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

— Short Version for EHS New Researcher Price*—

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Abstract

Does technological change favor agile entrants or adaptable incumbents? I examine this using Scotland's industrialization, testing whether steam power allowed new locations to "leapfrog" centers 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 geoclimatic 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 became abundant. Micro-evidence reveals that incumbent mill sites were significantly more likely to survive and industrialize. Rather than facing obsolescence, water-powered parishes became centers of steam adoption and industrial diversification and retained specialized mechanical skills. 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

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1 Introduction

Why did some regions flourish during the Industrial Revolution while others languished? A dominant narrative in economic history, powerfully summarized by Sidney Pollard, argues that "the map of the British Industrial Revolution [...] is simply the map of the coalfields" (1981, p. 4). This coal-centric perspective, 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 perspective, however, risks overlooking the kinetic energy source that powered early mechanization and shaped economic activity for centuries prior: water. Scholars like Reynolds (1983), Mokyr (1992), and Crafts (2004) have long emphasized that the roots of the Industrial Revolution lie in the sophisticated application of water power, a technology widespread 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 general-purpose technology allow other regions to bypass, or "leapfrog", established centers? The latter view suggests a process of creative destruction, where incumbents become "locked in" to older technology – trapped by sunk costs in canals and water wheels – while agile entrants in new locations seize the advantage. Recent empirical work by Hornbeck et al. (2024) on the United States supports this "incumbent lock-in" hypothesis, showing that early water-powered centers were bypassed by steam-powered entrants. Similar dynamics of leapfrogging have been observed in later energy transitions by Franck and Galor (2021) and Fritzsche and Wolf (2023).

Scotland provides an ideal setting to test these competing hypotheses. As a center of the Enlightenment and the birthplace of James Watt, it was at the technological frontier. Its rugged topography also supported over 1,200 water mills by 1755, on the eve of industrialization. Using a newly constructed dataset combining the locations of these mills with parish-level demographic, industrial and individual-level census data spanning nearly 150 years, this paper provides robust causal evidence against leapfrogging in the Scottish context.

I demonstrate that pre-industrial water mills were not technological dead ends but foundational pillars of transformation. By 1891, a parish with one additional water mill in 1755 had experienced approximately 8% greater cumulative population growth than an otherwise similar parish. Crucially, this effect intensified precisely during the diffusion of steam power (1820s–1840s). I further bolster these aggregate findings with a micro-analysis of mill survival, showing that sites with high water power potential were significantly more likely to survive and transition to industrial production. I argue that this persistence was driven by two mechanisms: technological complementarity, where steam was initially adopted to augment water power, and human capital accumulation, where mill communities generated the specialized mechanical skills necessary for the new industrial age.

2 Historical Context and Data

Scotland entered the Industrial Revolution with a long tradition of water power use. Present in Europe since Roman times, water mills were an integral part of pre-industrial production (Curwen, 1944; Langdon, 2004). Scotland's rugged geography provided almost ideal conditions for their use. The central Lowlands feature fast-flowing rivers that drop sharply from uplands, providing strong hydraulic head (Jonell et al., 2023). Prior to 1750, small water mills dotted large parts of Scotland, used for a wide range of productive activities including grain grinding, sawing, and textile processing (Reynolds, 1983; Lucas, 2006; Jonell et al., 2024).

While the "great age of water power in Scotland" lasted from around 1730 to 1830 (Whatley, 1997), British industry faced a critical choice in the 1820s: expand water infrastructure or switch to coal (Malm, 2014). While steam eventually triumphed, the transition in Scotland was distinctively gradual. As Whatley (1997) notes, Scottish industry remained dependent on water power significantly longer than northern England, with water accounting for nearly 44% of industrial power output as late as 1835. Even as steam engines proliferated, water power remained a viable alternative due to cost advantages and technological improvements like the hydraulic turbine (Chapman, 1970; Cameron, 1985; National Library of Scotland, 2021).

2.1 The Roy Military Survey: A "Great Map" of Proto-Industry

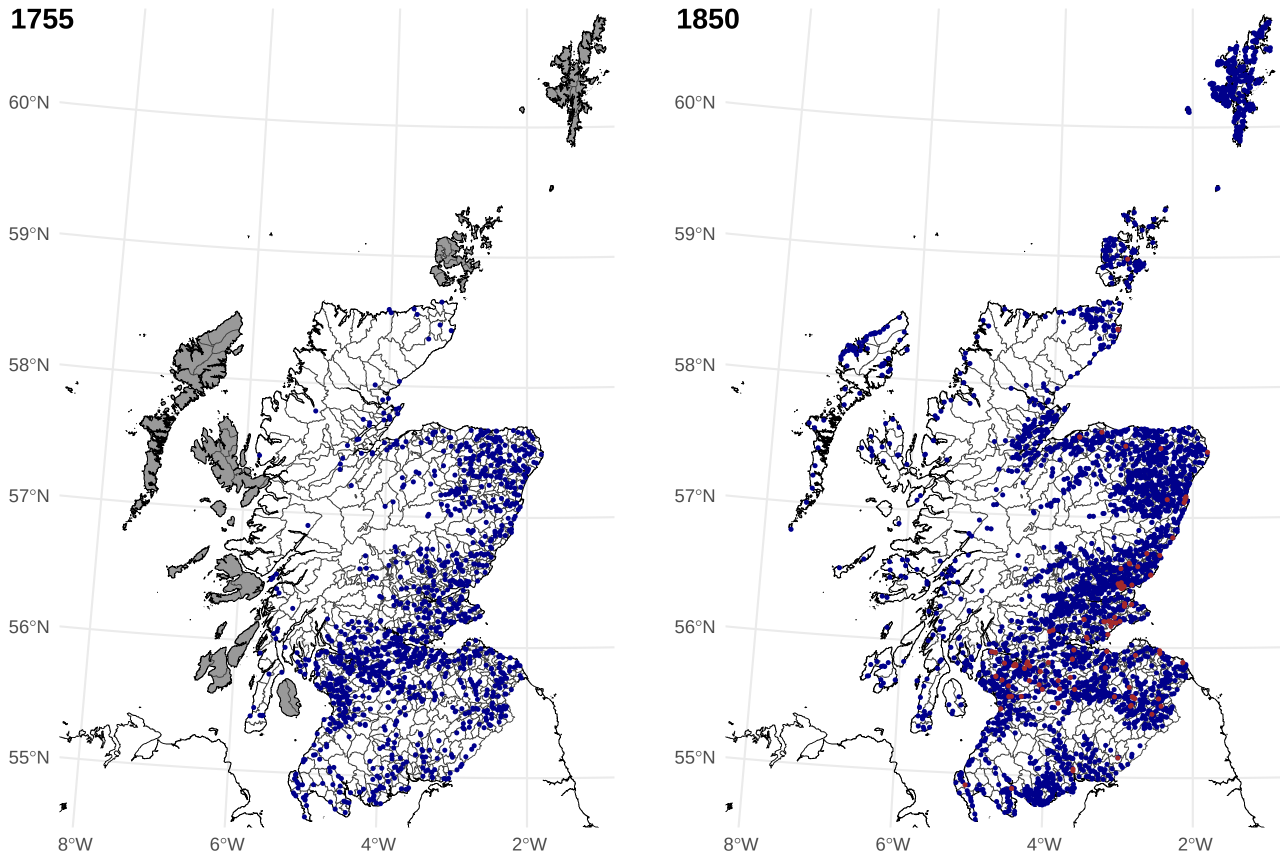
The empirical backbone of this analysis is the Roy Military Survey of Scotland (1747-1755). Created in the aftermath of the Jacobite Rising to facilitate troop movements, it represents the only comprehensive topographic mapping of the UK predating the nineteenth-century Ordnance Survey. From this "Great Map", Jonell et al. (2024) have digitized the locations of over 1,200 water mills, providing a precise snapshot of fixed capital investment at the very dawn of industrialization.

2.2 Parish Consistency and Visual Evidence

Long-run demographic analysis is enabled by the remarkable stability of Scottish civil parish boundaries. Unlike the frequent administrative fragmentation observed in England, Scottish parishes remained spatially consistent from the mid-eighteenth century until the 1950s. This allows for the construction of a consistent panel dataset linking Webster's 1755 census to decennial censuses from 1801 to 1891 (National Records of Scotland, 2022).

The expansion of this industrial network is visualized in Figure 1. The left panel shows the dispersion of proto-industrial mills in 1755, clustered in agriculturally viable areas. The right panel shows the explosion of industrial activity by 1850, illustrating how the industrial landscape evolved from this proto-industrial skeleton.

Figure 1: 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 watermills. 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.

3 Empirical Strategy

A central challenge in estimating the long-run effect of water mills is endogeneity. Mills were not located randomly; they were built in areas with economic demand and suitable geography. If unobserved factors, such as local institutional quality or general economic dynamism, drove both mill construction and later growth, simple regression estimates would be biased.

To estimate the effect of 1755 mills on outcomes like population growth ($\Delta \log(Pop_{i,t})$)[1] while addressing these concerns, I employ a panel specification with 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:

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

where $Mills_{i,1755}$ is instrumented to account for endogeneity. Following the methodology established by Mokyr et al. (2022) for Domesday England, the instrument is the interaction between Water Power Potential (Supply) and Agricultural Land Capability (Demand). Water power potential is calculated from historical moisture balance and topography, representing the physical capacity of a location to generate kinetic energy (Jonell et al., 2024). In the pre-industrial era, high overland transport costs meant mills needed to be located near grain supplies, so the share of land suitable for crop cultivation proxies for local demand (Soil Survey of Scotland Staff, 1981).

The logic is that while water potential or fertile land might independently influence growth through various channels (e.g., transport or agricultural wealth), their interaction specifically predicts the economic viability of establishing a water mill in 1755. The exclusion restriction relies on this specific interaction affecting nineteenth-century growth only through the legacy of the mills. I control for the main effects of both water potential and land capability, as well as distances to coal, ports, and cities, ensuring the instrument isolates variation driven by milling suitability. The first-stage F-statistic consistently exceeds 200, confirming the instrument's relevance.

[1] $\Delta \log(Pop_{i,t})$ represents the log population change in parish i from period $t-1$ to period t. In the case of decadal population growth, growth rates over varying census intervals are standardized 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 $\Delta^{cum} \log(Pop_{i,t}) = \log(Pop_{i,t}) - \log(Pop_{i,1755})$.

To further validate the instrument, I conduct placebo tests interacting water power potential with port access and coastal proximity. These alternative interactions fail to predict mill location significantly, reinforcing that the main instrument captures the specific conditions for milling. Additionally, a reduced-form test on the subsample of parishes with zero mills shows no effect of the instrument on population growth, supporting the exclusion restriction. I estimate the effect of 1755 mills on outcomes using a panel specification with parish and year fixed effects, clustering standard errors using the method proposed by Conley (1999) to account for spatial spillovers.

4 Results I: Growth and Industrial Transition

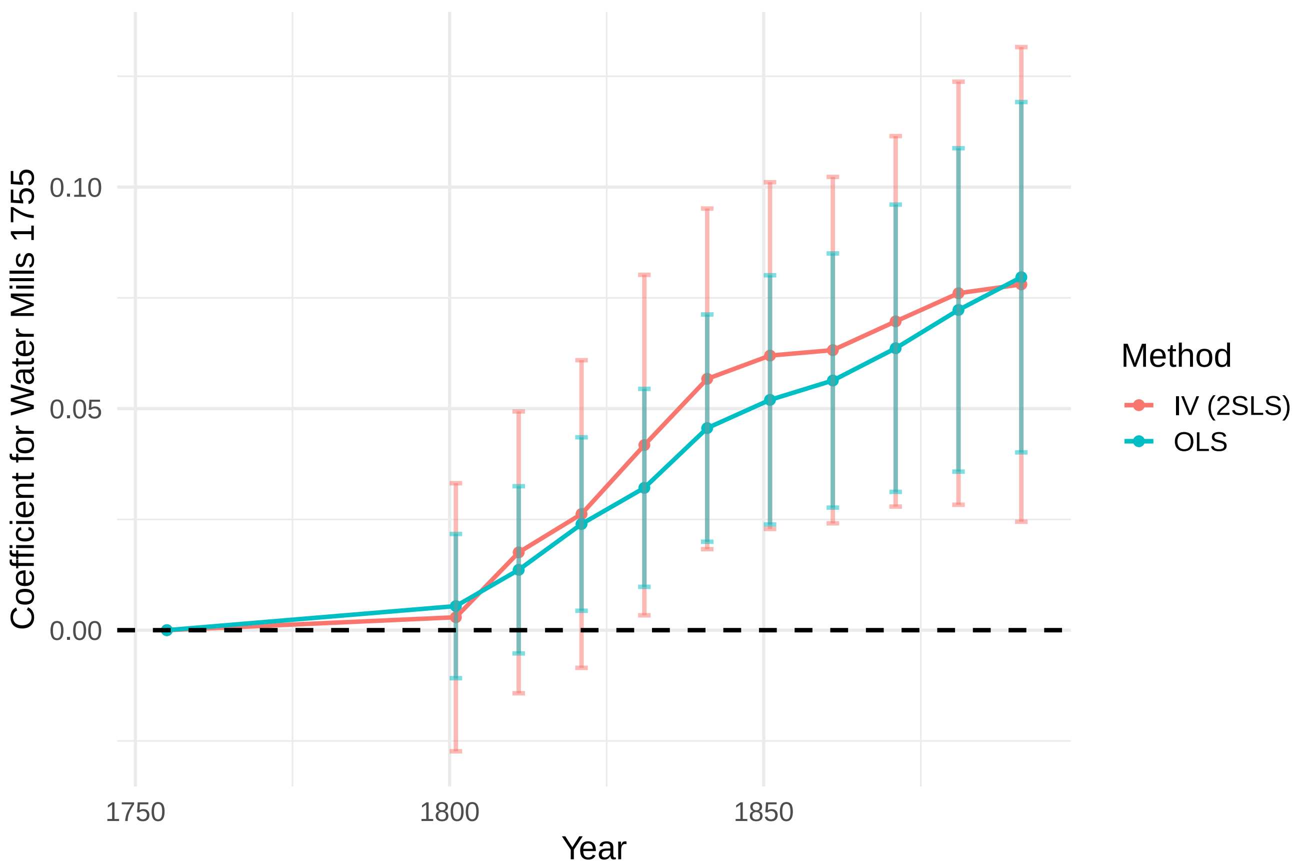
4.1 Population Growth as a Proxy for Development

Population growth is arguably the most reliable indicator of local economic development in the absence of direct output data in this period. Figure 2 presents the coefficients from the IV regression of cumulative population growth (1755–1891) on the number of mills in 1755.

The results show a striking temporal pattern. The effect of pre-industrial mills is negligible before 1800. However, it becomes positive and statistically significant in the 1820s and continues to rise through the 1840s – precisely the period when steam power began to diffuse widely. By 1891, the coefficient reaches 0.078, implying that one additional mill in 1755 generated an 8% increase in cumulative population growth over the long run.

This timing directly contradicts the "lock-in" hypothesis. If water mills were technological dead ends, we would expect their advantage to fade as steam became the dominant technology. Instead, the advantage solidified during the steam era, suggesting that these locations successfully transitioned.

Figure 2: 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.

4.2 Testing for Leapfrogging

Did steam engines leapfrog water-powered locations? If the "incumbent lock-in" findings of Hornbeck et al. (2024) for the US applied to Scotland, we would expect new steam factories to bypass the inconvenient, river-bound locations of the proto-industrial era in favor of coal-rich or urban sites. The Scottish data suggest the opposite.

As shown in Table 1, the number of water mills in 1755 is a strong, positive predictor of steam adoption. By 1800, approximately six additional pre-industrial mills were associated with the installation of one additional steam engine outside of collieries (Kanefsky, 2025). Furthermore, pre-industrial mills strongly predict textile factory power capacity in 1838. An additional 1755 mill is associated with a significant increase in total horsepower in textile factories.

This supports a narrative of complementarity rather than substitution. As Chapman (1970) and Whatley (1997) note, steam engines were often initially installed as auxiliary power sources to combat the seasonality of water flow. Existing infrastructure – dams, lades, and mill buildings – represented sunk costs that made it cheaper to upgrade an existing site than to build a new steam factory from scratch (Turner, 1958; National Library of Scotland, 2021). Additionally, Nuvolari et al. (2011) show that steam engines were frequently used to pump water back up to mill ponds. Far from being leapfrogged, parishes rich in water mills became the beachheads of the steam economy.

Table 1: Regression Analysis of Water Mills and Early Industrialization

Dependent variable:	Total Steam Engines 1800		Non-Colliery Steam Engines 1800		Total 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
F-stat. (1st Stage)		241.31		241.31		241.31
Std. Errors	Conley (100km)	Conley (100km)	Conley (100km)	Conley (100km)	Conley (100km)	Conley (100km)

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. 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.

5 Micro-Evidence: Mill Survival and Transformation

While the parish-level evidence demonstrates path dependence, it does not reveal the fate of the individual mills. Did the original sites survive and adapt, or were they merely markers for locations where unrelated industries later emerged? To answer this, I estimate a series of Probit models at the mill level. I track the fate of 1,200 mills from 1755 to 1850, defining survival as the presence of a mill structure within 500 meters of the original site to account for minor hydraulic relocations (Turner, 1958). The estimation takes the form:

$$\Pr(Y_{i,p} = 1 | X_i, Z_p) = \Phi(\beta_0 + \beta_1 X'i + \beta_2 Z'p + \epsilon_{i,p}) \quad (2)$$

where $Y_{i,p}$ is a binary variable indicating the outcome (survival, steam adoption, or industrialization) for mill i in parish p.

Approximately 62% of the mills present in 1755 were still in use a century later. Modeling the probability of survival reveals that local water power potential was the single most important predictor. Consistent with the argument that hydraulic infrastructure represented valuable fixed capital (Reynolds, 1983), high-potential sites were 42 percentage points more likely to survive than low-potential ones.[2]

Crucially, I find evidence of technological complementarity: while distance to coal was a strong negative predictor of steam adoption, water power potential had no such negative effect. This refutes the notion that steam was merely a substitute for scarce water. Furthermore, high water power potential increased the probability of a surviving mill transitioning from grain grinding to industrial uses like textiles, paper, or metal manufacturing by 23 percentage points. Thus, the "best" water sites were the ones that survived and industrialized, subsequently adopting steam if coal was accessible. This sequential upgrading where water geography determined the location and coal geography determined the power mix explains the absence of leapfrogging.

[2] A one-unit increase in water power potential within a 1 km radius is roughly the difference between the worst and the best-endowed mill.

Table 2: Probit Analysis of Mill Survival and Transformation

Dependent variable:	Mill Survival (1850)		Switched to Steam (1850)		Industrialized (1850)	
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
Pseudo R2	0.025	0.033	0.083	0.167	0.018	0.037
Std. Errors	Conley (50km)	Conley (50km)	Conley (50km)	Conley (50km)	Conley (50km)	Conley (50km)

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-meter radius of the original site in the 1850 Ordnance Survey. Columns 3-4 and 5-6 are estimated on the subsample of surviving mills, modeling the probability of adopting steam power and transitioning to industrial production, respectively. 'Switched to steam' indicates the presence of a steam-powered mill, while 'Industrialized' 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.

6 Results II: The Human Mechanism

If water mills drove population growth, what was the demographic mechanism? And if they facilitated technological adoption, was it merely a matter of physical infrastructure, or was human capital involved?

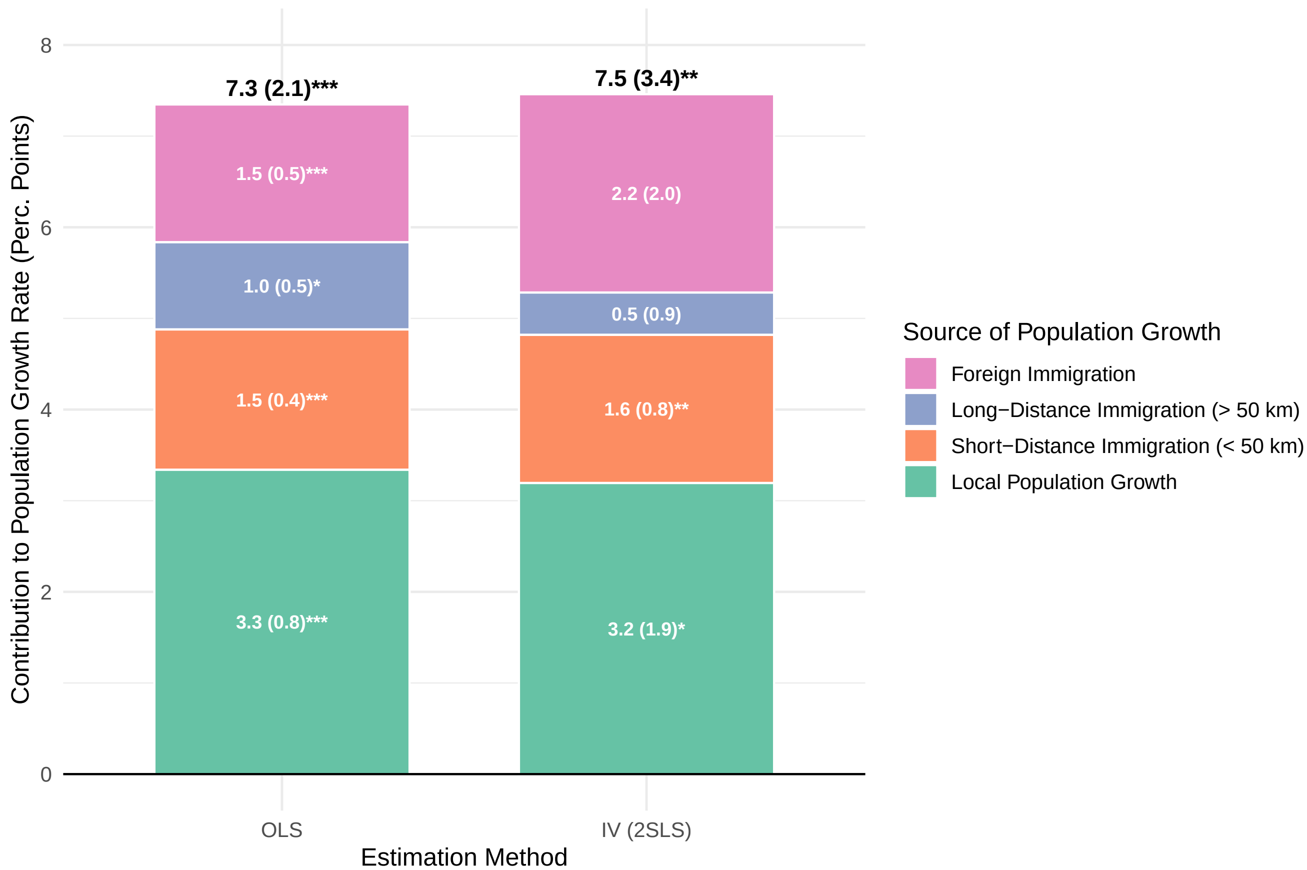
6.1 Demography: Migration, not Fertility

Demographic transition theory suggests industrialization might increase fertility via higher incomes or decrease it via opportunity costs (Becker et al., 2010; Galor, 2011). However, my analysis finds no causal effect of water mills on child-woman ratios or household size in 1851. The growth was driven entirely by migration.

Decomposing the 7.5% population growth effect observed between 1801 and 1851 using 1851 census data (Schürer et al., 2024) reveals distinct channels (Figure 3). Approximately 3% of the growth came from the "local growth component", primarily reflecting reduced emigration from these thriving parishes. The remaining 4.5% was split roughly equally between short-distance migrants (from within 50km) and foreign migrants. Long-distance internal migration played a surprisingly minor role given the Highland Clearances at the time, which is, however, consistent with recent evidence that their aggregate demographic effects on industrial centers were modest compared to the localized pull of wages (Gibson, 2006; Devine, 2018).

Crucially, the foreign component consists almost entirely of Irish immigrants. By 1851 there were over 200,000 Irish-born living in Scotland, a 90% increase since 1841 Schürer et al. (2024). This indicates that water-mill parishes created labor markets robust enough to absorb huge inflows of famine refugees. As Houston and Withers (1990) argues, the lack of institutional barriers to movement in Scotland allowed labor to flow efficiently to these growing industrial centers. The "pull" of the mills was strong enough to redirect the "push" of the famine, consistent with the findings of Hatton and Williamson (1998) regarding the responsiveness of migration to economic opportunity.

Figure 3: Decomposition of Population Growth (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 watermills in 1755. The height of each column represents the coefficient for total population growth, which is displayed at the top. Total population growth is decomposed using an identity where the 1851 population is split into locally born residents, internal migrants, and foreign immigrants, each normalized by the 1801 population. This allows the total growth coefficient to be expressed as the sum of coefficients for these distinct demographic components, separating the effects of retention (reduced emigration) from in-migration. These components 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. 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.

6.2 Human Capital: Mills as Schools

Beyond physical infrastructure, water mills fostered the accumulation of mechanical skills. Constructing and maintaining mills required specialized craftsmen – millwrights – who possessed the practical engineering knowledge necessary for the Industrial Revolution. Mokyr (1992) and Mokyr et al. (2022) have famously argued that these artisans were the "unsung heroes" of industrialization, providing the competence that made the macro-inventions of the era actually workable.

Using individual-level data from the 1851 census, I find a strong positive relationship between the number of 1755 mills and the share of millwrights and machinery makers in the 1851 population as presented in Table 3. To address the concern that this simply reflects skilled workers moving to jobs (sorting), I analyze occupations based on birthplace.

The results hold: individuals born in parishes with more pre-industrial mills were significantly more likely to become millwrights or machinery manufacturers, regardless of where they lived in 1851. This supports the view that these mills acted as "technical schools" or environments of knowledge spillover, generating a local supply of human capital that facilitated the adoption of subsequent technologies (Kelly et al., 2023; Hinrichs, 2025). When steam engines arrived, the local expertise required to install, repair, and operate them was already present.

Table 3: Regression Analysis of Water Mills and Skills in 1851

Dependent variable:	Pct. Millwrights 1851		Pct. Machinery Mf. 1851		Pct. Tools Mf. 1851		Pct. Skilled 1851		Pct. Unskilled 1851	
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)	(0.139)	(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
F-stat. (1st Stage)		238.98		238.98		238.98		238.98		238.98
Std. Errors	Conley (100km)	Conley (100km)	Conley (100km)	Conley (100km)	Conley (100km)	Conley (100km)	Conley (100km)	Conley (100km)	Conley (100km)	Conley (100km)

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. 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.

7 Conclusion

The map of the Scottish Industrial Revolution was not a "blank slate" written solely by coal; it was written over an existing network of water powered proto-industry. This paper demonstrates that pre-industrial water mills were powerful engines of long-run growth, generating significant population increases and guiding the location of steam-powered industry.

The findings offer a clear counter-example to the "incumbent lock-in" and "leapfrogging" hypotheses recently documented in other contexts by Hornbeck et al. (2024), Franck and Galor (2021), and Fritzsche and Wolf (2023). Unlike in the US, where steam led to the abandonment of water-powered sites, Scottish incumbents successfully adapted. This persistence was underpinned by a dual legacy: the physical adaptability of mill sites for steam power (technological complementarity), and the human capital accumulation of specialized mechanical skills among the local population.

Ultimately, this study challenges the mono-causal coal narrative associated with Pollard (1981) and Wrigley (1959). While coal was undoubtedly crucial, its benefits were most effectively exploited in regions that already possessed a proto-industrial base. The kinetic energy of the eighteenth century laid the physical and human foundations for the steam power of the nineteenth, highlighting the enduring power of path dependence in economic development and confirming the insights of Reynolds (1983) and Mokyr et al. (2022) regarding the deep roots of industrialization.

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