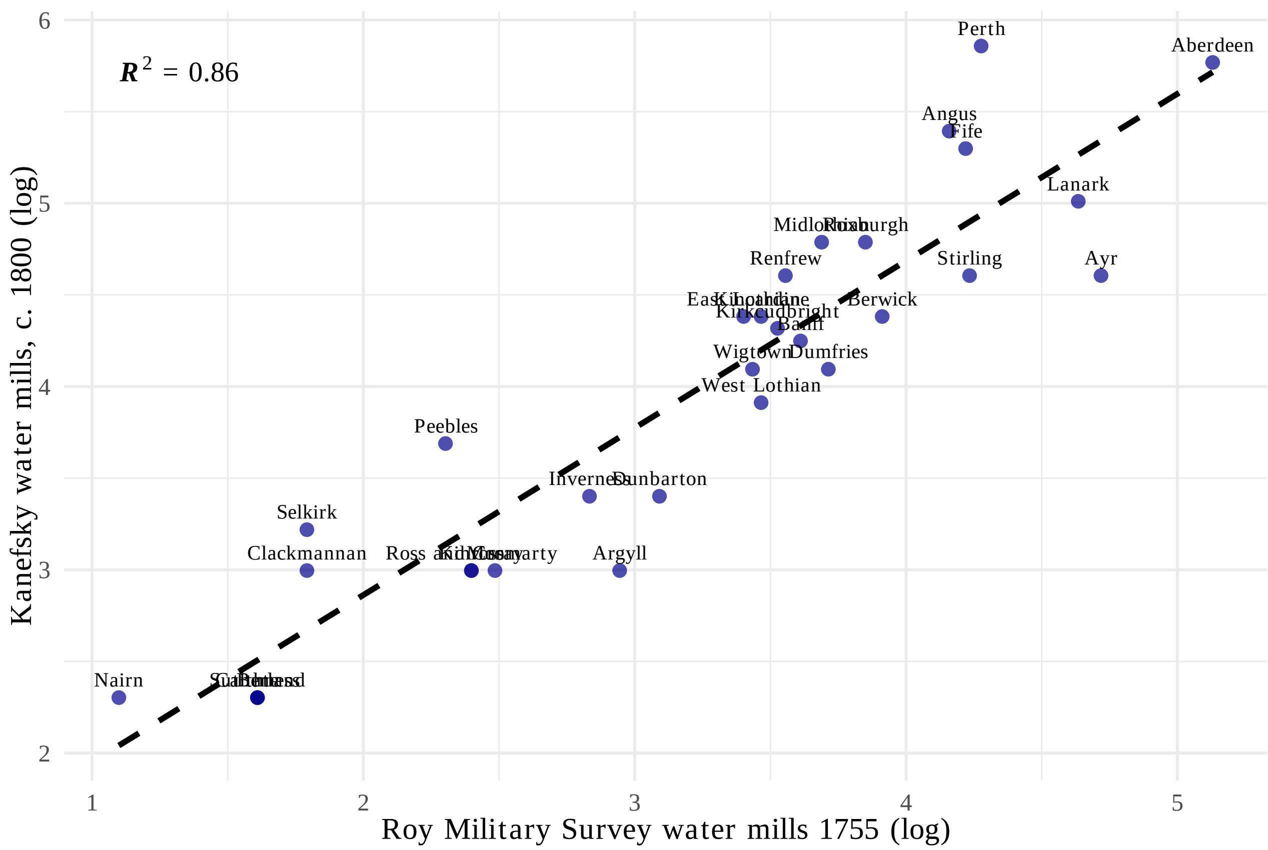
Shepherd and Ralston (1982) conducted a systematic multi-source cartographic and field survey of the Grampian Region specifically to assess the Roy map as a settlement source, cross-referencing it against subsequent county maps, estate documents, and aerial survey. They found that the coverage of productive structures is high: a comparison for south-east Scotland revealed that fewer than five percent of farmsteads in existence at the time were omitted, and the drainage and settlement patterns were confirmed as broadly accurate (Shepherd and Ralston, 1982, p. 495). Mills, as permanent fixed-capital installations tied to running water are precisely the category of feature least prone to the type of omission or stylistic generalisation that affects the representation of, for example, rig-and-furrow agriculture.

The survival analysis in Section 4.4 further corroborates this. Of the nearly 1,200 mills recorded in 1755, approximately 62 percent (746 sites) were still identifiable in the 1850 Ordnance Survey within a 500-metre radius of their original location. This high rate of physical continuity is itself informative: it confirms that the 1755 entries were not just incidental marks on a rapid military sketch. Furthermore, the strongest predictor of survival was local water power potential. The fact that the spatial pattern of 1755 mill locations is well explained by the same geographic endowment that predicts which of those sites appear in the independently compiled 1850 survey lends strong support to the view that the Roy Survey recorded mills systematically rather than selectively. Had the cartographers noted mills in an ad-hoc or idiosyncratic manner, there is no reason to expect the resulting distribution to align so closely with the hydraulic geography that also structured the later Ordnance Survey record.

External Validation: The Kanefsky Comparison To provide external validation, I perform an independent cross-check on the Roy mill counts by comparing county-level totals from the digitised Roy data against the county mill records assembled by Kanefsky (1979) from a range of industrial surveys dating to approximately 1800. The gap of roughly 45 years means exact agreement is not expected. As shown in Section 4.4, approximately 38 percent of mills present in 1755 were no longer in use by 1850 and new mills were constructed in the intervening decades.

Kanefsky's county-level account yields approximately 2,600 water mills for the Scottish mainland around 1800, against the approximately 1,200 sites recorded on the Roy map – a ratio of roughly two to one (Kanefsky, 1979, p. 216). This discrepancy likely stems from three factors. First, genuine mill construction over the intervening four decades naturally inflated the later stock. Second, Roy's mandate was military rather than industrial; the survey aimed at mapping terrain, settlements, and defensible positions, not compiling a comprehensive inventory of milling capacity. Consequently, the Roy survey likely overlooked smaller, mechanically simple horizontal mills. These primitive, low-capital installations were common in rugged terrains and served subsistence needs rather than industrial markets (Reynolds, 1983; Grano and Bishop, 2017), rendering them marginal to both a military sketch and the scope of this analysis. Third, Kanefsky's figures for the northern and western counties rest partly on backward extrapolation from the later Ordnance Survey maps. He cautions that his Scottish data carry a margin of error of perhaps 15–20 percent and are "much more leaky" than those for England and Wales (Kanefsky, 1979, p. 214). This methodology risks overstating the 1800 stock by importing later mill construction into an earlier baseline.

Figure A.1: Roy Water Mills (1755) vs. Kanefsky Water Mills (c. 1800)



Notes: The figure plots the log number of water mills recorded in the Roy Military Survey of Scotland (1747–1755) against the log number of mills recorded by Kanefsky (1979) around 50 years later, aggregated to the county level. Each point represents one Scottish county and is labelled accordingly. The dashed line shows the OLS regression fit; the displayed statistic is the R^2 coefficient from a bivariate regression on the log-log scale.

Sources: Roy mill counts aggregated from georeferenced locations by Jonell et al. (2024); Kanefsky mill counts from Kanefsky (1979).

Despite these differences in absolute numbers, the relative ranking of counties by mill density should be stable if both sources accurately capture the same underlying geography of hydraulic fixed capital. As Figure A.1 demonstrates, the two series are indeed strongly and positively correlated across Scottish counties. Counties identified by Roy as mill-rich – Aberdeenshire, Perthshire, Lanarkshire – rank similarly in the Kanefsky data. Counties with few or no recorded mills in 1755 likewise appear at the low end around 1800. Deviations from the regression line plausibly reflect genuine construction and destruction between the two observation windows rather than systematic mismeasurement in either source.

Crucially for my empirical strategy, any omissions from the Roy record are unlikely to introduce systematic spatial bias. The mills Roy was most prone to miss were small or architecturally inconspicuous structures – precisely those with the lowest capital value and the weakest connection to long-run industrialisation. Classical attenuation implies that if omitted mills were included, the estimated relationship between hydraulic capital endowments and subsequent population growth could only be strengthened, not weakened. The coefficients reported in the main text are therefore conservative, and the cross-validation supports treating the Roy mill counts as a credible and effectively unbiased spatial signal of proto-industrial water power investment.

A.2 Full Regression Tables

The tables in this section present the complete regression results, displaying all control variables individually rather than collapsing them into grouped categories. The model specifications are identical to those in the main text, as evidenced by the unchanged coefficients for the number of water mills in 1755. The only difference lies in the reporting of each control variable's individual coefficients, offering a detailed view of their contributions to the model. These results underscore the consistent and statistically significant relationships between water mills and the dependent variables, even when accounting for a broad array of potentially confounding factors.

Table A.3: First-Stage Regression Analysis

Dependent Variable:	Water Mills 1755					
Method:	OLS					
	(1)	(2)	(3)	(4)	(5)	(6)
Water Power Pot. × Land Cap.	0.655***	0.771***	0.838***	0.828***	0.827***	0.835***
	(0.054)	(0.059)	(0.087)	(0.091)	(0.111)	(0.092)
Water Power Potential		−0.051*	−0.077**	−0.073*	−0.074*	−0.075*
		(0.028)	(0.033)	(0.039)	(0.042)	(0.043)
Ruggedness		0.016	−0.012	−0.011	−0.011	−0.011
		(0.010)	(0.017)	(0.017)	(0.022)	(0.020)
Parish Area		0.003	0.004**	0.003*	0.003*	0.004
		(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Coast or Navigable River		0.112	0.119	0.091	0.041	0.097
		(0.082)	(0.114)	(0.105)	(0.135)	(0.084)
Distance to Port (log x+1)		−0.026	0.002	−0.004	0.000	−0.019
		(0.090)	(0.091)	(0.095)	(0.111)	(0.106)
Distance to Coal (log x+1)		−0.249***	−0.167**	−0.173**	−0.174**	−0.135
		(0.055)	(0.073)	(0.075)	(0.083)	(0.098)
Land Capability			−1.533***	−1.470***	−1.451**	−1.559***
			(0.535)	(0.521)	(0.565)	(0.522)
Population Density 1755 (log)			0.120***	0.127***	0.125**	0.141***
			(0.041)	(0.047)	(0.055)	(0.054)
Market Potential 1755			0.019*	0.014	0.014	0.019
			(0.011)	(0.011)	(0.015)	(0.021)
Steam Engines 1800			0.039	0.040	0.036	0.036
			(0.035)	(0.036)	(0.040)	(0.040)
Canal				0.720	0.752	0.767*
				(0.451)	(0.474)	(0.451)
Railway Line 1851				−0.088	−0.094	−0.138
				(0.096)	(0.102)	(0.088)
Percentage of Catholics 1755					−0.630	−0.710
					(1.014)	(1.045)
Royal Burgh					0.445	0.434
					(0.346)	(0.325)
Highland Clearances					0.104	0.190
					(0.298)	(0.271)
Battle 1500-1750					−0.263	−0.256
					(0.204)	(0.206)
Latitude						0.000
						(0.000)
Longitude						0.000
						(0.000)
Num. Obs.	795	795	787	787	787	787
R2	0.208	0.281	0.317	0.323	0.330	0.334
R2 Adj.	0.207	0.274	0.307	0.312	0.315	0.317

Notes: This table reports results from the first-stage regression specification for the following analyses in this paper. The number of water mills in 1755 is regressed on the instrument (water power potential interacted with land capability) and a vector of control variables. Robust standard errors adjusted for spatial correlation are reported in parentheses; *** denotes statistical significance at the 0.01 level, ** at the 0.05 level, and * at the 0.1 level, all for two-sided hypothesis tests. All regressions include a constant.

Table A.4: Regression Analysis of Water Mills and Early Industrialisation

Dependent Variable:	Total Steam Engines 1800		Non-Colliery Engines 1800		Textile Power 1838 (log x+1)	
Method:	OLS	IV (2SLS)	OLS	IV (2SLS)	OLS	IV (2SLS)
	(1)	(2)	(3)	(4)	(5)	(6)
Water Mills 1755	0.223	0.176	0.125***	0.170**	0.092**	0.272**
	(0.161)	(0.276)	(0.046)	(0.083)	(0.042)	(0.123)
Water Power Potential	−0.007	−0.005	0.008	0.006	0.019	0.011
	(0.021)	(0.018)	(0.011)	(0.011)	(0.022)	(0.019)
Ruggedness	−0.001	−0.002	0.003	0.004	0.018	0.022
	(0.018)	(0.017)	(0.009)	(0.009)	(0.022)	(0.022)
Parish Area	0.003	0.003	0.001	0.001	0.001	0.001
	(0.002)	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)
Coast or Navigable River	0.570*	0.547	0.215**	0.237**	−0.229	−0.139
	(0.314)	(0.336)	(0.097)	(0.101)	(0.175)	(0.151)
Distance to Port (log x+1)	−0.286	−0.290	0.046	0.050	−0.077	−0.062
	(0.272)	(0.286)	(0.044)	(0.046)	(0.129)	(0.116)
Distance to Coal (log x+1)	−0.032	−0.036	0.189***	0.193***	−0.033	−0.017
	(0.173)	(0.183)	(0.057)	(0.064)	(0.091)	(0.088)
Land Capability	−1.358***	−1.380***	−0.730***	−0.708***	−0.561**	−0.475
	(0.458)	(0.483)	(0.134)	(0.120)	(0.275)	(0.402)
Population Density 1755 (log)	0.780**	0.787**	0.222**	0.215**	0.607***	0.580***
	(0.360)	(0.378)	(0.092)	(0.088)	(0.201)	(0.189)
Market Potential 1755	0.056	0.057	0.055***	0.054***	0.005	0.003
	(0.040)	(0.040)	(0.013)	(0.012)	(0.022)	(0.020)
Canal	−0.337	−0.288	0.386***	0.340***	−0.202	−0.391*
	(0.523)	(0.489)	(0.129)	(0.127)	(0.154)	(0.221)
Railway Line 1851	0.309	0.308	0.112	0.113	0.469***	0.473***
	(0.412)	(0.426)	(0.143)	(0.148)	(0.158)	(0.167)
Percentage of Catholics 1755	−0.831	−0.761	−0.774***	−0.840***	−1.106***	−1.377**
	(0.889)	(0.842)	(0.195)	(0.206)	(0.338)	(0.570)
Royal Burgh	1.008	1.046	0.150	0.114	0.227	0.080
	(1.036)	(1.084)	(0.243)	(0.255)	(0.192)	(0.245)
Highland Clearances	0.183	0.176	−0.004	0.003	0.000	0.029
	(0.196)	(0.216)	(0.154)	(0.153)	(0.280)	(0.309)
Battle 1500-1750	−0.459	−0.455	−0.165	−0.169	−0.209**	−0.225**
	(0.511)	(0.503)	(0.135)	(0.143)	(0.106)	(0.112)
Latitude	0.000	0.000	0.000*	0.000*	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Longitude	0.000	0.000	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Num. Obs.	787	787	787	787	787	787
R2	0.126	0.118	0.185	0.167	0.190	0.202
R2 Adj.	0.105	0.098	0.166	0.148	0.171	0.183

Notes: This table reports results from OLS and IV regressions of the number of steam engines before 1800 and combined total power output (water and steam) in textile factories in 1838 on the number of water mills in 1755. In contrast to the other tables, economic base controls exclude steam engines. Robust standard errors adjusted for spatial correlation are reported in parentheses; *** denotes statistical significance at the 0.01 level, ** at the 0.05 level, and * at the 0.1 level, all for two-sided hypothesis tests. All regressions include a constant.

Table A.5: Regression Analysis of Water Mills and Industrial Mills in 1850

Dependent Variable (Mills in 1850):	Metal and Machinery		Textiles		Chemicals		Wood and Paper		Alcohol and Tobacco	
Method:	OLS	IV (2SLS)	OLS	IV (2SLS)	OLS	IV (2SLS)	OLS	IV (2SLS)	OLS	IV (2SLS)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Water Mills 1755	0.018**	0.034**	0.254***	0.540***	0.032***	0.070	0.180***	0.582***	0.035***	0.061*
	(0.007)	(0.013)	(0.091)	(0.110)	(0.009)	(0.045)	(0.047)	(0.093)	(0.011)	(0.031)
Water Power Potential	−0.001	−0.001	0.040	0.027	−0.003	−0.004	−0.010	−0.028	−0.001	−0.002
	(0.003)	(0.003)	(0.043)	(0.036)	(0.004)	(0.004)	(0.022)	(0.017)	(0.004)	(0.006)
Ruggedness	0.001	0.002	0.040	0.047	0.001	0.002	0.018	0.027	−0.002	−0.001
	(0.001)	(0.002)	(0.037)	(0.042)	(0.004)	(0.004)	(0.012)	(0.023)	(0.002)	(0.003)
Parish Area	0.000	0.000	0.001	0.001	0.000	0.000*	0.002*	0.003**	0.000	0.000
	(0.000)	(0.000)	(0.002)	(0.002)	(0.000)	(0.000)	(0.001)	(0.001)	(0.000)	(0.000)
Coast or Navigable River	0.013	0.022	−0.147	0.001	0.010	0.030	−0.281*	−0.072	0.078***	0.092***
	(0.020)	(0.021)	(0.243)	(0.198)	(0.056)	(0.067)	(0.152)	(0.163)	(0.018)	(0.022)
Distance to Port (log x+1)	−0.009	−0.008	−0.136	−0.117	0.021	0.024	−0.012	0.015	0.028*	0.030*
	(0.013)	(0.015)	(0.218)	(0.231)	(0.057)	(0.056)	(0.070)	(0.077)	(0.016)	(0.017)
Distance to Coal (log x+1)	0.015	0.016*	0.279*	0.305**	0.044**	0.047**	0.178***	0.214**	0.044***	0.046***
	(0.010)	(0.010)	(0.159)	(0.150)	(0.018)	(0.023)	(0.064)	(0.101)	(0.014)	(0.016)
Land Capability	−0.125***	−0.119**	−1.249***	−1.131*	−0.022	−0.006	−0.940**	−0.775	−0.146***	−0.135***
	(0.044)	(0.047)	(0.354)	(0.586)	(0.038)	(0.034)	(0.401)	(0.482)	(0.039)	(0.030)
Population Density 1755 (log)	0.070**	0.068**	1.190***	1.157***	0.102*	0.098*	0.408***	0.362**	0.016	0.013
	(0.032)	(0.031)	(0.330)	(0.313)	(0.059)	(0.057)	(0.125)	(0.161)	(0.014)	(0.012)
Market Potential 1755	0.003*	0.003*	0.029	0.026	0.013*	0.013*	0.028***	0.025**	0.013***	0.013***
	(0.002)	(0.002)	(0.050)	(0.046)	(0.007)	(0.008)	(0.009)	(0.011)	(0.003)	(0.004)
Steam Engines 1800	0.010	0.009	0.084	0.071	0.022	0.020	0.017	−0.001	0.009	0.008
	(0.010)	(0.009)	(0.075)	(0.077)	(0.020)	(0.018)	(0.019)	(0.021)	(0.007)	(0.005)
Canal	0.021	0.003	0.018	−0.284	−0.014	−0.054	0.191	−0.233	0.124*	0.096
	(0.023)	(0.015)	(0.899)	(0.839)	(0.058)	(0.086)	(0.194)	(0.228)	(0.068)	(0.064)
Railway Line 1851	0.057**	0.057**	0.627***	0.637***	0.097**	0.099**	0.067	0.083	−0.013	−0.012
	(0.025)	(0.025)	(0.143)	(0.174)	(0.039)	(0.041)	(0.097)	(0.082)	(0.014)	(0.019)
Percentage of Catholics 1755	−0.128	−0.153	−1.059*	−1.495**	−0.257***	−0.316**	0.135	−0.479	0.095	0.055
	(0.106)	(0.114)	(0.578)	(0.717)	(0.099)	(0.150)	(1.667)	(1.426)	(0.275)	(0.292)
Royal Burgh	0.036	0.023	−0.412*	−0.630**	−0.077	−0.106	−0.008	−0.315	−0.003	−0.023
	(0.041)	(0.033)	(0.213)	(0.303)	(0.087)	(0.105)	(0.188)	(0.295)	(0.030)	(0.040)
Highland Clearances	0.019	0.022	0.031	0.079	−0.022	−0.016	−0.277	−0.211	0.040	0.044
	(0.025)	(0.028)	(0.338)	(0.290)	(0.035)	(0.028)	(0.207)	(0.229)	(0.051)	(0.051)
Battle 1500-1750	−0.051	−0.053	−0.579***	−0.610***	−0.032	−0.036	0.161	0.118	−0.015	−0.017
	(0.038)	(0.042)	(0.154)	(0.130)	(0.043)	(0.039)	(0.177)	(0.148)	(0.026)	(0.034)
Latitude	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Longitude	0.000	0.000	0.000	0.000	0.000	0.000*	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Num. Obs.	787	787	787	787	787	787	787	787	787	787
R2	0.139	0.137	0.116	0.117	0.110	0.111	0.174	0.251	0.246	0.231
R2 Adj.	0.117	0.116	0.094	0.095	0.088	0.089	0.153	0.232	0.227	0.212

Notes: This table reports results from OLS and IV regressions of various classes of industrial mills in 1850 on the number of water mills in 1755. Robust standard errors adjusted for spatial correlation are reported in parentheses; *** denotes statistical significance at the 0.01 level, ** at the 0.05 level, and * at the 0.1 level, all for two-sided hypothesis tests. All regressions include a constant.

Table A.6: Regression Analysis of Water Mills and Industrial Mills in 1900

Dependent Variable (Mills in 1900):	Metal and Machinery		Textiles		Chemicals		Wood and Paper		Alcohol and Tobacco	
Method:	OLS	IV (2SLS)	OLS	IV (2SLS)	OLS	IV (2SLS)	OLS	IV (2SLS)	OLS	IV (2SLS)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Water Mills 1755	0.012	0.044*	0.152*	0.470***	0.035*	0.067	0.243***	0.776***	0.023***	0.053**
	(0.012)	(0.025)	(0.080)	(0.125)	(0.018)	(0.055)	(0.057)	(0.130)	(0.006)	(0.025)
Water Power Potential	0.001	−0.001	0.059	0.044	−0.002	−0.004	−0.005	−0.028	0.002	0.001
	(0.004)	(0.003)	(0.044)	(0.031)	(0.004)	(0.004)	(0.041)	(0.030)	(0.003)	(0.005)
Ruggedness	−0.008	−0.007	0.048	0.055	0.004	0.005	0.016	0.028	−0.002	−0.001
	(0.006)	(0.006)	(0.035)	(0.039)	(0.005)	(0.006)	(0.019)	(0.024)	(0.002)	(0.003)
Parish Area	0.000	0.000	0.000	0.000	0.000	0.000	0.003*	0.003	0.000	0.000
	(0.000)	(0.000)	(0.002)	(0.002)	(0.000)	(0.000)	(0.002)	(0.002)	(0.000)	(0.000)
Coast or Navigable River	0.041	0.058	−0.271	−0.105	0.030	0.047	−0.343*	−0.067	0.050**	0.066***
	(0.040)	(0.044)	(0.279)	(0.233)	(0.057)	(0.075)	(0.196)	(0.190)	(0.023)	(0.024)
Distance to Port (log x+1)	0.028	0.030	−0.038	−0.017	0.019	0.021	0.019	0.055	0.013	0.015
	(0.028)	(0.026)	(0.149)	(0.163)	(0.041)	(0.044)	(0.089)	(0.093)	(0.019)	(0.019)
Distance to Coal (log x+1)	0.044**	0.047**	0.162	0.190*	0.030	0.033	0.230***	0.277**	0.032***	0.034***
	(0.018)	(0.019)	(0.118)	(0.115)	(0.023)	(0.025)	(0.073)	(0.115)	(0.010)	(0.013)
Land Capability	−0.134***	−0.121**	−1.542***	−1.412***	−0.052	−0.038	−1.152**	−0.934*	−0.105***	−0.093**
	(0.046)	(0.048)	(0.300)	(0.518)	(0.054)	(0.068)	(0.504)	(0.532)	(0.037)	(0.041)
Population Density 1755 (log)	0.056	0.052	1.285***	1.249***	0.107**	0.103**	0.519***	0.459***	0.029***	0.026**
	(0.044)	(0.041)	(0.279)	(0.267)	(0.053)	(0.052)	(0.158)	(0.161)	(0.011)	(0.013)
Market Potential 1755	0.006	0.006	0.008	0.006	0.012	0.012	0.039**	0.034	0.009***	0.008**
	(0.006)	(0.005)	(0.038)	(0.037)	(0.008)	(0.008)	(0.016)	(0.021)	(0.003)	(0.004)
Steam Engines 1800	0.014	0.013	0.066	0.052	0.019	0.017	0.034	0.011	0.009	0.008
	(0.011)	(0.012)	(0.067)	(0.065)	(0.017)	(0.015)	(0.027)	(0.022)	(0.006)	(0.005)
Canal	0.120	0.086	0.112	−0.224	−0.126	−0.159	0.790**	0.229	0.100**	0.068
	(0.082)	(0.075)	(0.668)	(0.657)	(0.084)	(0.105)	(0.316)	(0.231)	(0.048)	(0.048)
Railway Line 1851	−0.014	−0.013	0.648***	0.660***	0.122***	0.124***	0.120	0.140	−0.010	−0.009
	(0.021)	(0.018)	(0.145)	(0.177)	(0.036)	(0.032)	(0.116)	(0.149)	(0.011)	(0.016)
Percentage of Catholics 1755	−0.049	−0.098	−0.414	−0.900	−0.281***	−0.330**	0.464	−0.348	0.170	0.123
	(0.041)	(0.075)	(0.666)	(0.802)	(0.075)	(0.140)	(2.423)	(2.228)	(0.288)	(0.312)
Royal Burgh	0.009	−0.016	0.071	−0.171	0.003	−0.022	0.365	−0.041	−0.021	−0.044
	(0.059)	(0.056)	(0.390)	(0.415)	(0.113)	(0.144)	(0.336)	(0.517)	(0.030)	(0.034)
Highland Clearances	0.034	0.039	0.060	0.113	−0.059	−0.054	−0.415	−0.327	0.084*	0.089*
	(0.049)	(0.049)	(0.458)	(0.418)	(0.041)	(0.043)	(0.326)	(0.254)	(0.049)	(0.050)
Battle 1500-1750	−0.029	−0.033	−0.216	−0.250	−0.079*	−0.083*	0.298**	0.241	−0.031	−0.034
	(0.033)	(0.044)	(0.241)	(0.190)	(0.041)	(0.048)	(0.149)	(0.209)	(0.024)	(0.033)
Latitude	0.000**	0.000**	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Longitude	0.000**	0.000*	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Num. Obs.	787	787	787	787	787	787	787	787	787	787
R2	0.093	0.098	0.138	0.148	0.107	0.106	0.228	0.308	0.175	0.184
R2 Adj.	0.071	0.076	0.116	0.127	0.085	0.083	0.209	0.291	0.155	0.164

Notes: This table reports results from OLS and IV regressions of various classes of industrial mills in 1900 on the number of water mills in 1755. Robust standard errors adjusted for spatial correlation are reported in parentheses; *** denotes statistical significance at the 0.01 level, ** at the 0.05 level, and * at the 0.1 level, all for two-sided hypothesis tests. All regressions include a constant.

Table A.7: Analysis of Mill Survival and Transformation 1755–1850

Dependent variable (1850):	Mill Survival		Switched to Steam		Industrialised	
Method:	Probit (AMEs)					
	(1)	(2)	(3)	(4)	(5)	(6)
Water Power Potential (1 km Radius)	0.381***	0.419***	−0.055	−0.074	0.183*	0.233*
	(0.080)	(0.076)	(0.061)	(0.061)	(0.094)	(0.126)
Ruggedness (1 km Avg.)	−0.002	−0.002	0.000	0.000	0.008**	0.006*
	(0.003)	(0.004)	(0.001)	(0.001)	(0.004)	(0.004)
Land Capability (5 km Avg.)	0.109	−0.014	−0.026	−0.025	−0.028	−0.091
	(0.071)	(0.086)	(0.038)	(0.035)	(0.118)	(0.137)
Altitude	0.000	0.000	0.000	0.000**	−0.001	−0.001
	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.001)
Mill Density (5 km Radius)	0.006	0.005	0.003	0.004	0.004	0.000
	(0.005)	(0.008)	(0.002)	(0.002)	(0.008)	(0.006)
Distance to Coalfield (log + 1)	0.012	0.026**	−0.012***	−0.012**	−0.005	0.006
	(0.011)	(0.011)	(0.004)	(0.005)	(0.015)	(0.018)
Distance to Coast or River (log)	−0.005	−0.007	−0.005	−0.004	0.000	−0.002
	(0.017)	(0.018)	(0.006)	(0.007)	(0.025)	(0.031)
Distance to Port (log)	−0.016	−0.005	0.001	−0.001	−0.037	−0.019
	(0.013)	(0.018)	(0.011)	(0.011)	(0.047)	(0.049)
Distance to Burgh (log)	−0.020**	−0.009	0.003	0.004	0.012	0.012
	(0.010)	(0.014)	(0.006)	(0.007)	(0.026)	(0.036)
Parish Pop. Density 1755 (log)		0.045		0.014		0.029
		(0.038)		(0.009)		(0.042)
Parish Market Potential 1755		0.002		−0.002		0.002
		(0.002)		(0.001)		(0.003)
Parish Perc. Catholics 1755		0.748		−0.730**		1.629***
		(0.479)		(0.330)		(0.303)
Parish on Canal		0.018		−0.303***		0.004
		(0.083)		(0.017)		(0.065)
Parish on Railway 1851		0.021		0.015		0.050
		(0.029)		(0.018)		(0.073)
Parish in Highland Clearances		−0.104		0.000		−0.004
		(0.075)		(0.028)		(0.112)
Parish Battle 1500-1750		−0.004		0.034**		−0.064
		(0.038)		(0.016)		(0.071)
Num. Obs.	1199	1187	746	737	746	737
Mean Dep. Var.	0.622	0.621	0.034	0.033	0.303	0.300
Pseudo R2	0.025	0.033	0.083	0.167	0.018	0.037

Notes: This table reports the Average Marginal Effects (AMEs) from Probit models examining the determinants of mill survival and transformation between 1755 and 1850. The unit of analysis is the individual water mill from the 1755 Roy Military Survey. Columns 1–2 model the probability of a mill site surviving to 1850, where survival is defined as the presence of any mill structure within a 500-metre radius of the original site in the 1850 Ordnance Survey. Columns 3–4 and 5–6 are estimated on the subsample of surviving mills, modelling the probability of adopting steam power and transitioning to industrial production, respectively. 'Switched to steam' indicates the presence of a steam-powered mill, while 'industrialised' refers to a transition to non-grain production. Parish-level controls, included in even-numbered columns, consist of 1755 population density, market potential, percentage of Catholics, and dummies for canal access, railway presence by 1851, Highland Clearances, and historical battles. Robust standard errors adjusted for spatial correlation (50 km cutoff) are reported in parentheses; *** denotes statistical significance at the 0.01 level, ** at the 0.05 level, and * at the 0.1 level, all for two-sided hypothesis tests. All regressions include a constant.

Table A.8: Regression Analysis of Water Mills and Fertility

Dependent Variable (1851):	Child-Woman Ratio		Avg. Household Size		Pct. 60+ Years Old	
Method:	OLS	IV (2SLS)	OLS	IV (2SLS)	OLS	IV (2SLS)
	(1)	(2)	(3)	(4)	(5)	(6)
Water Mills 1755	0.004	0.007	0.016	0.038	−0.022	0.143*
	(0.004)	(0.007)	(0.016)	(0.025)	(0.059)	(0.079)
Water Power Potential	0.000	0.000	−0.002	−0.003	−0.055***	−0.062***
	(0.002)	(0.002)	(0.007)	(0.007)	(0.017)	(0.022)
Ruggedness	−0.003	−0.003	−0.004	−0.003	0.001	0.005
	(0.002)	(0.002)	(0.006)	(0.007)	(0.031)	(0.029)
Parish Area	0.000	0.000	0.000	0.000	0.004**	0.004**
	(0.000)	(0.000)	(0.001)	(0.001)	(0.002)	(0.002)
Coast or Navigable River	−0.004	−0.002	−0.071	−0.060	−0.289	−0.205
	(0.016)	(0.017)	(0.048)	(0.048)	(0.196)	(0.177)
Distance to Port (log x+1)	0.001	0.002	0.034	0.036	−0.114	−0.104
	(0.009)	(0.009)	(0.023)	(0.024)	(0.091)	(0.103)
Distance to Coal (log x+1)	−0.020**	−0.019***	−0.036**	−0.034*	0.310***	0.326***
	(0.008)	(0.007)	(0.017)	(0.020)	(0.089)	(0.102)
Land Capability	0.007	0.009	0.262**	0.270**	−1.183**	−1.116**
	(0.045)	(0.044)	(0.123)	(0.112)	(0.531)	(0.518)
Population Density 1755 (log)	−0.038***	−0.039***	−0.327***	−0.330***	0.389***	0.370***
	(0.011)	(0.011)	(0.036)	(0.031)	(0.135)	(0.126)
Market Potential 1755	−0.001	−0.001	−0.011***	−0.012***	−0.026	−0.028
	(0.001)	(0.001)	(0.003)	(0.003)	(0.019)	(0.021)
Steam Engines 1800	0.002*	0.002	0.004	0.003	−0.009	−0.017
	(0.001)	(0.001)	(0.005)	(0.004)	(0.026)	(0.034)
Canal	0.061	0.058	0.164**	0.141**	−0.845***	−1.019***
	(0.048)	(0.049)	(0.069)	(0.065)	(0.308)	(0.180)
Railway Line 1851	0.019	0.019	−0.158***	−0.157***	−0.580***	−0.574***
	(0.020)	(0.020)	(0.041)	(0.040)	(0.192)	(0.193)
Percentage of Catholics 1755	0.102	0.097	0.420	0.386	−0.409	−0.662
	(0.083)	(0.080)	(0.396)	(0.434)	(2.843)	(2.631)
Royal Burgh	−0.023**	−0.026**	−0.138	−0.155*	0.189	0.064
	(0.010)	(0.012)	(0.088)	(0.090)	(0.164)	(0.162)
Highland Clearances	−0.064***	−0.064***	−0.262**	−0.259**	−0.027	0.000
	(0.019)	(0.019)	(0.105)	(0.102)	(0.278)	(0.281)
Battle 1500-1750	−0.020	−0.020	0.105	0.103	−0.237	−0.255
	(0.016)	(0.016)	(0.087)	(0.089)	(0.187)	(0.181)
Latitude	0.000	0.000	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Longitude	0.000	0.000	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Num. Obs.	785	785	785	785	785	785
R2	0.154	0.153	0.317	0.317	0.327	0.330
R2 Adj.	0.133	0.132	0.300	0.300	0.311	0.314

Notes: This table reports results from OLS and IV regressions of demographic variables on the number of water mills in 1755. Robust standard errors adjusted for spatial correlation are reported in parentheses; *** denotes statistical significance at the 0.01 level, ** at the 0.05 level, and * at the 0.1 level, all for two-sided hypothesis tests. All regressions include a constant.

Table A.9: Regression Analysis of Water Mills and Internal Migration

Dependent Variable (1801–1851):	Total Pop. Growth		Short-Distance Immig.		Long-Distance Immig.		Foreign Immigration		Local Pop. Growth	
Method:	OLS	IV (2SLS)	OLS	IV (2SLS)	OLS	IV (2SLS)	OLS	IV (2SLS)	OLS	IV (2SLS)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Water Mills 1755	7.757***	7.961***	3.436***	3.311*	1.728***	2.430	0.960*	0.468	1.633***	1.752**
	(2.196)	(3.039)	(0.870)	(1.903)	(0.631)	(1.956)	(0.524)	(0.850)	(0.424)	(0.796)
Water Power Potential	0.731	0.722	0.926*	0.932*	0.174	0.143	−0.409**	−0.387**	0.039	0.034
	(0.893)	(0.715)	(0.556)	(0.551)	(0.386)	(0.388)	(0.179)	(0.178)	(0.195)	(0.173)
Ruggedness	−1.057	−1.052	−1.052**	−1.055**	0.249	0.266	0.081	0.070	−0.335**	−0.332**
	(0.659)	(0.687)	(0.455)	(0.448)	(0.437)	(0.471)	(0.157)	(0.148)	(0.153)	(0.146)
Parish Area	−0.062	−0.062	−0.063**	−0.063**	−0.003	−0.003	0.018*	0.018	−0.014	−0.014
	(0.055)	(0.068)	(0.028)	(0.027)	(0.018)	(0.020)	(0.010)	(0.011)	(0.012)	(0.010)
Coast or Navigable River	−3.216	−3.112	−0.972	−1.036	−5.436	−5.078	2.546**	2.295**	0.646	0.706
	(6.283)	(6.433)	(6.666)	(6.700)	(3.503)	(4.047)	(1.045)	(0.908)	(1.984)	(2.084)
Distance to Port (log x+1)	−2.722	−2.709	0.221	0.213	−1.374	−1.329	−2.285	−2.317	0.716	0.723
	(4.140)	(4.188)	(2.483)	(2.441)	(1.729)	(1.676)	(1.747)	(1.839)	(0.889)	(0.927)
Distance to Coal (log x+1)	−8.698*	−8.678*	−6.789**	−6.801**	−0.523	−0.457	−0.503	−0.550	−0.882*	−0.871*
	(4.705)	(4.838)	(3.399)	(3.331)	(1.475)	(1.412)	(0.657)	(0.767)	(0.452)	(0.505)
Land Capability	6.869	6.951	0.584	0.533	10.072	10.356	−4.662*	−4.862*	0.876	0.924
	(9.063)	(7.679)	(10.298)	(10.167)	(6.726)	(6.469)	(2.781)	(2.877)	(0.714)	(1.139)
Population Density 1755 (log)	2.309	2.286	−0.348	−0.333	−1.454	−1.534	3.091***	3.147***	1.020*	1.006*
	(5.865)	(5.483)	(4.587)	(4.702)	(2.027)	(2.109)	(1.042)	(1.036)	(0.541)	(0.588)
Market Potential 1755	−0.700	−0.702	−0.537	−0.536	0.100	0.094	−0.235	−0.231	−0.028	−0.029
	(0.800)	(0.825)	(0.534)	(0.467)	(0.425)	(0.391)	(0.257)	(0.265)	(0.355)	(0.311)
Steam Engines 1800	0.220	0.211	−0.009	−0.003	0.153	0.122	−0.121	−0.100	0.197	0.192
	(0.654)	(0.769)	(0.250)	(0.287)	(0.359)	(0.405)	(0.158)	(0.159)	(0.277)	(0.266)
Canal	13.652	13.436	−2.112	−1.980	7.498	6.755	2.421	2.941	5.845***	5.720***
	(11.974)	(11.181)	(7.565)	(6.941)	(6.582)	(7.149)	(2.617)	(2.333)	(1.035)	(0.949)
Railway Line 1851	18.281*	18.288*	2.438	2.434	10.839***	10.863***	1.850*	1.833*	3.155	3.159
	(9.623)	(9.426)	(4.844)	(4.843)	(4.191)	(3.983)	(0.964)	(1.063)	(1.993)	(1.989)
Percentage of Catholics 1755	7.277	6.964	38.141	38.333	−20.002***	−21.082***	−13.554	−12.799	2.693	2.511
	(23.625)	(26.054)	(31.028)	(31.083)	(4.996)	(3.352)	(9.393)	(9.844)	(4.163)	(4.735)
Royal Burgh	4.839	4.684	5.164	5.259	−0.027	−0.560	0.458	0.831	−0.756	−0.846
	(7.664)	(6.830)	(4.218)	(3.822)	(4.459)	(3.949)	(2.395)	(2.516)	(1.404)	(1.427)
Highland Clearances	−0.468	−0.435	1.994	1.974	−7.402**	−7.289**	−0.652	−0.731	5.591	5.610
	(17.241)	(16.775)	(6.521)	(6.562)	(3.592)	(3.664)	(2.328)	(2.181)	(5.359)	(5.290)
Battle 1500-1750	7.725	7.704	2.635	2.648	1.671	1.597	2.272	2.324	1.147	1.135
	(7.732)	(7.783)	(3.584)	(3.650)	(4.648)	(4.784)	(1.545)	(1.592)	(1.398)	(1.418)
Latitude	0.000	0.000	0.000	0.000*	0.000	0.000	0.000	0.000	0.000**	0.000**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Longitude	0.000*	0.000	0.000	0.000	0.000	0.000	0.000*	0.000**	0.000***	0.000***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Num. Obs.	785	785	785	785	785	785	785	785	785	785
R2	0.191	0.169	0.145	0.130	0.079	0.076	0.154	0.144	0.291	0.272
R2 Adj.	0.171	0.148	0.124	0.108	0.056	0.053	0.133	0.122	0.274	0.254

Notes: This table reports results from OLS and IV regressions of total relative population growth between 1801 and 1851, as well as its components, on the number of water mills in 1755. All population growth measures are expressed in percentage terms. Total population growth is decomposed as described in the main text. Robust standard errors adjusted for spatial correlation are reported in parentheses; *** denotes statistical significance at the 0.01 level, ** at the 0.05 level, and * at the 0.1 level, all for two-sided hypothesis tests. All regressions include a constant.

Table A.10: Regression Analysis of Water Mills and Foreign Immigration

Dependent Variable (1801–1851):	All Foreign Immigration		Ireland		England and Wales		Europe (Other)		Rest of the World	
Method:	OLS	IV (2SLS)	OLS	IV (2SLS)	OLS	IV (2SLS)	OLS	IV (2SLS)	OLS	IV (2SLS)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Water Mills 1755	1.633***	1.752**	1.528***	1.531**	0.038	0.134	0.011***	0.007	0.018	0.032**
	(0.424)	(0.796)	(0.405)	(0.753)	(0.110)	(0.193)	(0.003)	(0.006)	(0.013)	(0.013)
Water Power Potential	0.039	0.034	0.000	0.000	0.035	0.030	−0.002	−0.002	0.002	0.001
	(0.195)	(0.173)	(0.095)	(0.094)	(0.043)	(0.039)	(0.002)	(0.002)	(0.004)	(0.003)
Ruggedness	−0.335**	−0.332**	−0.331***	−0.331***	−0.003	−0.001	0.000	0.000	0.004	0.004
	(0.153)	(0.146)	(0.125)	(0.123)	(0.050)	(0.054)	(0.003)	(0.002)	(0.005)	(0.005)
Parish Area	−0.014	−0.014	−0.015	−0.015	0.001	0.001	0.000	0.000	0.000	0.000
	(0.012)	(0.010)	(0.012)	(0.012)	(0.002)	(0.002)	(0.000)	(0.000)	(0.000)	(0.000)
Coast or Navigable River	0.646	0.706	−0.347	−0.346	0.854***	0.902***	0.058***	0.056***	0.048	0.055
	(1.984)	(2.084)	(1.876)	(1.991)	(0.233)	(0.276)	(0.017)	(0.019)	(0.038)	(0.035)
Distance to Port (log x+1)	0.716	0.723	0.182	0.182	0.584	0.590	−0.005	−0.005	−0.021	−0.020
	(0.889)	(0.927)	(0.930)	(0.928)	(0.391)	(0.392)	(0.012)	(0.012)	(0.025)	(0.026)
Distance to Coal (log x+1)	−0.882*	−0.871*	−0.706	−0.706	−0.180	−0.171	0.011	0.010	−0.006	−0.005
	(0.452)	(0.505)	(0.692)	(0.722)	(0.277)	(0.259)	(0.007)	(0.007)	(0.028)	(0.026)
Land Capability	0.876	0.924	0.987**	0.989	0.195	0.233	−0.077**	−0.078**	−0.162**	−0.156*
	(0.714)	(1.139)	(0.452)	(0.657)	(0.927)	(1.026)	(0.034)	(0.033)	(0.077)	(0.084)
Population Density 1755 (log)	1.020*	1.006*	0.188	0.188	0.700**	0.689**	0.026*	0.026*	0.099**	0.098**
	(0.541)	(0.588)	(0.583)	(0.611)	(0.354)	(0.330)	(0.014)	(0.015)	(0.040)	(0.040)
Market Potential 1755	−0.028	−0.029	−0.010	−0.010	−0.035	−0.036	0.004**	0.004***	0.003	0.003
	(0.355)	(0.311)	(0.287)	(0.265)	(0.044)	(0.043)	(0.002)	(0.001)	(0.004)	(0.004)
Steam Engines 1800	0.197	0.192	0.174	0.174	0.028	0.024	0.001	0.001	−0.001	−0.001
	(0.277)	(0.266)	(0.267)	(0.275)	(0.036)	(0.034)	(0.002)	(0.002)	(0.004)	(0.004)
Canal	5.845***	5.720***	4.559***	4.556***	1.377***	1.276***	−0.004	0.000	0.033	0.019
	(1.035)	(0.949)	(0.883)	(1.042)	(0.340)	(0.249)	(0.019)	(0.018)	(0.076)	(0.068)
Railway Line 1851	3.155	3.159	2.755	2.755	0.371**	0.374**	0.002	0.001	−0.040	−0.039
	(1.993)	(1.989)	(1.890)	(1.872)	(0.182)	(0.189)	(0.013)	(0.013)	(0.036)	(0.042)
Percentage of Catholics 1755	2.693	2.511	4.199	4.194	−0.910	−1.058	−0.112**	−0.107**	−0.206***	−0.228***
	(4.163)	(4.735)	(4.474)	(4.862)	(1.045)	(1.135)	(0.048)	(0.045)	(0.077)	(0.080)
Royal Burgh	−0.756	−0.846	−1.385	−1.387	0.663	0.590	0.014	0.017	0.034	0.024
	(1.404)	(1.427)	(1.234)	(1.199)	(0.456)	(0.468)	(0.020)	(0.019)	(0.028)	(0.022)
Highland Clearances	5.591	5.610	4.570	4.570	0.908	0.924	−0.004	−0.005	0.027	0.029
	(5.359)	(5.290)	(5.182)	(5.141)	(0.711)	(0.738)	(0.016)	(0.016)	(0.042)	(0.045)
Battle 1500-1750	1.147	1.135	0.705	0.705	0.269	0.259	0.013	0.014	0.107**	0.106**
	(1.398)	(1.418)	(1.150)	(1.161)	(0.339)	(0.344)	(0.018)	(0.019)	(0.051)	(0.049)
Latitude	0.000**	0.000**	0.000	0.000	0.000**	0.000**	0.000**	0.000**	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Longitude	0.000***	0.000***	0.000***	0.000***	0.000**	0.000**	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Num. Obs.	785	785	785	785	785	785	785	785	785	785
R2	0.291	0.272	0.300	0.278	0.224	0.225	0.142	0.131	0.092	0.091
R2 Adj.	0.274	0.254	0.283	0.261	0.205	0.205	0.120	0.110	0.070	0.068

Notes: This table reports results from OLS and IV regressions of total relative immigration between 1801 and 1851 (measured as described in the main text), as well as immigration by parts of the world, on the number of water mills in 1755. All immigration measures are expressed in percentage terms. Robust standard errors adjusted for spatial correlation are reported in parentheses; *** denotes statistical significance at the 0.01 level, ** at the 0.05 level, and * at the 0.1 level, all for two-sided hypothesis tests. All regressions include a constant.

Table A.11: Regression Analysis of Water Mills and Occupations in 1851

Dependent Variable (1851):	Pct. Agriculture		Pct. Manufacturing		Pct. Metal Mf.		Pct. Agricultural Mf.		Pct. Textile Mf.	
Method:	OLS	IV (2SLS)	OLS	IV (2SLS)	OLS	IV (2SLS)	OLS	IV (2SLS)	OLS	IV (2SLS)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Water Mills 1755	−0.314	−0.219	0.281***	0.795*	0.011*	0.014***	0.235***	0.791*	0.043***	0.053**
	(0.195)	(0.272)	(0.104)	(0.468)	(0.006)	(0.005)	(0.085)	(0.455)	(0.014)	(0.023)
Water Power Potential	−0.176	−0.180	0.108	0.085	−0.002	−0.002	0.098	0.073	0.003	0.003
	(0.168)	(0.167)	(0.094)	(0.078)	(0.002)	(0.002)	(0.102)	(0.076)	(0.004)	(0.004)
Ruggedness	−0.030	−0.027	0.052	0.064	0.002	0.003	0.045	0.058	−0.007**	−0.006**
	(0.108)	(0.105)	(0.080)	(0.072)	(0.002)	(0.002)	(0.076)	(0.066)	(0.003)	(0.003)
Parish Area	−0.004	−0.004	−0.002	−0.002	0.000	0.000	−0.001	−0.001	0.000	0.000
	(0.010)	(0.010)	(0.008)	(0.008)	(0.000)	(0.000)	(0.009)	(0.008)	(0.000)	(0.000)
Coast or Navigable River	−0.681	−0.632	−2.664**	−2.402**	−0.080**	−0.079**	−2.836**	−2.552**	−0.003	0.002
	(1.105)	(1.050)	(1.146)	(1.129)	(0.036)	(0.036)	(1.164)	(1.202)	(0.027)	(0.026)
Distance to Port (log x+1)	0.316	0.322	0.200	0.233	−0.006	−0.006	0.286	0.321	−0.005	−0.005
	(0.396)	(0.403)	(0.505)	(0.470)	(0.010)	(0.010)	(0.496)	(0.443)	(0.011)	(0.010)
Distance to Coal (log x+1)	1.197***	1.206***	−1.156***	−1.107***	0.041**	0.042**	−0.964***	−0.911***	−0.062***	−0.061***
	(0.461)	(0.445)	(0.297)	(0.327)	(0.021)	(0.021)	(0.254)	(0.280)	(0.024)	(0.023)
Land Capability	6.556***	6.594***	0.965	1.173	0.124*	0.126*	1.083*	1.308	−0.074	−0.070
	(1.090)	(1.102)	(1.086)	(1.359)	(0.075)	(0.075)	(0.618)	(0.972)	(0.084)	(0.092)
Population Density 1755 (log)	−6.182***	−6.193***	2.679***	2.620***	−0.021	−0.021	2.854***	2.791***	0.015	0.014
	(0.776)	(0.772)	(0.689)	(0.673)	(0.035)	(0.035)	(0.741)	(0.721)	(0.013)	(0.013)
Market Potential 1755	−0.015	−0.016	0.038	0.034	0.004	0.004	−0.013	−0.017	−0.003	−0.003
	(0.067)	(0.064)	(0.130)	(0.122)	(0.004)	(0.004)	(0.124)	(0.111)	(0.006)	(0.006)
Steam Engines 1800	0.035	0.031	0.003	−0.020	−0.002	−0.002	−0.009	−0.033	0.008	0.007
	(0.060)	(0.060)	(0.146)	(0.152)	(0.002)	(0.002)	(0.132)	(0.151)	(0.007)	(0.007)
Canal	0.213	0.112	−3.889***	−4.433***	−0.051	−0.055	−4.337***	−4.924***	0.230***	0.220***
	(1.003)	(1.157)	(1.073)	(1.515)	(0.034)	(0.036)	(0.969)	(1.444)	(0.080)	(0.067)
Railway Line 1851	−3.256***	−3.253***	2.773***	2.790***	0.004	0.004	2.352**	2.371**	0.110**	0.110**
	(0.597)	(0.650)	(0.990)	(0.890)	(0.022)	(0.022)	(1.031)	(0.918)	(0.052)	(0.053)
Percentage of Catholics 1755	5.986***	5.840***	−0.325	−1.114	−0.095**	−0.100**	−0.305	−1.159	0.002	−0.013
	(1.061)	(0.904)	(3.506)	(3.824)	(0.044)	(0.049)	(3.224)	(3.602)	(0.077)	(0.072)
Royal Burgh	−1.954**	−2.026**	0.491	0.101	0.001	−0.002	0.818*	0.396	−0.016	−0.023
	(0.822)	(0.902)	(0.415)	(0.511)	(0.028)	(0.028)	(0.471)	(0.454)	(0.025)	(0.029)
Highland Clearances	−2.198*	−2.183*	−0.245	−0.162	0.005	0.005	−0.046	0.043	0.033	0.035
	(1.283)	(1.268)	(1.339)	(1.392)	(0.041)	(0.041)	(1.273)	(1.346)	(0.044)	(0.045)
Battle 1500-1750	1.137	1.127	−0.655	−0.710	−0.066***	−0.067***	−1.264	−1.323	0.135**	0.134**
	(1.321)	(1.349)	(1.691)	(1.611)	(0.022)	(0.022)	(1.552)	(1.481)	(0.063)	(0.061)
Latitude	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000**	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Longitude	0.000***	0.000*	0.000	0.000*	0.000	0.000	0.000	0.000*	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Num. Obs.	785	785	785	785	785	785	785	785	785	785
R2	0.474	0.472	0.305	0.308	0.121	0.118	0.268	0.272	0.171	0.156
R2 Adj.	0.461	0.458	0.288	0.291	0.099	0.096	0.250	0.254	0.150	0.135

Notes: This table reports results from OLS and IV regressions of occupational shares in 1851 on the number of water mills in 1755. The dependent variables are derived from the 1851 census, classified using EA17 and EA51 codes (e.g., EA17=1 for Agriculture, EA51=7 for Metal Manufacturing). Each occupational share represents the percentage of the total resident population of that parish in 1851 employed in that sector. Robust standard errors adjusted for spatial correlation are reported in parentheses; *** denotes statistical significance at the 0.01 level, ** at the 0.05 level, and * at the 0.1 level, all for two-sided hypothesis tests. All regressions include a constant.

Table A.12: Regression Analysis of Water Mills and Skills in 1851

Dependent Variable (1851):	Pct. Millwrights		Pct. Machinery Mf.		Pct. Tools Mf.		Pct. Skilled		Pct. Unskilled	
Method:	OLS	IV (2SLS)	OLS	IV (2SLS)	OLS	IV (2SLS)	OLS	IV (2SLS)	OLS	IV (2SLS)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Water Mills 1755	0.028***	0.040**	0.035***	0.035*	0.005**	0.014	0.112**	0.185*	−0.316	−0.166
	(0.010)	(0.017)	(0.012)	(0.021)	(0.002)	(0.009)	(0.048)	(0.099)	(0.229)	(0.258)
Water Power Potential	0.001	0.000	0.000	0.000	0.001	0.000	−0.011	−0.014	−0.233*	−0.239*
	(0.002)	(0.001)	(0.003)	(0.003)	(0.001)	(0.001)	(0.026)	(0.022)	(0.122)	(0.132)
Ruggedness	0.002	0.003*	0.001	0.001	0.000	0.000	0.005	0.006	0.033	0.037
	(0.002)	(0.002)	(0.002)	(0.002)	(0.000)	(0.001)	(0.018)	(0.020)	(0.073)	(0.076)
Parish Area	0.000**	0.000*	0.000	0.000	0.000	0.000	0.001	0.001	−0.003	−0.003
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.001)	(0.009)	(0.012)
Coast or Navigable River	−0.044***	−0.038***	−0.017	−0.017	−0.006	−0.002	−0.423*	−0.386	−0.797	−0.721
	(0.009)	(0.009)	(0.023)	(0.023)	(0.004)	(0.004)	(0.222)	(0.235)	(1.088)	(1.026)
Distance to Port (log x+1)	−0.003	−0.002	−0.030**	−0.030**	0.001	0.002	−0.309	−0.305	0.222	0.232
	(0.007)	(0.008)	(0.013)	(0.014)	(0.003)	(0.004)	(0.235)	(0.236)	(0.438)	(0.438)
Distance to Coal (log x+1)	0.000	0.002	−0.005	−0.005	0.001	0.002	−0.209	−0.202	1.428***	1.442***
	(0.009)	(0.009)	(0.010)	(0.010)	(0.002)	(0.003)	(0.142)	(0.140)	(0.428)	(0.422)
Land Capability	0.087**	0.093***	−0.061	−0.061	0.013	0.016	−1.813***	−1.784***	5.089***	5.149***
	(0.037)	(0.030)	(0.039)	(0.043)	(0.020)	(0.025)	(0.348)	(0.364)	(0.881)	(0.831)
Population Density 1755 (log)	−0.018	−0.019	0.041***	0.041***	0.011*	0.010**	1.878***	1.870***	−5.198***	−5.215***
	(0.012)	(0.012)	(0.014)	(0.015)	(0.006)	(0.005)	(0.100)	(0.094)	(0.891)	(0.889)
Market Potential 1755	0.000	0.000	0.003	0.003	0.000	−0.001	−0.099***	−0.099***	0.075	0.074
	(0.001)	(0.001)	(0.003)	(0.003)	(0.000)	(0.000)	(0.022)	(0.021)	(0.069)	(0.068)
Steam Engines 1800	−0.001	−0.001	−0.001	−0.001	0.000	−0.001	0.029	0.025	−0.006	−0.012
	(0.002)	(0.003)	(0.002)	(0.003)	(0.000)	(0.001)	(0.033)	(0.033)	(0.052)	(0.049)
Canal	−0.018	−0.032	−0.061*	−0.061	−0.013	−0.022	0.100	0.022	1.116	0.958
	(0.016)	(0.023)	(0.035)	(0.038)	(0.010)	(0.017)	(0.387)	(0.337)	(1.702)	(1.722)
Railway Line 1851	−0.007	−0.006	0.070***	0.070***	0.005	0.006	0.290**	0.292**	−2.444***	−2.439***
	(0.016)	(0.016)	(0.018)	(0.018)	(0.006)	(0.008)	(0.126)	(0.124)	(0.526)	(0.559)
Percentage of Catholics 1755	0.121***	0.102***	0.150	0.150	0.002	−0.011	−1.195	−1.308	2.423	2.194
	(0.026)	(0.039)	(0.115)	(0.126)	(0.018)	(0.029)	(1.624)	(1.602)	(2.145)	(2.163)
Royal Burgh	−0.016**	−0.026***	−0.039*	−0.039*	−0.007	−0.014	0.441	0.385	−1.512***	−1.625***
	(0.007)	(0.008)	(0.023)	(0.023)	(0.010)	(0.013)	(0.293)	(0.279)	(0.510)	(0.581)
Highland Clearances	−0.021*	−0.019	0.005	0.005	0.008*	0.010*	0.289	0.301	−0.622	−0.598
	(0.011)	(0.013)	(0.022)	(0.023)	(0.004)	(0.005)	(0.255)	(0.232)	(0.890)	(0.872)
Battle 1500-1750	−0.022*	−0.023*	−0.003	−0.003	0.041**	0.040**	−0.108	−0.116	1.986	1.970
	(0.012)	(0.014)	(0.037)	(0.037)	(0.020)	(0.016)	(0.149)	(0.160)	(1.498)	(1.568)
Latitude	0.000	0.000*	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Longitude	0.000	0.000	0.000	0.000	0.000	0.000*	0.000*	0.000*	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Num. Obs.	785	785	785	785	785	785	785	785	785	785
R2	0.180	0.131	0.190	0.159	0.038	0.043	0.314	0.312	0.412	0.408
R2 Adj.	0.160	0.110	0.170	0.138	0.015	0.019	0.297	0.295	0.397	0.394

Notes: This table reports results from OLS and IV regressions of skilled and unskilled occupational shares in 1851 on the number of water mills in 1755. The dependent variables are derived from the 1851 census. 'Pct. Skilled' and 'Pct. Unskilled' are classified using HISCLASS codes (6/7 and 11/12/13, respectively), while specific manufacturing skills use Occode and EA51 codes. All shares are calculated as the percentage of the total resident population of that parish in 1851. Robust standard errors adjusted for spatial correlation are reported in parentheses; *** denotes statistical significance at the 0.01 level, ** at the 0.05 level, and * at the 0.1 level, all for two-sided hypothesis tests. All regressions include a constant.

Table A.13: Regression Analysis of Water Mills and Birthplace Skills in 1851

Dependent Variable (1851):	BP Pct. Millwrights		BP Pct. Machinery Mf.		BP Pct. Tools Mf.		BP Pct. Metal Mf.		BP Pct. Textile Mf.	
Method:	OLS	IV (2SLS)	OLS	IV (2SLS)	OLS	IV (2SLS)	OLS	IV (2SLS)	OLS	IV (2SLS)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Water Mills 1755	0.116***	0.133**	0.124***	0.148***	0.004*	0.006**	0.032**	0.035**	0.288**	0.765*
	(0.037)	(0.054)	(0.035)	(0.043)	(0.002)	(0.002)	(0.013)	(0.017)	(0.136)	(0.456)
Water Power Potential	0.004	0.003	0.005	0.004	0.000	0.000	−0.001	−0.002	0.114	0.093
	(0.004)	(0.004)	(0.005)	(0.003)	(0.001)	(0.001)	(0.006)	(0.006)	(0.105)	(0.092)
Ruggedness	0.005	0.006	0.008	0.008*	0.000	0.000	−0.006	−0.006	0.084	0.095
	(0.004)	(0.004)	(0.005)	(0.005)	(0.001)	(0.001)	(0.005)	(0.005)	(0.092)	(0.087)
Parish Area	0.000*	0.000	0.000	0.000	0.000	0.000	0.000	0.000	−0.004	−0.003
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.009)	(0.010)
Coast or Navigable River	−0.055*	−0.046	−0.101**	−0.089**	−0.002	−0.001	0.039	0.040	−3.420***	−3.173**
	(0.028)	(0.032)	(0.044)	(0.043)	(0.005)	(0.005)	(0.033)	(0.034)	(1.316)	(1.255)
Distance to Port (log x+1)	−0.002	−0.001	−0.029	−0.027	−0.001	−0.001	0.022	0.022	−0.123	−0.091
	(0.016)	(0.018)	(0.025)	(0.026)	(0.003)	(0.003)	(0.028)	(0.028)	(0.536)	(0.550)
Distance to Coal (log x+1)	−0.002	−0.001	−0.009	−0.007	0.006***	0.007***	−0.059**	−0.059**	−1.011***	−0.969***
	(0.012)	(0.013)	(0.013)	(0.014)	(0.002)	(0.002)	(0.028)	(0.029)	(0.378)	(0.363)
Land Capability	0.177***	0.184***	0.229**	0.239**	−0.012	−0.012	−0.261*	−0.260*	3.574***	3.769***
	(0.060)	(0.062)	(0.090)	(0.096)	(0.010)	(0.010)	(0.152)	(0.151)	(0.931)	(1.245)
Population Density 1755 (log)	−0.024	−0.025	0.020	0.017	0.004	0.004	0.058**	0.058**	2.501***	2.447***
	(0.022)	(0.022)	(0.030)	(0.031)	(0.005)	(0.006)	(0.028)	(0.026)	(0.676)	(0.639)
Market Potential 1755	−0.003	−0.004	0.005	0.004	0.001	0.001	0.001	0.001	−0.050	−0.055
	(0.002)	(0.002)	(0.005)	(0.005)	(0.000)	(0.000)	(0.006)	(0.006)	(0.118)	(0.142)
Steam Engines 1800	−0.004	−0.005	−0.009***	−0.010**	−0.001	−0.001	0.001	0.001	−0.037	−0.058
	(0.005)	(0.006)	(0.003)	(0.005)	(0.000)	(0.001)	(0.003)	(0.003)	(0.093)	(0.118)
Canal	−0.100*	−0.117*	−0.121**	−0.146**	−0.012	−0.014*	0.171**	0.168**	−4.509***	−5.011***
	(0.053)	(0.066)	(0.060)	(0.060)	(0.008)	(0.008)	(0.074)	(0.072)	(1.196)	(1.480)
Railway Line 1851	0.005	0.006	0.104***	0.105***	0.018**	0.018**	0.080	0.080	2.738***	2.756***
	(0.022)	(0.023)	(0.033)	(0.031)	(0.009)	(0.009)	(0.049)	(0.050)	(0.855)	(0.799)
Percentage of Catholics 1755	0.224	0.199	0.297	0.261	−0.047	−0.050	−0.361***	−0.365***	−1.794	−2.521
	(0.170)	(0.217)	(0.369)	(0.410)	(0.034)	(0.031)	(0.128)	(0.131)	(3.481)	(3.911)
Royal Burgh	−0.017	−0.029	−0.028	−0.046	0.013	0.012	−0.002	−0.004	0.395	0.032
	(0.034)	(0.027)	(0.031)	(0.032)	(0.013)	(0.013)	(0.038)	(0.036)	(0.306)	(0.288)
Highland Clearances	−0.059**	−0.057**	−0.083	−0.079	−0.003	−0.003	−0.022	−0.022	0.247	0.326
	(0.023)	(0.025)	(0.057)	(0.065)	(0.012)	(0.012)	(0.032)	(0.032)	(1.654)	(1.725)
Battle 1500-1750	−0.046	−0.048	−0.099***	−0.102**	0.022***	0.022**	0.130**	0.130**	−1.144	−1.195
	(0.036)	(0.038)	(0.036)	(0.041)	(0.009)	(0.009)	(0.053)	(0.052)	(1.598)	(1.521)
Latitude	0.000***	0.000***	0.000	0.000	0.000**	0.000**	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Longitude	0.000	0.000	0.000***	0.000***	0.000	0.000	0.000	0.000	0.000**	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Num. Obs.	787	787	787	787	787	787	787	787	787	787
R2	0.317	0.127	0.292	0.186	0.043	0.039	0.205	0.194	0.337	0.339
R2 Adj.	0.300	0.106	0.275	0.166	0.019	0.016	0.185	0.174	0.320	0.323

Notes: This table reports results from OLS and IV regressions of birthplace-based skilled occupational shares (for individuals aged 30+) in 1851 on the number of water mills in 1755. This methodology groups all individuals in the 1851 census by their parish of birth. The dependent variable is the share of individuals born in a given parish (and aged 30 or older) who held a specific skilled occupation, classified by Occode or EA51 codes. This percentage is calculated relative to the total population born in that parish aged 30 or older, regardless of where they resided in 1851. Robust standard errors adjusted for spatial correlation are reported in parentheses; *** denotes statistical significance at the 0.01 level, ** at the 0.05 level, and * at the 0.1 level, all for two-sided hypothesis tests. All regressions include a constant.

A.3 Identification Strategy: Extensions and Diagnostics

A.3.1 Reduced Form and Exclusion Restriction Test

This section provides further evidence for the validity of the instrumental variable strategy by presenting the reduced-form estimates and, more importantly, a direct test of the exclusion restriction. For the IV estimates to yield a consistent estimate of the local average treatment effect, the instrument must satisfy the exogeneity condition, i.e., it must be orthogonal to the error term in the structural equation. This requires that the interaction between water power potential and land capability has no direct effect on population growth, net of its influence via the endogenous variable, the number of water mills. The primary threat to identification is the possibility that the instrument is correlated with unobserved heterogeneity at the parish level, such as latent institutional quality or specific geographic advantages not captured by the control variables, which could independently drive long-run development.

To formally test this assumption, I employ a falsification test designed to detect violations of the exclusion restriction. The logic of this test is to examine whether the instrument has any predictive power for the outcome in a subsample where the hypothesised causal channel – the presence of mills – is "switched off." This is achieved by restricting the analysis to only those 248 parishes that had zero water mills in 1755. If the instrument's effect on population growth operates exclusively through its impact on mill placement, then it should have no statistically significant effect in this "no-mills" subsample. A significant coefficient in this regression would suggest the instrument influences the outcome through an alternative pathway and thus violates the exclusion restriction.

Table A.14 presents the results of this exercise. Columns 1 and 2 report the standard reduced-form estimates for the full sample, confirming that the instrument is a significant predictor of population growth. This establishes the "intent-to-treat" effect, showing that parishes with geographic characteristics suitable for milling did indeed experience greater long-run growth.

The crucial results are presented in Columns 3 and 4, which contain the estimates from the restricted "no-mills" sample. Across all census periods, the coefficients for the instrument are statistically indistinguishable from zero, with very small point estimates. This result is precisely what the identification strategy requires. It provides additional empirical evidence that the instrument does not have a direct causal effect on population growth in the absence of water mills. This finding mitigates concerns about unobserved confounding variables and reinforces the interpretation that the instrument's influence on Scotland's long-run development was channeled specifically through its role in determining the geography of pre-industrial water mills.

A.3.2 Weak Instrument Diagnostics and Robust Inference

Standard inference relying on asymptotic normality can be misleading if instruments are weak. To address this, I report the Effective F-statistic proposed by Olea and Pflueger (2013), which is robust to heteroskedasticity and autocorrelation. As shown in Figure A.2, the Effective F-statistic far exceeds the critical value of 10 and the more conservative thresholds established by Stock and Yogo (2002). This confirms that the water power potential–land capability interaction is a highly relevant instrument, consistent with the large first-stage F-statistic reported in Table 1. The interaction instrument's dual-component structure is noteworthy in this regard: because it requires the simultaneous presence of both hydraulic energy supply and grain-milling demand to predict mill placement, it tends to generate sharper first-stage variation than a single geographic proxy would, which is reflected in the strong effective F-statistic.

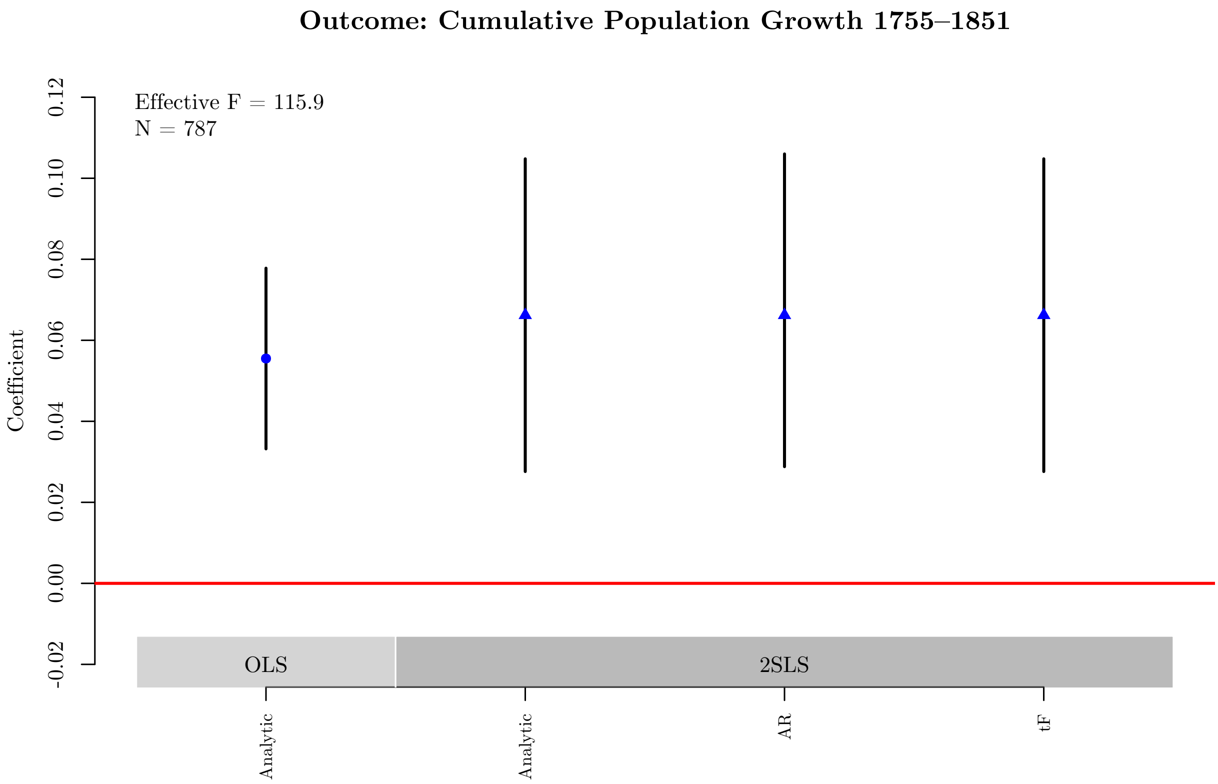
To further ensure that the significance of the results is not an artefact of weak identification, I report two sets of robust confidence intervals in Figure A.2. First, I compute the Anderson–Rubin (AR) confidence interval. Unlike standard Wald intervals, the AR statistic is robust to arbitrarily weak instruments. The 95% AR confidence interval for cumulative population growth 1755–1851 strictly excludes zero. Second, I report the tF confidence interval developed by Lee et al. (2022). The tF procedure adjusts the standard error based on the first-stage F-statistic, providing a more accurate critical value than the standard normal approximation when the first stage is strong but not infinite. The resulting 95% tF interval is comparable to the other confidence intervals. This consistency across methods confirms that the positive effect of pre-industrial water mills on long-run population growth is statistically significant and robust to identification concerns.

Table A.14: Reduced Form and Exclusion Restriction Test

Sample:	Full Sample		No Water Mills in 1755	
Dependent Variable (Pop. Growth):	Decadal	Cumulative	Decadal	Cumulative
Method:	Reduced Form (OLS)			
	(1)	(2)	(3)	(4)
WPP × Land Cap. × Factor (1801)	0.002	0.008	−0.007	−0.033
	(0.003)	(0.015)	(0.010)	(0.042)
WPP × Land Cap. × Factor (1811)	0.014**	0.022	0.007	−0.026
	(0.005)	(0.015)	(0.016)	(0.044)
WPP × Land Cap. × Factor (1821)	0.008	0.029*	0.002	−0.024
	(0.007)	(0.016)	(0.015)	(0.044)
WPP × Land Cap. × Factor (1831)	0.014**	0.043**	0.000	−0.024
	(0.006)	(0.017)	(0.015)	(0.041)
WPP × Land Cap. × Factor (1841)	0.011*	0.055***	−0.003	−0.027
	(0.006)	(0.018)	(0.015)	(0.046)
WPP × Land Cap. × Factor (1851)	0.005	0.060***	0.007	−0.020
	(0.005)	(0.017)	(0.013)	(0.050)
WPP × Land Cap. × Factor (1861)	0.000	0.060***	−0.001	−0.021
	(0.007)	(0.017)	(0.019)	(0.062)
WPP × Land Cap. × Factor (1871)	0.005	0.065***	0.003	−0.018
	(0.007)	(0.018)	(0.015)	(0.070)
WPP × Land Cap. × Factor (1881)	0.004	0.069***	0.000	−0.018
	(0.005)	(0.020)	(0.019)	(0.075)
WPP × Land Cap. × Factor (1891)	0.001	0.070***	−0.009	−0.027
	(0.006)	(0.022)	(0.013)	(0.082)
Geographic and Environmental Controls	Yes	Yes	Yes	Yes
Agricultural and Economic Base Controls	Yes	Yes	Yes	Yes
Transportation and Infrastructure Controls	Yes	Yes	Yes	Yes
Institutional and Cultural Controls	Yes	Yes	Yes	Yes
Latitude-Longitude	Yes	Yes	Yes	Yes
Num. Obs.	8380	8380	2480	2480
R2	0.213	0.282	0.196	0.191
R2 Adj.	0.194	0.265	0.126	0.120

Notes: This table presents results from the reduced-form regression and a direct test of the instrument's exclusion restriction. Columns 1 and 2 report the reduced-form estimates for the full sample, where the dependent variables (decadal and cumulative logarithmic population growth as in Table 2) are regressed directly on the instrument (water power potential interacted with land capability). Columns 3 and 4 test the exclusion restriction by running the same regression on a subsample restricted to only those parishes with zero water mills in 1755. The statistical insignificance of the coefficients in these columns supports the validity of the instrument. Robust standard errors adjusted for spatial correlation are reported in parentheses; *** denotes statistical significance at the 0.01 level, ** at the 0.05 level, and * at the 0.1 level, all for two-sided hypothesis tests. All regressions include a constant and the full set of controls used in the main analysis.

Figure A.2: OLS vs IV Estimates and AR/tF Confidence Intervals



Notes: This figure displays the OLS and IV coefficients for the effect of water mills in 1755 on cumulative population growth 1755–1851, with all standard controls included. To account for potential weak instrument bias, both the Anderson-Rubin (AR) 95% confidence interval and the tF adjusted 95% confidence interval proposed by Lee et al. (2022) are reported. The Effective F-statistic indicates a strong first stage. Both robust intervals exclude zero, confirming the statistical significance of the estimates.
Sources: Author's calculations.

A.3.3 Sensitivity to Exclusion Restriction Violations

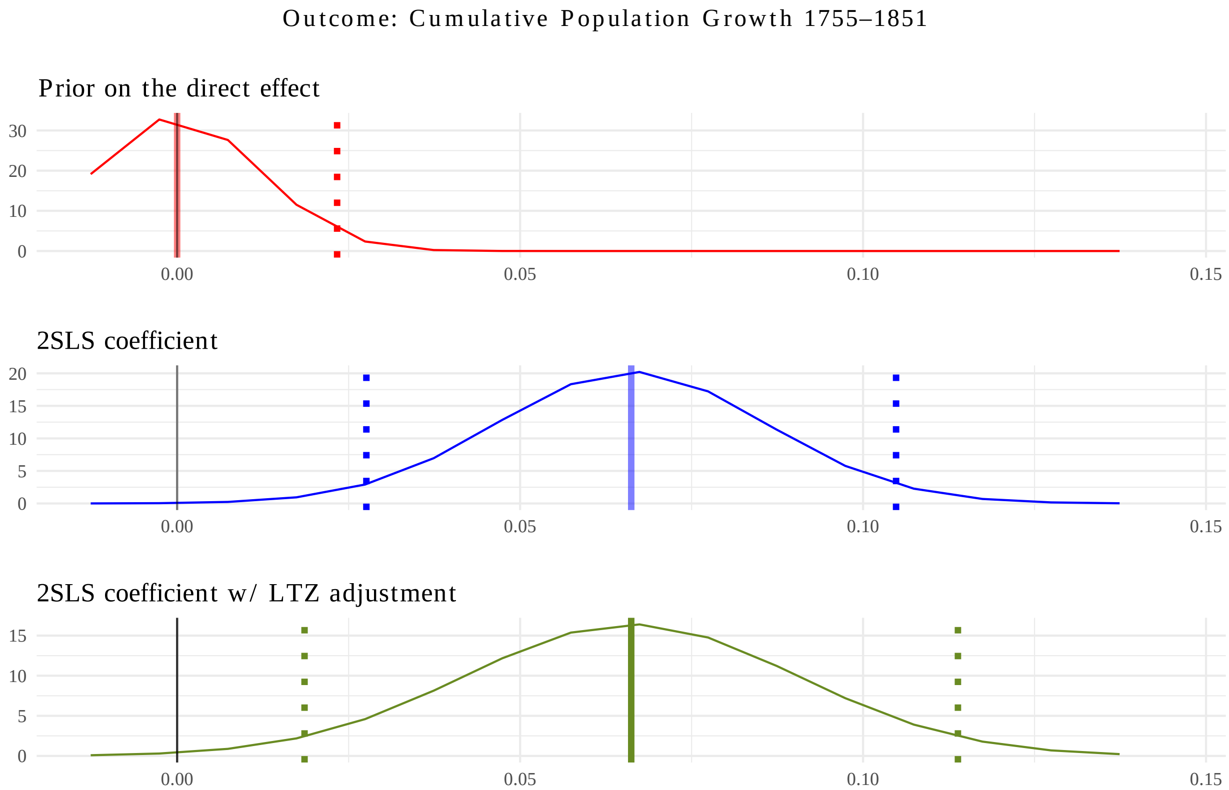
The validity of the IV relies on the assumption that the interaction between water power potential and land capability affects population growth only through pre-industrial water mill placement. To test the sensitivity of my results to this assumption, I employ the "Plausibly Exogenous" framework developed by Conley et al. (2012). This method allows for a relaxation of the strict exclusion restriction by assuming that the direct effect of the instrument (γ) on the outcome is close to, but not necessarily exactly, zero. This concern is particularly salient here: while I control for water power potential and land capability as separate regressors, one might worry that their interaction proxies for some broader endowment of environmental quality – for instance, parishes with fast-flowing rivers and productive soils may have also enjoyed superior natural drainage or superior access to upland summer pastures – that independently fostered growth through channels unrelated to mills. The Local-to-Zero analysis directly addresses this concern.

I implement the Local-to-Zero (LTZ) approximation. To parametrise the uncertainty regarding the exclusion restriction, I define a prior belief about the magnitude of the direct effect. Specifically, I assume the direct effect γ follows a normal distribution centred at zero with a standard deviation proportional to the reduced-form coefficient (β_{RF}):

$$\gamma \sim N(0, \sigma^2) \quad \text{where} \quad \sigma = 0.2 \times |\beta_{RF}|$$

This prior is conservative: it allows for a direct channel where the instrument could account for a substantial portion (20%) of the total reduced-form relationship. Figure A.3 displays the resulting confidence bounds. Even under this relaxed assumption, the 95% confidence interval remains strictly positive. This indicates that the finding of water mills fostering long-run population growth is not driven by the direct effect of geography on development, but rather by the historical placement and persistence of water mills themselves. The result also complements the zero-mills falsification test in Section A.3.1: both approaches, from different angles, arrive at the same conclusion that the instrument's identifying variation flows through mills rather than through some unmodelled geographical channel.

Figure A.3: Sensitivity to Exclusion Restriction Violations



Notes: This figure presents the results of the "Local-to-Zero" (LTZ) sensitivity analysis following Conley et al. (2012). The plot shows the estimated coefficients of water mills in 1755 on cumulative population growth 1755–1851, with all standard controls included (with 95% confidence bounds), while allowing the instrument (water power potential interacted with land capability) to have a direct effect on the outcome. The prior for the direct effect is centred at zero with a standard deviation equal to 20% of the reduced-form coefficient. The bounds remain positive, indicating robustness to plausible violations of the exclusion restriction.
Sources: Author's calculations.

A.3.4 Placebo Instruments

To further enhance confidence in the instrumental variable strategy, this section presents a series of placebo tests designed to verify the uniqueness and specificity of the chosen instrument. The core assumption of the IV approach is that the interaction between water power potential (supply) and agricultural land capability (demand) is a particularly strong predictor of pre-industrial mill placement, and that it affects long-run development primarily through its effect on mill construction. A potential concern is that this interaction might simply be capturing a broader, unobserved characteristic of locations that were generally favourable for economic development, which would violate the exclusion restriction.

To address this, I construct several "placebo" instruments by interacting one of the main instrument's components with other plausible geographic or economic variables that could also influence development. Specifically, I test whether interacting water power potential or land capability with coastal/river access or proximity to a port produces a similarly strong predictor of mill location. If these alternative interaction terms were equally or more predictive than the main instrument, it would suggest that the original instrument is not isolating the specific technological and economic conditions required for pre-industrial milling but rather proxying for general economic potential.

Table A.15 reports the results of these tests. The specification is identical to the first-stage regression in Table 1, with the dependent variable being the number of water mills in 1755. Column 1 shows the baseline result for the main instrument. Subsequent columns add one placebo interaction term at a time while retaining the main instrument.

The results strongly support the validity of the original instrument. Across all specifications, the interaction between water power potential and land capability remains a highly significant and stable predictor of mill placement, with a coefficient consistently around 0.8. In contrast, the placebo interactions are either statistically insignificant (Columns 2, 4, and 5) or, in one case, significant but with a substantially smaller coefficient (Column 3). The interaction of water power potential with inverse distance to a port is statistically significant, which is plausible as port access could also proxy for economic demand. However, the main instrument remains robust in the same specification. This indicates that while other factors mattered, the specific combination of water energy supply and local agricultural demand was a uniquely powerful determinant of where pre-industrial mills were built. Overall, these tests provide no evidence to suggest that the main instrument is misspecified and strengthen the case for its validity.

Table A.15: Placebo Interaction Instrument Tests

Dependent Variable:	Water Mills 1755				
Method:	OLS				
	(1)	(2)	(3)	(4)	(5)
Water Power Pot. × Land Cap.	0.835***	0.835***	0.727***	0.841***	0.839***
	(0.092)	(0.093)	(0.079)	(0.094)	(0.089)
WPP × Coast/River Access		0.002			
		(0.033)			
WPP × Distance to Port (Inv.)			0.445***		
			(0.165)		
Land Cap. × Coast/River Access				0.486	
				(0.488)	
Land Cap. × Distance to Port (Inv.)					0.683
					(0.601)
Geographic and Environmental Controls	Yes	Yes	Yes	Yes	Yes
Agricultural and Economic Base Controls	Yes	Yes	Yes	Yes	Yes
Transportation and Infrastructure Controls	Yes	Yes	Yes	Yes	Yes
Institutional and Cultural Controls	Yes	Yes	Yes	Yes	Yes
Latitude-Longitude	Yes	Yes	Yes	Yes	Yes
Num. Obs.	787	787	787	787	787
R2	0.334	0.334	0.351	0.335	0.335
R2 Adj.	0.317	0.316	0.334	0.318	0.318

Notes: This table presents the results of placebo tests for the first-stage regression to assess the validity of the main instrument. The dependent variable is the number of water mills in 1755. Column 1 reports the baseline first-stage regression from Table 1. Each subsequent column adds an alternative placebo interaction term to test whether the main instrument's predictive power is unique. The placebo variables are constructed by interacting one component of the main instrument (water power potential or land capability) with another plausible geographic variable (coastal/river access or inverse distance to the nearest port). Robust standard errors adjusted for spatial correlation are reported in parentheses; *** denotes statistical significance at the 0.01 level, ** at the 0.05 level, and * at the 0.1 level, all for two-sided hypothesis tests. All regressions include a constant and the full set of controls used in the main analysis.

A.4 Spatial Econometrics

A.4.1 Robustness to Alternative Standard Error Specifications

The panel structure in the population growth dataset, which tracks Scottish parishes over a span of nearly 150 years, necessitates a careful and deliberate approach to the specification of standard errors. Observations within the same parish across different decades are unlikely to be independent. Persistent, unobserved parish-level characteristics such as local institutional quality, entrepreneurial culture, or unique topographical features can systematically shape development trajectories, generating serial correlation in the error terms. The failure to account for this time-series dependence can lead to a substantial downward bias in standard errors.

Furthermore, given the localised nature of industrial development and migration, economic shocks and growth trends were unlikely to remain neatly confined within parish boundaries. Spillover effects from industrial agglomeration, the construction of a new canal, or the arrival of famine migrants could readily propagate to neighbouring parishes, producing spatial correlation. Both serial and spatial dependence violate the standard assumption of independently and identically distributed errors. If ignored, this violation inflates t-statistics and increases the probability of committing a Type I error. These concerns are particularly acute in long historical panels, where the extended time horizon amplifies the potential for serial correlation and where local economic spillovers are central to the processes under investigation.

To address these econometric challenges, the main analysis employs the spatial clustering corrections proposed by Conley (1999). This non-parametric estimator has become the standard in empirical settings with both temporal and geographic dependence (Dell, 2010; Nunn and Puga, 2012). It offers a flexible framework for correcting for correlation across both dimensions simultaneously without imposing a rigid parametric structure on the error covariance. In practice, the procedure accounts for serial correlation by treating observations from the same parish in different years as separated by zero spatial distance, thereby allowing their errors to be arbitrarily correlated over time. Simultaneously, it corrects for spatial correlation across parishes within a specified geographic radius, which is set here at 100 kilometres.

While the Conley correction is the preferred method, reliance on a single technique risks the findings being sensitive to its specific assumptions. For this reason, this section presents a robustness exercise where the main population growth models are re-estimated using a more conventional approach: standard errors clustered at the parish level. This method, rooted in the work of Arellano (1987), addresses serial correlation by allowing for an arbitrary error correlation structure within each parish over time. Its primary limitation in the present context, however, is that it assumes independence across parishes, regardless of their geographic proximity. This is a strong and likely counterfactual assumption given the potential for local spillovers in industrial and demographic outcomes. This makes parish clustering a more restrictive specification than Conley's correction, but it serves as a conservative and informative benchmark that is widely understood and directly comparable with a large body of applied economics literature.

The results from this alternative specification are presented in Table A.16. A direct comparison with the baseline results in Table 2 reveals that the estimated standard errors, and by extension the statistical significance of the coefficients, remain stable across the two methods. This stability under two conceptually distinct correction methods indicates that the significance of the main coefficients is not contingent on the choice of an error correction method. The empirical conclusions do not hinge on the more sophisticated Conley adjustment but are equally supported by the more conventional parish clustering approach.

A.4.2 Spatial Unit Root Tests

In the main empirical analysis, I employ standard errors adjusted for spatial correlation following Conley (1999) to account for the interdependence of observations across Scottish parishes. However, recent econometric advances by Müller and Watson (2024) suggest that standard Heteroskedasticity and Autocorrelation Consistent (HAC) corrections may be insufficient in the presence of strong spatial dependence. Specifically, analogously to well-established results in time series econometrics (Granger and Newbold, 1974), the presence of spatial unit roots can lead to spurious statistical significance even when variables are essentially unrelated.

To address this concern, I follow the practitioner's guide for diagnosing and handling strong spatial dependence provided by Becker et al. (2025). Using their Stata package *spur*, I implement the testing procedure developed by Müller and Watson (2024). I adopt the sequential decision rule outlined in Figure 5 of Becker et al. (2025) to determine the appropriate inference

Table A.16: Population Growth Analysis with Clustered Standard Errors

Dependent Variable:	Decadal Pop. Growth		Cumulative Pop. Growth	
Method:	OLS	IV (2SLS)	OLS	IV (2SLS)
	(1)	(2)	(3)	(4)
Water Mills 1755 × Factor (1801)	0.002	0.001	0.008	0.007
	(0.002)	(0.003)	(0.007)	(0.013)
Water Mills 1755 × Factor (1811)	0.008***	0.015***	0.017**	0.021
	(0.002)	(0.005)	(0.008)	(0.014)
Water Mills 1755 × Factor (1821)	0.010***	0.009*	0.027***	0.030**
	(0.002)	(0.005)	(0.008)	(0.015)
Water Mills 1755 × Factor (1831)	0.009***	0.016***	0.036***	0.046***
	(0.002)	(0.004)	(0.009)	(0.016)
Water Mills 1755 × Factor (1841)	0.014***	0.015***	0.049***	0.061***
	(0.003)	(0.005)	(0.010)	(0.018)
Water Mills 1755 × Factor (1851)	0.006**	0.006	0.055***	0.066***
	(0.003)	(0.005)	(0.011)	(0.020)
Water Mills 1755 × Factor (1861)	0.004	0.001	0.060***	0.067***
	(0.003)	(0.005)	(0.013)	(0.022)
Water Mills 1755 × Factor (1871)	0.008***	0.007	0.067***	0.074***
	(0.003)	(0.005)	(0.014)	(0.024)
Water Mills 1755 × Factor (1881)	0.009***	0.006	0.076***	0.080***
	(0.003)	(0.005)	(0.015)	(0.026)
Water Mills 1755 × Factor (1891)	0.007***	0.002	0.083***	0.082***
	(0.002)	(0.005)	(0.016)	(0.028)
Geographic and Environmental Controls	Yes	Yes	Yes	Yes
Agricultural and Economic Base Controls	Yes	Yes	Yes	Yes
Transportation and Infrastructure Controls	Yes	Yes	Yes	Yes
Institutional and Cultural Controls	Yes	Yes	Yes	Yes
Latitude-Longitude	Yes	Yes	Yes	Yes
Num. Obs.	7870	7870	7870	7870
R2	0.219	0.213	0.316	0.301
R2 Adj.	0.199	0.192	0.298	0.283
Std. Errors	by: parish	by: parish	by: parish	by: parish

Notes: This table tests the robustness of the main findings by replicating the population growth analysis from Table 2 with an alternative standard error specification. The regression specification is identical, but standard errors are clustered at the parish level to account for potential serial correlation within each parish over time. The similarity of these results to those in Table 2, which use Conley spatial standard errors, demonstrates that the findings are robust to different methods of correcting for correlated errors. Robust standard errors clustered by parish are reported in parentheses; *** denotes statistical significance at the 0.01 level, ** at the 0.05 level, and * at the 0.1 level, all for two-sided hypothesis tests. All regressions include a constant and the full set of controls used in the main analysis.

Table A.17: Spatial Unit Root Diagnostics for Key Variables

Variable	Num. Obs.	P-Value I(0)	P-Value I(1)	Conclusion
Water Mills 1755	795	0.145	0.263	Inconclusive
Cumulative Pop. Growth 1755-1851	838	0.254	0.020	Stationary
Non-Colliery Steam Engines 1800	851	0.205	0.001	Stationary
Total Textile Power 1838 (log)	851	0.128	0.003	Stationary
Pct. Manufacturing 1851	846	0.291	0.002	Stationary
Pct. Agriculture 1851	846	0.031	0.014	Inconclusive
Pct. Metal Mf. 1851	846	0.347	0.000	Stationary
Pct. Machinery Mf. 1851	846	0.095	0.026	Stationary
Pct. Tools Mf. 1851	846	0.178	0.004	Stationary
Pct. Millwrights 1851	846	0.070	0.048	Stationary
Pct. Skilled 1851	846	0.149	0.198	Inconclusive

Notes: This table reports diagnostic test results for the presence of spatial unit roots using the method developed by Müller and Watson (2024). Following the practitioner's guide by Becker et al. (2025), the procedure employs two separate tests: first, a test of the null hypothesis that the variable is spatially stationary ($I(0)$); second, a test of the null hypothesis that the variable contains a spatial unit root ($I(1)$). Standard inference methods (such as the Conley standard errors used in this paper) are valid if the test fails to reject stationarity ($p(I(0)) > 0.05$) and rejects the unit root hypothesis ($p(I(1)) < 0.05$). Cases where both null hypotheses are accepted or rejected are classified as 'Inconclusive', while failing to reject $I(1)$ and rejecting $I(0)$ indicates a Spatial Unit Root. The results show that the main dependent variables are stationary, supporting the use of standard spatial error corrections (Conley standard errors).

method. The tests utilise low-frequency weighted averages of the data to discriminate between a spatial $I(1)$ process and a spatial $I(0)$ process within a Local-to-Unity (LTU) framework:

First, I test the null hypothesis that the dependent variable is spatially stationary ($I(0)$). Next, I test the null hypothesis that the dependent variable contains a spatial unit root ($I(1)$). Standard inference methods (such as the Conley standard errors used in this paper) are appropriate when the test fails to reject stationarity ($p(I(0)) > 0.05$) and rejects the unit-root hypothesis ($p(I(1)) < 0.05$). Outcomes in which both null hypotheses are either rejected or not rejected are classified as inconclusive. Becker et al. (2025) note that, in such cases, the most appropriate inference method depends on the specific circumstances. In contrast, failing to reject $I(1)$ while rejecting $I(0)$ provides evidence of a spatial unit root.

Table A.17 reports the results of these diagnostics. I use the *spurtest* command to test the null hypothesis that a variable contains a spatial unit root ($H_0 : I(1)$). Rejection of the null indicates that the variable is spatially stationary ($I(0)$).

Table A.17 reports the results of these diagnostics. For population growth, the primary dependent variable in this paper, I can reject the presence of a spatial unit root at the 5% level ($p = 0.020$). Simultaneously, I fail to reject the null hypothesis of stationarity ($p = 0.256$). According to the Becker et al. (2025) decision tree, this confirms that the dependent variable is $I(0)$, and therefore standard inference methods are appropriate.

Similarly, for my measures of industrialisation—non-colliery steam engines, textile factory power, and manufacturing share—I can strongly reject the null hypothesis of a spatial unit root. The stationarity of these dependent variables suggests that the risk of spurious regression is minimal in the main specifications. Therefore, the standard spatial econometric methods (Conley standard errors) employed in Table 2, Table 3, and Table 7 are appropriate for valid inference.

I note that for the main explanatory variable, water mills in 1755, I cannot reject the null hypothesis of a spatial unit root ($p = 0.262$). This relatively high degree of spatial persistence is consistent with the variable representing a geographic endowment rooted in topography and hydrology, which naturally exhibit spatial correlation. However, as Müller and Watson (2024) demonstrate, spurious regression primarily arises when both the dependent and independent variables exhibit unit roots. Since the outcome variables regarding population and industrial structure are stationary, applying spatial differencing transformations is unnecessary. Therefore, I proceed with the level specifications in the main text, confident that the results are not artefacts of spurious spatial correlation.

Finally, regarding the human capital analysis, I cannot reject the null of a spatial unit root for the broad share of skilled workers ($p = 0.198$). While this suggests some caution, it is crucial to observe that the null is rejected for millwrights as well as the metal, machinery and tool manufacturing shares, which are the specific occupational group most mechanically linked to the water mill technology. The stationarity of these key mechanism variables, combined with the stationarity of the manufacturing sector as a whole, supports the interpretation that the observed skill accumulation is a genuine economic response to the presence of mills, rather than a spurious spatial trend.