The spread of steam power: How neighbors mattered, 1841 – 1863

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Abstract: Diffusion of technology played a crucial role in the onset of Industrial Revolution. We focus on the spread of the Industrial Revolution's most vaunted technology, the steam engine. We are interested in estimating the effect of a location's own geographic and economic conditions (access to transportation, level of urbanization, size of local market) on steam engine adoption, and of the interaction between neighboring locations. Our data come from three steam engine censuses undertaken in 1841, 1852 and 1863 in the then Habsburg Empire. The level of geographic detail allows us to disaggregate the Empire's territory down to the district level (where districts were somewhat smaller than US counties). We combine this information with data on local fuel prices, navigability of rivers, the spread of the railroad, the results of the 1857 population census, latitude and longitude of each district's administrative center and other geographic data to produce a dataset of 1468 observations for each of the three years. Using a spatial-autoregressive model that allows for neighborhood effects operating both through neighbors' explanatory variables as well as neighbors' dependent variable, we are able to quantify the contribution of each district's own conditions for technology adoption relative to those of its neighbors, identify locations that were the most influential sources of technological diffusion as well as those that were most (and least) auspiciously located recipients.

1. Introduction

The steam engine was one of the most crucial inventions of the Industrial Revolution and a prime example of a general-purpose technology. Its development and diffusion has received considerable attention over the years, especially as it pertained to economic development of Great Britain and the United States. But while its importance as a source of productivity gain has been investigated and approximately gauged (Crafts, 2004), the study of the actual process of adoption and diffusion has been undertaken mostly at a relatively aggregated level of countries or large regions within countries (Atack et al., 1980; Nuvolari et al, 2011).

We seek to measure and assess the determinants of steam power adoption and their spatial interactions on a local level. Using a unique dataset from Central Europe from the middle of the 19th century, we are able to measure the direct and indirect ("spillover") effects of local characteristics on the spread of steam power. These characteristics include the availability of large local markets, mainly determined by a location's population, closeness and size of urban centers and their political importance. Against this backdrop, we evaluate the impact on adoption of outside, non-local influences. To do this, we include measures capturing the quality of connection to distant markets (such as river navigability and railroad connection) and influences working across national borders.

Our data come from a collection of government statistics describing the economic, political and technological situation in the Habsburg Empire between 1841 and 1863. Central to our dataset are three comprehensive surveys/censuses of all steam engines in the whole empire, which include both the number of steam engines at a particular location as well as total horsepower and which allow us to reconstruct the extent of steam power use on the level of districts, the smallest administrative units in the empire (equivalent to US counties but smaller). Using a probit model to investigate the determinants of steam engine adoption and a spatial-correlation model to assess the interactions between various locations, we find that the steam engine technology spread from two separate sources:

one consisted of the few large cities within the empire (e.g. Vienna, Budapest, Brno) which were able to generate enough local demand and technological know-how to spur technological advance locally. In measuring the geographic extent of a location's influence, we show that, for example, Vienna's net impact on the total horsepower in a district 50 miles away was about 5 HP. The other source were the neighboring German states, most importantly Prussia, which significantly affected the spread of steam through Bohemia, Moravia and Silesia. We also highlight the consistently significant impact of railroad connection on steam power adoption in smaller and more remote districts. In contrast with the railroads, the access to navigable river has a much more mixed record as an effective stimulant of steam engine use.

2. Technology diffusion as an economic problem

Our research spans several literatures. To begin, the spread of steam engine technology has received much attention in the economic history literature. Atack et. al. (1980) investigates the diffusion of steam technology by developing cost estimates per horsepower generated by steam and water across various regions of the United States. Nuvolari et. al (2011) use data collected by Kanefsky (1979) on the number of steam engines across counties, they study the spread of the steam engine throughout the 18th century in England using 84 counties as the geographical unit of observation. The dataset utilized in Nuvolari (2011) is perhaps the most similar to ours except that ours has greater geographical detail. Rosenberg (2004) incorporates data from the northeastern United States. They describe the effect of steam technology on a firm's decision to locate production facilities. They find the introduction of steam allowed firms to locate away from the previously predominant power source, water. This allowed firms to locate closer to large sources of labor, which in turn endogenously caused cities to grow as manufacturing hubs developed. This last point however has been met with some controversy (Abrams 2008).

Outside the realm of economic history, a large literature has devoted itself to technological diffusion across regions. Following the economic geography literature pioneered by Krugman (1991), Crafts (2005) analyzes scale effects of industrial clusters throughout Great Britain during the steam era, finding clusters develop in locations in which intensive factors are relatively less costly. In a similar vein, our analysis documents the geographic detail of steam location as well as a site's access to local transportation (through railroads and navigable rivers). Koch and Ertur (2007) construct a spatially-augmented Solow model which incorporates spatial relationships in the growth of knowledge as well as technological spillovers with physical capital. The authors note spatial dependence is often detected in cross-country growth empirics and therefore should be documented at the theoretical level as well. Through this framework they determine technological spillover effects are important in explaining growth convergence.

Also along the lines of the growth literature, steam engines are often documented as general purpose technologies (GPT). Jovanovic (2004a) outlines the criteria for inclusion of a technology as a GPT, as well as several common outcomes upon a GPT's technological introduction. Craft (2004) evaluates the contribution of steam engines to overall economic growth in Britain in the 19th century. Finally, our analysis rests on the rich spatial economic literature. We primarily follow the framework as discussed in Drukker et al (2011), Elhorst (2010) and Schabenberger et. al. (2005).

3. Diffusion of steam power in Central Europe

Central Europe was certainly not at the helm of technology adoption during the period discussed. Discounting curiosities, such as the steam-powered fountains in the gardens of the Schwarzenberg palace in Vienna and on the Esterhazy estate in Eisenstadt, the industrial use of steam power in the Habsburg Empire started in 1818. By early 1852, the empire boasted 788 steam engines (excluding locomotives and steamboats); by 1863 some 3791 of them.

The Austrian government keenly followed the diffusion of the technology within the Empire, seeing its importance for industrial development. The three empire-wide surveys that form the backbone of our dataset were the fruit of this interest. The earliest of the three, in 1841, was part of a larger statistical overview of all industry within the realms under Habsburg dominion and it was fairly brief, given that the whole empire had about 241 steam engines of 3011 horsepower, all in all.[1] This survey is clearly the least satisfactory of the three: it admits an incomplete coverage of Hungary and has no coverage of the Krakow Republic, which was only annexed in 1846.[2] Another steam engine census was commissioned in 1852 by the Trade Ministry. It followed on the heels of a violent suppression of the 1848 revolutions in Hungary, Bohemia, Italy and Vienna, which made clear to the empire's rulers the urgency of economic reform. Detailed statistical knowledge was to undergird all such reform efforts and several other surveys of various industrial sectors were undertaken during the 1850s. The last steam engine census was undertaken in 1863 as a follow-up on the 1852 survey. The initiative arose from within the newly established Central Statistical Commission as a way, no doubt, to prove its mettle. All three surveys provided detailed information on the location of each steam engine, its horsepower and sector of employment. Aggregate statistics on the place, year and cost of steam engine construction were also published but given their aggregate nature, we do not use them in this paper.

The detailed information on the location of individual steam engines (down to the village level) allowed us to construct a dataset containing steam engine use and total horsepower (HP) available on the level of a district ("Bezirk"). Districts were the smallest administrative units. They were a product of the administrative reforms of 1852-56 and there were 1565 of them in the whole empire. Table 1 shows that, as of the 1857 census, the average district had about 23.3 thousand inhabitants on an area

[1] By contrast, Britain already had a total of 165.000 steam horsepower in 1830 (Crafts, 2004).
[2] The survey makes note of only 9 steam engines (100 hp) in Hungary and that because they were all made by domestic, Austrian producers. The extent of this omission is unlikely to be very large however – in the 1852 survey, which claimed complete coverage, Hungary had mere 87 steam engines, so the 1841 tally could not have been significantly higher than the 9 engines recorded.

of 440.5 km^2 (172 square miles). The table also provides some basic information about the spread of steam power. Only about 5.7% of all districts had a steam engine in 1841.[3] By 1863, the penetration increased to 39.9%. The diffusion was very uneven across the empire (Table 2).[4] While Moravia and Bohemia were pioneers in steam engine adoption, bringing in the first specimens in 1818 and 1823, Dalmatia did not get its first steam engine until 1863. In most provinces, the boom in steam came in the 1850s. Even so, by 1863, the adopting districts averaged among themselves mere 6.5 steam engines with 101.6 horsepower. Only the large cities could claim to have made an unambiguous move towards steam power: Vienna had 156 engines (1750 HP), Budapest 95 engines (1607 HP), Brno – the Moravian capital – 86 engines (1326 HP). The sectoral composition of the total employed horsepower in 1863 is described in Table 3. The lion's share of steam engines were put to use in industry, with special local conditions accounting for the rest: the coal fields of Bohemia, Moravia and Silesia were responsible for the high share of steam power in mining there, while the threshing machines in Hungary and the Italian provinces made up their large horsepower totals in the agriculture column.

4. Data description

Our purpose is to relate the adoption of the steam engine to the local market conditions and to the mutual influence among neighboring areas and districts. To that end, we have collected a set of district-level characteristics that capture the size of the local market, its connection to the outside world and its position among neighbors. We draw our data from several sources.[5] The steam engine surveys of 1841, 1852 and 1863 have been described in the previous section. These data are combined with information on transportation network, population size, geographic location and administrative status.

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[3] The district is the unit of observation even for the 1841 dataset in spite of their creation only in 1852 – 56 because the detailed geographical information about the steam engines allows us to assign even the 1841 steam engines to their post-1852 districts.
[4] See map in Figure 1 for the description and location of individual provinces.
[5] See the Appendix for more detailed description and full citations.

The two main aspects of the transportation infrastructure are the gradual spread of railroad and the network of navigable rivers. Some attempts with horse-drawn railroad were made in the late 1820s but they were modest and by 1860, they were all converted into steam railroads. Modern network construction commenced in 1837 and the basic network was complete by the end of the railway boom of 1867 – 1873. Starting in 1867, the Austrian government published annually the Eisenbahn-Jahrbuch (Railroad yearbook) which enumerated all the lines ever opened by all railroad companies operating within the empire, together with the date of opening, end-point stations and mileage. Using this information and corroborating it with available historical and modern maps we were able to reconstruct the extent of the entire railroad network as of 1841, 1852 and 1863 (see map in Figure 2 for 1863). We then generated two variables. One is an indicator variable for each district in each year which equals 1 if the district had a railroad and 0 otherwise. Table 1 shows that some 3.5% of all districts had a railroad in 1841. By 1863, this statistic increased to 22.4%. The problem with the simple indicator is that it is a rather crude measure: for example, it treats all non-connected districts as equally devoid of railroad (they all have zero). That is not very realistic, of course: a district whose immediate neighbor has a railroad is likely in a very different position, economically, than a district that is a few hundred miles away from the closest railroad connection. To capture this difference, we constructed a distance variable which is zero for districts that were on a railroad in a given year and equals the shortest distance to a railroad for districts that were not on one yet. According to Table 1, the average of this variable declined from 223.3 km in 1841 to 49.1 km in 1863.

River navigability was a more cumbersome characteristic to capture because most sources usually record the extent of actual navigation rather than the extent of technical feasibility of ship travel. We used sources of three kinds: geography studies and textbooks (including encyclopaedias), trade statistics and military manuals. Each of these sources analyzed the hydrography from a slightly different angle. For example, military manuals often reported longer stretches of rivers as navigable, compared to trade publications, because they paid less attention to the profitability of a given route and more to feasibility. In fact, the extent of reported navigation often shrank from one trade publication to the next as the railroad network (a close and often superior substitute) expanded. In most cases, and especially for major rivers, however, the sources were in broad agreement. In coding our indicator variables of a district's river access, we first checked whether the sources were in consensus about extent of navigability; if they were not, we sought to establish and use the technically feasible extent of navigability. If even that was unavailable, we chose the longest (and earliest) extent cited in the several trade-related publications. The preference for technical navigability was motivated by our desire to avoid endogeneity in this variable. One consequence is, however, that the navigability indicator is time-invariant.

A subset of river ports was also steamship-navigable. Information on steamship navigability was only available in trade publications. All the rivers that were good for steamships, bar one, were navigable from a point of confluence with some other river.[6] We therefore consider steamship navigability also exogenous because it depended on river depth which was exogenously determined by the combined mass of water in the confluent rivers.

Canals may pose a problem regarding endogenity but, fortunately, the canal network in the Habsburg Empire was very limited and 22 of the 32 districts that had a canal also had access to some other navigable river so their indicator variable for navigability would not be affected by the canals. All of the canals were built more than several decades before the studied time period; the canals in province Venetia even several centuries.

As a final part of the set of transportation variables, we code access to sea as an indicator variable. It affects only a handful of districts along the Adriatic coast.

The transportation network gives us an indication about each district's access to distant markets but we are also interested in the impact of local demand and local market. Unfortunately, we do not

[6] For example, the Drau was steamship-navigable only from its confluence with the Mur at Legrad; the Sava from confluence with Kulpa at Sisak. The one exception was the Moldau which became steamship navigable 20 km (15 miles) above its confluence with the Elbe at Melnik.

have any sufficiently detailed measure of local wealth or incomes. Our proxy for the size of local market is the district-level population from the 1857 census. This was the first modern census conducted in the lands of the Habsburg Empire and the only one that was organized in a centralized fashion.[7] Using the population figures and information on the area of each district, we also construct population density as a measure of urbanization in each district.

We also include a set of "political variables" that capture the importance of certain locations as it was recognized by the administrative reform of 1852 – 1856. Some 88 cities across the whole empire were granted an autonomous, self-government status which turned them into separate urban districts. At the same time, these same cities were the district seats for their own hinterlands. This arrangement created a set a logically-connected pairs of districts titled, for example, Salzburg (city) and Salzburg (suburbs). Bigger cities, such as Vienna, Prague or Budapest could have more than one suburb district while smaller ones had none. We create separate indicator variables for the city districts and for the suburb districts. The Austrian government, for all its reformist zeal, was relatively conservative in granting the city autonomy, meaning that a vast majority of the cities thus honored were traditional urban centers rather than the products of recent industrialization. We also create a separate dummy variable for the twenty provincial capitals which form a subset of autonomous cities (with the exception of the Dalmatian capital Zara which did not have a self-government statute).

While the city-suburb dichotomy captures some of the neighborhood spillovers between districts, neighbors likely mattered also on the grander scale of cross-border influences. After all, the steam engine technology came to the Habsburg Empire from Western Europe. One may therefore suspect that convenient location close to the Western border and busy trade connection with Western neighbors may positively impact a district's likelihood of adopting a steam engine. We therefore construct a set of indicator variables for the seven countries or regions which shared a border with the

[7] The 1869 and subsequent censuses were already run separately from Vienna for the Western part and Budapest for the Eastern part of the Dual Monarchy.

Habsburg Empire. They take on 1 for districts that were on the border and 0 otherwise. The border variables follow the border as it stood between 1859 and 1866.[8] The mean values of these indicator variables are summarized in Table 1.

5. Empirical strategy

All in all, our data set comprises three cross-sections (for 1841, 1852 and 1863) but it does not constitute a panel. Most of the variables, either by design or by data availability, do not vary across years. The only exceptions are railroad access and the dependent variable, total horsepower in district.

Our analysis falls into three parts. In the first part, we estimate the relative importance of various determinants of steam engine adoption. The dependent variable is a dichotomous indicator of whether a district had a steam engine in a given year or not. We use a probit model for this estimation.

The second part of our analysis looks at the determinants of the extent of steam power use. Here the dependent variable is the total horsepower employed in each district. Since a large fraction of districts in any given year had no steam engine whatsoever, the obvious model to estimate is a censored variable model, such as the tobit. This is what we do.

The third part of our analysis pertains to the existence of spillovers between neighboring districts. Spatial-correlation models are based on the idea that outcomes as well as error terms can be correlated across space. Our estimated specification includes not only the explanatory variables described above but also a spatial lag of the dependent variable, horsepower:

Eq. 1 $$y = \lambda Wy + X\beta + u; u = \rho Wu + \varepsilon$$

In this expression, y is an $Nx1$ vector of horsepower (where N is the number of observations – districts), X are the explanatory variables and W is an NxN weighting matrix. The weights assigned to neighbors are equal to the inverse of a distance between any two districts and they are zero along the

[8] The Habsburg Empire lost its province of Lombardy to the Kingdom of Piedmont after the Franco-Austrian War in 1859. For that reason, steam engines in Lombardy did not make it into the 1863 steam engine census. The seven neighbors of Austria were Prussia, Saxony, Bavaria, Switzerland, Italy (we combine the border with various Italian statelets into a single dummy variable), Turkey and Russia.

diagonal. Such weighting scheme, or its variations, is standard in the spatial correlation literature (Elhorst, 2010; Koch & Ertur, 2007). The coefficient λ captures and controls for the impact of steam engine technology that cross district borders, although it should not be interpreted as a direct measure of technological spillover (as will become apparent shortly). Our specification also allows for spatial correlation in the error term where districts are again weighted by inverse distance. Leaving out the spatial lag when the true underlying data-generating process is co-determined across space can potentially produce the same bias as would arise from omitting an important variable. In order to test for spatial correlation, we calculate the Moran's *I* statistic:

$$I = \frac{\frac{1}{\sum_i \sum_j w_{ij}} \sum_i \sum_j w_{ij} (X_i - \bar{X})(X_j - \bar{X})}{\frac{1}{N} \sum_i (X_i - \bar{X})^2}$$

In short, the Moran's *I* statistic is equal to the coefficient λ that would obtain if *y* was regressed just on a spatial lag of itself and a constant (and no other explanatory variables) (LeSage, 2008). If it is significantly different from zero, then spatial correlation is present and should be accounted for. In our data, it equals 0.25 for the 1863 horsepower data and is statistically different from zero. Spatial correlation is present.

In estimating this model, the *a priori* assumption is that the spillover process is stationary, i.e. that λ is less than the inverse of the highest eigenvalue of the weighting matrix *W* (Debreu and Herstein, 1953). Because of the interaction between the explanatory variables and the spatial lag, the estimated coefficients are not the marginal effects of the explanatory variables. This becomes obvious, when we rearrange eq. 1 to yield

Eq. 2 $$y = (I - \lambda W)^{-1} X\beta + (I - \lambda W)^{-1} (I - \rho W)^{-1} \varepsilon .$$

In this expression, given that the λ-process is stationary,

Eq 3. $$(I - \lambda W)^{-1} = I + \lambda W + \lambda^2 WW + \lambda^3 WWW + ...$$

and the matrix of marginal effects of a variable *k* (because every exogenous change in any given location reverberates through the whole economy affecting every other location in proportion to the weights specified to *W*) becomes

Eq 4.
$$\begin{bmatrix} \frac{\partial y_1}{\partial x_{1k}} & \cdot & \frac{\partial y_1}{\partial x_{Nk}} \\ \cdot & \cdot & \cdot \\ \frac{\partial y_N}{\partial x_{1k}} & \cdot & \frac{\partial y_N}{\partial x_{Nk}} \end{bmatrix} = \left(I + \lambda W + \lambda^2 WW + \lambda^3 WWW + \ldots\right)\beta_k .$$

The marginal effect can be divided into two forces, which are often described as *direct* and *indirect* effects (Elhorst, 2010). The expressions that lie along the diagonal of this matrix are direct effects; off-diagonal expressions capture the indirect effects. Let there be two locations, home location *i* and away location *j*. Broadly speaking, the direct effect is an effect of a district *i*'s explanatory variable x_{ik} on the dependent variable in that same district, y_i. What the spatial correlation specification allows for (that a simple regression does not) is the spatial echo where the change in x_{ik} impacts y_j which in return affects y_i which again bounces back to y_i and so on until the spillover effect spends itself (λ^n converges to zero). The total (direct) effect of x_{ik} on y_i is a sum of all this back and forth. The indirect effects are conceptualized similarly: $\frac{\partial y_j}{x_{ik}}$ is the total impact x_{ik} of on y_i after it reverberates throughout all the districts. The *indirect effect* would be that outcome which occurs from an exogenous change in a variable in the away location on the number of steam engines in the home location. As can be seen from the matrix in Eq. 4, the off-diagonal elements in each column are the indirect effect of district *i*'s explanatory variables on each of all other districts while the off-diagonal elements in the row summarize the indirect effect of all other districts on y_i. The appeal of this specification of the marginal effects is that one can theoretically estimate the mutual influence of any pair of districts in the dataset. Moreover, given that the linear functional form in eq. 2 is linear, multiplying the derivatives by the actual values of explanatory variables yields an estimate – predicted value – of the actual total impact of any one district on any other.

One additional aspect deserves a separate mention and that is the likely endogeneity of railroad construction. Our dataset covers a period when the network was being built practically from the scratch and it is quite realistic to assume that cities and locations undergoing a particularly dynamic industrial development would have been more likely to attract a railroad connection.

Our instrument is based partly on history and partly on geography. We assume that the historical provincial capitals, such as Prague, Linz, Krakow etc. were attractive railroad destinations independently of their industrial development because they had already been important and powerful political and administrative centers before the industrial revolution. Moreover, between 1841 and 1854, railroad construction was government-run and political and military aspects took precedence over matters economic (Taylor, 1948). As for all other districts that were not provincial capitals, we argue that their likelihood for getting a railroad was affected by their good geographic fortune, namely whether or not they lay on the route between the provincial capitals. So, to construct our instrumental variable, we first draw up a map of connector lines between the capitals of any two neighboring provinces, as shown in Figure 3. Then, for each district, we obtain the latitude and longitude for the district seat and calculate the shortest distance to the closest of these connector lines. That is our instrument for the variable "distance to the closest railroad" described in the previous section. We use the IV approach in connection with the probit estimation, the tobit model as well as the spatial correlation model.

All the models also include numerous *kreis* fixed effects where *kreis* was the second lowest level of administration right above the districts. A *kreis* included about 10 contiguous districts on average. Including a dummy for each of these means that the coefficients and marginal effects are estimated from the variation within these *kreises*. In this way, we are doing our best to mitigate any sort of omitted variable bias: the *kreis* dummies, given that there are 138 of them, should be able to absorb at least some of the regional variation not accounted for by our explanatory variables.

6. Results

A total of 1468 observations were used in the estimation of these models (some exceptions apply – see the relevant tables). This is less than the total of 1565 districts in the whole Habsburg Empire in 1857 when the census was undertaken. The omitted 97 districts lay in the province of Lombardy which was lost in the war of 1859 and which do not therefore feature in the 1863 steam engine census. In order to improve comparability across years, we decided to exclude these from all estimation. The results are presented in Tables 4-6. Reported are the coefficients and (where applicable) the marginal effects of various explanatory variables.

6.1 Probit model

First, let us look at the probit results. These are estimated for each of the three survey years separately. We will evaluate the impact of neighbors against the backdrop of the impact of each district's own, local conditions.

Start with political/administrative characteristics: capital status and self-government status. The marginal effects of those variables were very high in each year. Being a provincial capital increased the likelihood of the steam engine technology appearing by 10.2 percentage points in 1841, 13.4 in 1852 and 26.1 in 1863. This is a sizeable impact given that even as late as 1863, just 39.9% districts currently had a steam engine. The impact of city autonomy was also non-negligible, although it was somewhat weaker (except in 1852). The indicator variable for a suburban district also has a consistently positive coefficient. Suburban districts were not different from other districts in any administrative or legal sense – the only thing special about them is that they lay next or around self-governing cities. That is what this indicator variable captures. The positive marginal effect of this suburban status then shows that whatever was going on inside the cities that was conducive to technology adoption, it was (in a diminished degree) rubbing off on the suburbs, too. For example, in 1863, the self-governing status increased the city's likelihood of steam power adoption by 15.2 percentage points and the immediate suburb's likelihood by 6.7 percentage points, all relative to districts that were farther afield in the countryside.

Note, however, that these indicator variables do not capture the district's size but its political or administrative importance.[9] The size is captured by district population and population did not have much of an impact until 1852. Prior to that, as in 1841, one standard deviation increase (by 18.3 thousand people – see Table 1) in local population increased the likelihood adoption by only about 1.8 percentage points. By 1863, this impact grew about tenfold.

What does this mean? At first blush, one may consider that the indicator variables of administrative and political status could be capturing the extra wealth available in cities relative to rural districts of equal population. We have tried a specification with squared population, which would presumably capture some of such wealth effect, but the effects of capital status and autonomous status were unaffected. What these cities had to offer apart from wealth, as seats of power, was lots of administrative infrastructure, such as working post office, policed market places – and last but not least the public procurement departments of local and provincial governments. Although we do not have any district-level data on the size of public sector purchases during this period, our steam engine data indicate that in 1863, the share of horsepower deployed in public utilities, such as to power water pumps in bath houses, for drainage or in train stations, reached 6% in the self-governing cities which was about nine times higher than this share in districts that were neither self-governing cities nor their suburbs. Vienna alone had about 10% of its horsepower (171 out of 1750) employed in the public sector, including the Mint and the government printing press.

[9] In fact, there was no systematic difference in the population sizes of self-governing cities and other districts – both reported an average of about 23 thousand people and a t-test cannot reject equality of the two means. The population of city districts was obviously much denser but density marginal effects are negligible.

One important way in which neighbors mattered in the adoption of the steam engine was as market destinations in the transportation network. This is represented by the river variables and by the distance to railroad. The river variables consistently turn out to be not very significant – practically or statistically. In fact, the three coefficients tend to be jointly statistically insignificant in all three years. Railroads was a different matter. Although the coefficient is statistically insignificant in 1841, the marginal effect implies that getting closer to a railroad by 10 km increased the chances of adopting the steam engine by about 1 percentage point. The standard deviation on the distance variable in 1841 was 178.9 km – so one standard deviation difference made a considerable impact and this impact even increased in subsequent years as railroad spread. By 1863, being 10 kilometers closer to a railroad had about the same impact on the probability of adopting the steam engine as having extra 2.000 inhabitants.

The border of neighboring countries effects are captured by the border dummy variables. Here, the consistent pattern is one of positive effect of borders with the German states (Prussia, Saxony and Bavaria) and a more mixed situation with all other borders.[10] The flow of technology and market influence played a major role in the adoption of steam power in the districts bordering the German states. The marginal effect of the three German borders is on par with the effects of self-government in some years or even with provincial capital status in 1852. The opposite can be said about the Turkish border which predicts failure (i.e. no steam power) perfectly in 1841 and 1852 and had a strong negative effect in 1863. The results correspond with the general impression that the benefits of modern technology spread throughout Europe from the North-East to South-West but what is particularly notable is how large the cross-border effect was.

6.2 Tobit model

The factors affecting actual extent of steam power use may differ from those determining the dichotomous decision of whether or not to adopt. So, we supplement the probit analysis with an

[10] Some border coefficients were not estimated in some years because they predicted failure perfectly.

instrumental-variable tobit. McDonald & Moffitt (1980) show that the total marginal effect in the tobit model can be split into the marginal effect of an explanatory variable on the probability of adoption and the marginal effect on the outcome variable (here, horsepower) conditional on it being positive. Specifically,

Eq. 5
$$\frac{\partial E\left[y_i | x_i\right]}{x_i} = \Pr\left[y_i > 0\right] \frac{\partial E\left[y_i | x_i, y_i > 0\right]}{\partial x_i} + E\left[y_i | x_i, y_i > 0\right] \frac{\partial \Pr\left[y_i > 0\right]}{\partial x_i}$$

Since we have analyzed a probit to get at the first question, we now report, next to the coefficients in Table 5, these derivatives of conditional mean horsepowers, $\frac{\partial E\left[y_i | x_i, y_i > 0\right]}{\partial x_i}$. Structurally, the effects in the tobit models are similar to the probit models (e.g. signs on coefficients are broadly the same) but relative size of the effects differs. The political variables again turn out to be very important and they are also, by and large, relatively precisely estimated. According to the estimates, the provincial capital status would add, on average, 51 horsepower to the local tally in 1852 and 70 in 1863. City self-government similarly contributed 65 and 29 horsepower in the two years and, as before, the positive impact rubbed off on the suburbs, bringing in 28.9 horsepower in 1852 and 6.7 horsepower in 1863. The political/administrative clout clearly made more impact in those self-governing towns that had smaller populations. The average marginal effect of population was about 1.02 in 1863 which means that one standard deviation increase (18.3 thousand people) would be associated with an increase in total horsepower by 18.7. In places like Vienna, Budapest, Prague and Brno where total horsepower counted in the hundreds, the net contribution of the political variables was therefore secondary but in smaller capitals, such as Linz (27.000 inhabitants) or Laibach (21.000), being the center of the province and a self-governing city on top of that must have made a big difference in being able to generate the market conditions to attract the new technology.

River variables are again statistically insignificant individually and jointly. Practically, their impact is minimal, with the exception of the marginal effect of the access top any river in 1863 which equals 49 horsepower. This is a sizeable effect but it only worked in places where the river was not steamship-navigable and was not one of the major rivers.[11] Some 110 districts in our sample fit that description. Railroad, on the other hand, mattered. Cutting the distance to railroad by one standard deviation in 1863 (64.4 km) would increase the district's steam power on average by 40.2 horse power which beats the effect of a self-governing status and is equivalent to the impact of about 40 thousand extra population. In 1852, the effects were even stronger, with the marginal effect of the railroad distance equaling -1.43 while the impact of district population reached 0.76. What these results imply is that railroad had a very differential impact on densely vs sparsely populated districts. The highly populated areas generated enough demand from within, precisely through their large population. The smaller places, however, got their break when the railroad arrived and opened an avenue to bigger markets.

Finally, there is the group of border variables. Comparing the probit and tobit results, it turns out that some of the neighboring countries had more of an impact on the decision to adopt while others on the actual extent of use of steam power. Prussia is a clear example: of the three German neighbors, it had the weakest impact on adoption but its marginal effect on total horsepower was 55.3 in 1852 and 71.3 in 1863 – bigger than for either Bavaria or Saxony. The steam engines in the districts bordering with Prussia were bigger on average because a large part of them was employed in coal mining which generally used more powerful steam engines. This factor is also a likely explanation for the high positive impact of the Russian border which otherwise had only meager impact on the adoption in 1863. The Turkish, Swiss and Italian border are very imprecisely estimated in 1852, presumably because they all perfectly predict failure to adopt in the probit specifications – i.e. all the districts bordering with Italy, Turkey and Switzerland were steam engine-free in 1852. By 1863, there appeared at least some variation in the outcomes of these districts which allowed for a more precise estimate of

[11] We count as major rivers the Danube, Drau, Mur, Sava, Tisza, Maros, Dniester, Elbe, Moldau, Wisla, Po, Adige.

the marginal effect and the results are consistent with the probit in that Turkey and Italy, as neighbors, were a drag on steam power diffusion.

6.3 Spatial correlation model

Our final piece of analysis is an estimate of the spatial correlation model. The estimation is somewhat problematic in that the spatial model introduced in the previous section does not explicitly account for the censoring of the dependent variable. We therefore run the spatial-correlation model only for 1863 and using only the 585 observations (districts) where the dependent variable, total horse power, is greater than zero. Using the results in the rightmost column of Table 6, we are arguing that the bias introduced by limiting the sample this way is not severe. The various models, from OLS to the spatial correlation model, produce results that are broadly similar to the tobit model which accounts for the censoring explicitly. The coefficient estimates on population, density, most of the border effects, impact of railroad and of the fuel price have similar values across the models. There are, however, some obvious differences such as the coefficient on the Russian border, the suburbs and access to any navigable river.

The coefficients λ and ρ, reported in Table 6, indicate that some spatial correlation is present even though it is not particularly strong. At 0.156, λ is statistically significant. In Table 7 we report the direct and indirect effects which were defined in section 5. At this point let us merely reiterate that the direct effect is the total effect of a district's own characteristics on its own total horsepower, including the bounce-back from other districts's response. The indirect effect is the total effect of a district's own characteristic on horsepower in all other districts across the empire. Both effects are going to be high in districts with environments conducive to technological advance which are also close to each other and which can therefore affect each other at "close range".

Take the example of Troppau (suburb), a district on a Prussian border that recorded the highest direct effect from that border, 342.8 horsepower. The reason why this value is high above the average direct effect of 302.8 is that Troppau (suburb) was not only on the Prussian border but also close to many other technologically progressive districts and the positive impact in Troppau reverberated through the local economy and some of it bounced back to Troppau. The neighbors of Troppau (suburb) mattered to the tune of 43 horse power, when it came to the impact of the Prussian influence.[12] At the other end of the spectrum is the district of Jaworzno, also on the Prussian border but far from other steam power-using districts, where the direct impact of that border was mere 299.8 horsepower. Troppau (suburb), however, also gave back: its indirect effect from being on the Prussian border on all other steam-adopting districts in the Empire equaled 520.6 horsepower. With the sample of 585 districts used in the calculation, this yields about 0.88 HP per district but, of course, most of that indirect effect would be concentrated again in the closest neighbors of Troppau (suburb). Other border variables show much less spectacular impact, with the exception of the Russian border which, however, seems to be heavily affected by the method of estimation, judging from Table 6.

Generally, Table 7 shows that the indirect effect – effect on neighbors – was on average somewhat weaker than direct effect. But it was also more varied, as it depended on each districts geographic location among other districts. For example, an exogenous increase in district population by 1000 inhabitants would increase the district's total horsepower by anywhere from 3.54 to 4.05 (average being 3.57) while it would increase neighbors' horsepower by a combined total of 0.9 – 6.99 (average 2.76).

Given the linear specification of the spatial correlation model one can use the data to calculate the predicted direct and indirect effects of individual locations. Table 8 shows in three panels the ten locations with the greatest predicted direct effect, the ten with the greatest predicted indirect effect and the ten largest recipients of positive impact from their surroundings. In light of our previous discussion, the results do not present too many surprises. Big cities, which were administrative centers and provincial capitals turned out to be able to generate an environment conducive to steam adoption

[12] Specifically, the value of this bounce-back would be 43 = 342.8 – 299.8 = the direct effect – the coefficient.

from within: their populations were large, the railroad was (mostly) present, the autonomous status and political importance helped. Comparison of the total predicted direct effect with the total observed horsepower shows that the explanatory variables can potentially explain a large part of what was going on in these cities. Vienna looms large over the rest of the panel on account of its large population (476.000), which made it about three times as large as the next largest city, Buda-Pest.

Many of the largest cities were also important as sources of technological development as is revealed in Panel B of the table. In most cases, the sum-total of their impact on others was greater than their own direct effect. The fact that the city centers were in this position to positively influence the diffusion of steam power elsewhere is another way to restate an earlier result from the probit and tobit analysis that the auspicious conditions in the important centers rubbed off positively on the suburbs. They account for a large portion of this indirect effect. There was, however, one even more powerful factor imparting technological progress and that was the influence of Prussia. In Panel C, we see the ten districts that benefitted most from what was going on around them. Note that the predicted direct effect in many of these places is either very small or even negative: they were small, far away from any connection with the rest of the world and administratively unimportant. The horsepower totals that we observe in these districts were clearly not a result of their own merits but of their lucky location the Prussian border. The locations in Panel A and Panel C were therefore very different from each other: the former benefited little if at all from their neighbors; the latter's technological prowess was all due to the "public good" of Prussian influence, whatever form it took.

As a final piece of analysis, let us look more closely at the nature of the indirect effect by considering the particular example of Vienna. According to Panel B in Table 8, Vienna's predicted total indirect effect was 1770.5 horsepower across all other districts in the sample. Naturally, the closer districts got a large share of that pie than the more distant ones. Figure 4 shows how that impact was distributed by distance. The shape of the graph is entirely a product of the specification of the weighting matrix in the estimation: the weights were a function of inverse distance. But the size of the impact on each neighboring location depends on the estimated size of λ and its interaction with Vienna's values of explanatory variables. The figure implies that at the radius of 40 km (≅ 25 miles), the predicted indirect effect stood at about 10 HP. At 80 km, it was 5 HP. This was a non-negligible amount of steam power given that the average engine in 1863 had 14.7 HP.

Conclusion

In the diffusion of any technology, original inventors and developers inevitable represent only a tiny minority of adopters. The rest receive the technological knowledge from someone. So, neighbors matter.

In the case of Central Europe, the most important neighbors – as sources of new technology – came in two varieties: big cities and technologically developed neighboring countries, particularly Prussia and (to a much lesser extent) Saxony and Bavaria. As for the smaller places, their best shot at adopting a steam engine was closely tied with their connection to the railroad network.

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Data Appendix

Steam engines

The dataset is a product of a combination of several sources. Information on the steam engines, their location, sector of employment and horsepower come from the following publications:

"Die Dampfmaschinen der Oesterreichischen Monarchie zu Ende des Verwaltungsjahres 1851", *Mittheilungen aus der Gebiet der Statistik* 1 (3), Vienna, 1852
"Die Dampfmaschinen der Oesterreichischen Monarchie nach de rim Jahre 1863 vorgenomennen Zahlung", ***Mittheilungen aus der Gebiet der Statistik*** 11 (2), Vienna 1864
K.K. Statistische Zentral-Commission, *Statistisches Jahrbuch der Oesterreichischen Monarchie fur das Jahr 1863*, Vienna 1864
Direction der administrativen Statistik im k.k. Ministerium fur Handel, Gewerbe und Offentliche Bauten, *Tafeln zur Statistk der Oesterreichischen MOnarchie fur das Jahr 1841*, Vienna 1844
Direction der administrativen Statistik im k.k. Ministerium fur Handel, Gewerbe und Offentliche Bauten, *Tafeln zur Statistik der Oesterreichischen Monarchie – II. Band fur die Jahren 1852 – 1854*, Vienna, 1859

Locations of steam engines and their assignment to district

Many of the steam engines were located in villages that either do not exist or have changed their names. Moreover, given the administrative reform of 1851 – 1856, the border of the newly created districts did not necessarily overlap with the manors that were units of administration prior to 1848. We checked the location and district assignments of steam engine locations with the use of several historical maps and various gazetteers, village lexicons and other sources, as well as the laws enacting the administrative reform which all included extensive, comprehensive and detailed tables assigning each location to a particular administrative unit. The sources are listed here:

Raffelsberger
Hornyansky
Scheda's map
Gemeindelexion 1900
III. generalmap
The laws themselves

River network and their navigability

Several sources, spanning the whole relevant period, were consulted to establish navigability of rivers. They fall in three groups: geography textbooks, trade studies and statistics and military manuals. Each group of sources has different motivation for studying rivers, so together they provide a richer picture regarding the viability and extent of river traffic. Based on their indications of navigability, we assigned to each river (with a few exceptions) the largest extent of navigability cited in any one of these sources. The sources are:

1835 Penny Encyclopedia, entry "Austria"
1837 von Roon Statenkunde
1839 Franz Ritter von Rudtorffer, Militar-Geographie von Europa, Prague 1839
1842 Schubert Staatskunde
1848 Voelter Erdbeschreibung
1852 Slama von Freyenstein, Handbuch der reinen und politischen Geographie mit besondere Rucksicht auf militarische Wichtigkeit, Brunn 1854

MGS 1853 on Wasserbau
MGS 1865 on Danubian traffic
SJOM/USJ 1876

Railroads

The detailed history of railroad construction was being published in every edition of the railroad yearbook. For the Italian provinces which were all lost by 1866, we used PF Kupka. The information in these publications was confronted with Scheda's 1856 map as well as with the 1910 generalmap and modern satellite imagery available on Google maps.

Eisenbahn Jahrbuch 1880
Kupka, PF. Oesterreichische Eisenbahnen 1822 – 1857, Vienna? 1888

Table 1 – Mean (standard deviation) of model variables			
N = 1468	**1841**	**1852**	**1863**
District has steam engine (%)	5.7 (23.2)	14.3 (35.0)	39.9 (49.0)
Number of steam engines in district (if>0)	2.8 (4.6)	3.8 (7.0)	6.46 (12.0)
Total horsepower (if>0)	35.8 (49.9)	50.2 (90.0)	101.6 (227.7)
District has railroad (%)	3.5 (18.3)	9.6 (29.5)	22.4 (41.7)
Shortest distance to a district with railroad (km)	223.3 (178.9)	112.0 (117.3)	49.1 (64.4)
District on sea shore (%)	4.1 (19.8)		
District has access to navigable river (%)	27.2 (44.5)		
District has access to a major navigable river (%)	19.6 (39.6)		
Steamship-navigable river (%)	9.2 (28.9)		
Access to river and/or railroad (%)	28.9 (45.3)	32.2 (46.7)	39.4 (48.9)
Population ('000)	23.3 (18.3)		
District area (km^2)	440.5 (358.7)		
Density (indiv/km^2)	140.0 (660.5)		
Fuel price (fl per 1m BTU)	1.2 (0.4)		
District on Prussian border	2.2 (14.8)		
District on Saxon border	1.6 (12.6)		
District on Bavarian border	2.7 (16.2)		
District on Swiss border	0.5 (6.8)		
District on Italian border	1.1 (10.7)		
District on Turkish border	3.3 (18.0)		
District on Russian border	2.2 (14.8)		
Note: "Major navigable rivers" are the Danube, Drau, Mur, Sava, Tisza, Maros, Dniester, Elbe, Moldau, Wisla, Po, Adige.			

Table 2 - Diffusion of the steam engine by province

	Percentage districts with a steam engine			Total horsepower in province		
Province	**1841**	**1852**	**1863**	**1841**	**1852**	**1863**
Bohemia	16.3	35.9	63.2	1068	3602	18365
Bukowina	0.0	0.0	12.5	0	0	108
Dalmatia	0.0	0.0	6.5	0	0	28
Galicia	0.6	4.5	20.1	16	194	2308
Austrian Littoral	3.3	13.3	26.7	53	262	841
Carinthia	0.0	0.0	31.0	0	0	1283
Carniola	6.5	12.9	29.0	113	98	285
Croatia-Slavonia	0.0	7.3	32.7	0	43	606
Lombardy-Venetia	0.6	5.0	23.3	96	257	1858
Moravia	20.5	47.4	78.2	570	2185	8769
Military Frontier	0.0	0.0	22.2	0	0	193
Upper Austria	2.1	4.3	27.7	4	14	440
Lower Austria	14.1	22.5	45.1	734	1363	5817
Salzburg	4.8	4.8	9.5	8	3	28
Silesia	21.7	26.1	73.9	199	901	4969
Serbian Voivodina & Banat	2.8	11.1	55.6	12	311	2435
Transylvania	1.2	0.0	7.1	14	0	240
Styria	1.5	9.2	36.9	8	292	3732
Tirol & Vorarlberg	1.3	4.0	8.0	14	13	237
Hungary	2.9	11.2	50.5	102	1002	6876

Source: See Appendix

Table 3 - Sectoral composition of horsepower in 1863, by province				
Province	**Agriculture**	**Mining**	**Industry**	**Public utilities**
Bohemia	64	4356	13755	165
Bukowina	18	12	78	
Dalmatia			28	
Galicia	8	968	1318	14
Austrian Littoral	40		801	
Carinthia		90	1177	16
Carniola		60	197	28
Croatia-Slavonia	58	16	465	
Lombardy-Venetia	1476		439	46
Moravia	11	1720	6973	65
Military Frontier			193	
Upper Austria			238	13
Lower Austria		159	5162	496
Salzburg			28	
Silesia	6	2593	2368	2
Transylvania			240	
Styria		153	3483	96
Tirol & Vorarlberg	0		231	6
Hungary	1603	454	7244	160

Note: Serbian Voivodina & Banat was merged into Hungary by 1863. Some provincial totals may differ from those in Table 2 due to changes in province borders.

Table 4 - Results of probit estimation						
Dependent variable:	**hp1841**		**hp1852**		**hp1863**	
	coeff (s.e.)	**mean mfx**	**coeff (s.e.)**	**mean mfx**	**coeff (s.e.)**	**mean mfx**
1(Prussian border)	0.49 (0.63)	0.031	0.21 (0.33)	0.028	0.30 (0.33)	0.082
1(Saxon border)	1.02 (0.54)	0.066	0.65 (0.35)	0.085	0.17 (0.37)	0.047
1(Bavarian border)	1.01 (0.55)	0.065	1.05 (0.41)	0.137	0.57 (0.32)	0.154
1(Swiss border)	5.90 (850.70)	0.380			0.41 (1.00)	0.110
1(Italian border)					-0.80 (0.65)	-0.218
1(Turkish border)					-0.37 (0.48)	-0.100
1(Russian border)			0.53 (0.61)	0.068	0.03 (0.38)	0.008
1(Provincial capital)	1.58 (0.75)	0.102	1.03 (0.84)	0.134	0.96 (0.70)	0.261
1(Self-governing city)	1.18 (0.55)	0.076	1.92 (0.39)	0.250	0.56 (0.28)	0.152
1(Suburb of s-g city)	0.20 (0.39)	0.013	0.40 (0.28)	0.052	0.25 (0.21)	0.067
Population	0.02 (0.01)	0.001	0.04 (0.01)	0.006	0.04 (0.01)	0.010
Population density	-0.14 (0.18)	-0.009	-0.25 (0.24)	-0.032	0.71 (0.28)	0.194
Distance to RR district	-0.01 (0.02)	-0.001	-0.02 (0.01)	-0.003	-0.01 (0.01)	-0.002
1(District on seashore)	3.87 (357.92)	0.249	-0.31 (0.65)	-0.041	0.27 (0.39)	0.074
1(Access to navigable river)	0.47 (0.49)	0.030	0.30 (0.28)	0.039	0.36 (0.20)	0.097
1(Access to major river)	-0.33 (0.58)	-0.021	-0.44 (0.34)	-0.058	-0.12 (0.22)	-0.033
1(Access to steamship-navigable river)	-0.02 (0.55)	-0.001	0.50 (0.34)	0.065	0.03 (0.24)	0.007
Fuel price	-0.02 (0.36)	-0.001	-0.48 (0.27)	-0.063	-0.08 (0.20)	-0.022
chi2_exog	0.02		1.857		0.074	
p_exog	0.887		0.173		0.785	
N	449		830		1260	
Note: hp1841 stands for total horsepower in district in 1841. Analogously for other dependent variables.						

Table 5 - Results of IV-Tobit estimation				
Dependent variable:	**hp1852**		**hp1863**	
	coeff. (s.e.)	$\frac{\partial E\left[y_i \mid x_i, y_i > 0\right]}{\partial x_i}$	**coeff. (s.e.)**	$\frac{\partial E\left[y_i \mid x_i, y_i > 0\right]}{\partial x_i}$
1(Prussian border)	97.7 26.6	55.308	262.9 46.8	71.310
1(Saxon border)	53.4 27.5	30.218	46.1 55.2	12.504
1(Bavarian border)	89.4 33.2	50.652	25.9 53.1	7.027
1(Swiss border)	-413.9 310000	-234.374	9.0 180.6	2.442
1(Italian border)	-410.4 210000	-232.418	-18.6 96.8	-5.046
1(Turkish border)	52.6 340000	29.765	-93.2 81.6	-25.274
1(Russian border)	40.6 49.8	22.990	66.8 68.8	18.107
1(Provincial capital)	90.4 40.2	51.218	259.1 66.7	70.262
1(Self-governing city)	115.7 23.5	65.532	109.0 37.7	29.556
1(Suburb of s-g city)	49.3 19.0	27.915	24.9 31.2	6.759
Population	1.4 0.2	0.766	3.8 0.4	1.026
Population density	-13.8 5.8	-7.837	-28.7 11.7	-7.780
Distance to RR district	-2.5 0.9	-1.431	-2.3 1.2	-0.625
1(District on seashore)	-14.1 47.2	-8.005	88.1 70.3	23.905
1(Access to navigable river)	16.7 20.9	9.453	49.0 31.9	13.290
1(Access to major river)	-34.8 25.6	-19.689	-25.0 35.4	-6.770
1(Access to steamship-navigable river)	27.7 26.3	15.713	-11.9 37.8	-3.230
Fuel price	-29.6 21.1	-16.767	-43.4 32.9	-11.782
chi2_exog	3.014		0	
p_exog	0.083		0.986	
N	1468		1468	
N censored (hp=0)	1257		883	
Note:				

Table 6 - Comparison of estimation results from various models				
Dependent variable:	**hp1863**	**hp1863**	**hp1863**	**hp1863**
Model:	**OLS**	**simple IV**	**IV-Tobit**	**Spatial IV**
1(Prussian border)	302.0 54.9	304.4 48.3	262.9 46.8	299.8 47.5
1(Saxon border)	26.6 63.8	33.3 56.8	46.1 55.2	31.5 55.3
1(Bavarian border)	-38.9 71.4	-40.4 62.7	25.9 53.1	-38.2 61.5
1(Swiss border)	-26.8 257.8	-33.4 226.4	9.0 180.6	-24.2 226.5
1(Italian border)	40.4 119.4	31.6 105.6	-18.6 96.8	41.7 104.3
1(Turkish border)	-5.6 186.4	7.5 164.8	-93.2 81.6	-17.6 163.3
1(Russian border)	169.1 124.6	187.8 112.9	66.8 68.8	167.7 109.6
1(Provincial capital)	184.8 78.8	175.7 70.5	259.1 66.7	164.6 72.1
1(Self-governing city)	90.8 50.7	82.0 46.4	109.0 37.7	76.9 46.1
1(Suburb of s-g city)	-20.3 37.8	-28.5 35.3	24.9 31.2	-56.0 36.5
Population	3.5 0.5	3.4 0.4	3.8 0.4	3.5 0.4
Population density	-32.8 12.9	-31.1 11.6	-28.7 11.7	-35.2 11.6
Distance to RR district	-1.7 0.7	-2.7 1.6	-2.3 1.2	-1.4 0.6
1(District on seashore)	66.3 101.2	82.6 92.1	88.1 70.3	65.1 84.1
1(Access to navigable river)	-1.9 41.4	-8.1 37.5	49.0 31.9	-1.0 36.1
1(Access to major river)	0.2 47.8	0.9 41.9	-25.0 35.4	-4.9 41.3
1(Access to steamship-navigable river)	-16.1 47.4	-9.3 42.9	-11.9 37.8	-11.3 41.0
Fuel price	-66.1 43.4	-74.6 40.2	-43.4 32.9	-60.7 37.5
λ				0.16 0.06
ρ				-0.15 0.07
R^2	0.395			
N	585	585	1468	585
p_exog			0.986	
chi2_exog			0	
Note: Standard errors are in brackets.				

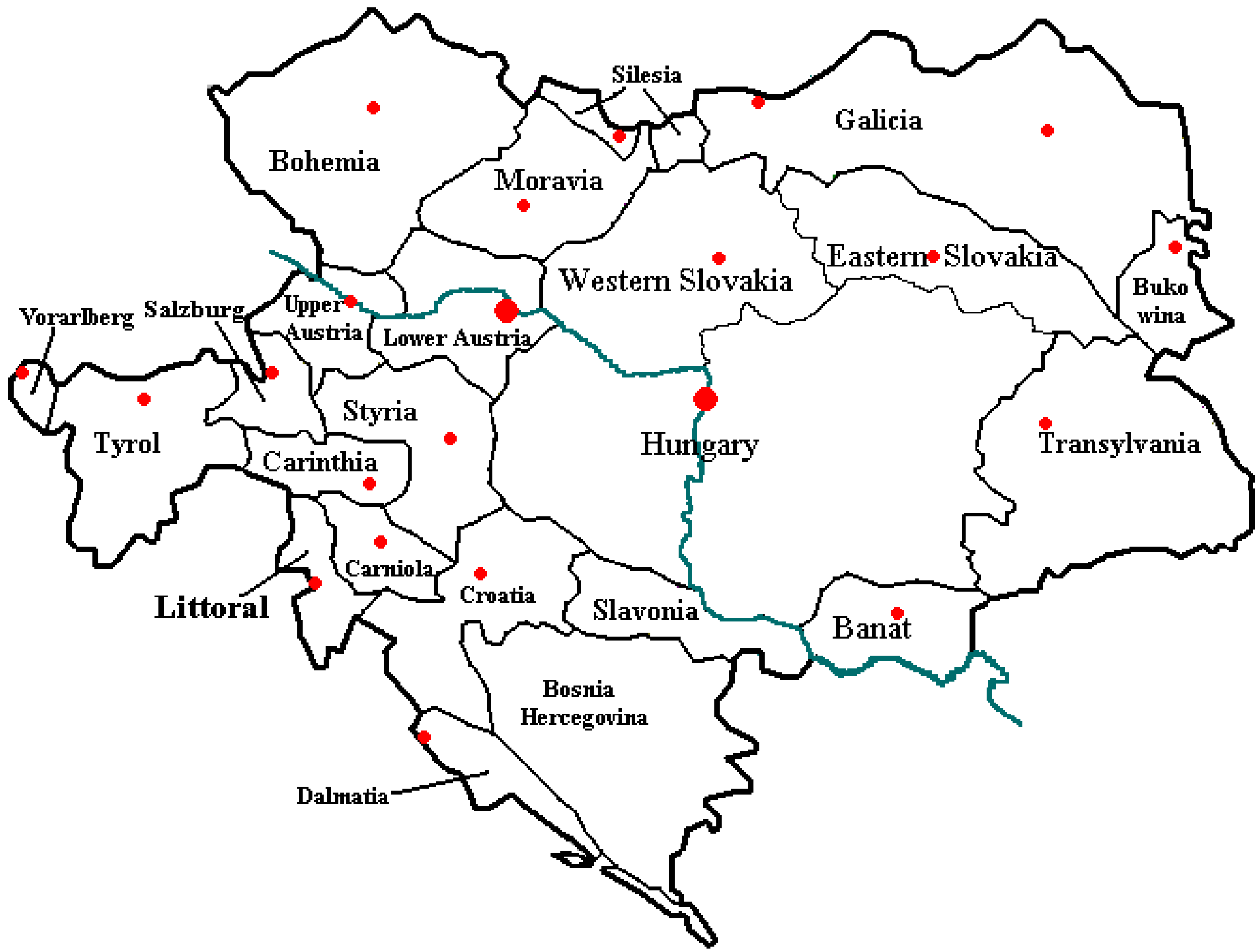
Table 7 - Direct and Indirect effects of explanatory variables, spatial-correlation model

	Direct effect			Indirect effect		
	average	min	max	average	min	max
1(Prussian border)	302.75	299.83	343.34	234.21	76.46	592.58
1(Saxon border)	31.86	31.55	36.13	24.64	8.05	62.35
1(Bavarian border)	-38.54	-43.71	-38.17	-29.82	-75.44	-9.73
1(Swiss border)	-24.43	-27.70	-24.19	-18.90	-47.81	-6.17
1(Italian border)	42.11	41.70	47.75	32.57	10.63	82.42
1(Turkish border)	-17.77	-20.16	-17.60	-13.75	-34.79	-4.49
1(Russian border)	169.39	167.76	192.11	131.04	42.78	331.56
1(Provincial capital)	166.21	164.61	188.50	128.58	41.98	325.34
1(Self-governing city)	77.65	76.90	88.06	60.07	19.61	151.99
1(Suburb to s-g city)	-56.57	-64.16	-56.03	-43.76	-110.73	-14.29
Population	3.57	3.54	4.05	2.76	0.90	6.99
Population density	-35.50	-40.26	-35.16	-27.46	-69.48	-8.97
Distance to RR district	-1.45	-1.65	-1.44	-1.12	-2.85	-0.37
1(District on seashore)	65.74	65.10	74.55	50.85	16.60	128.67
1(Access to navigable river)	-1.03	-1.17	-1.02	-0.80	-2.02	-0.26
1(access to major river)	-4.98	-5.65	-4.93	-3.85	-9.75	-1.26
1(Access to steamship-navigable river)	-11.43	-12.97	-11.32	-8.84	-22.38	-2.89
Fuel price	-61.31	-69.53	-60.72	-47.43	-120.01	-15.49

Note:

Table 8 - Predicted direct and indirect effects on HP in 1863 and their comparison					
Panel A: Top 10 self-made districts					
Province	**District**	**Total direct effect**	**Total indirect effect**	**Total impact from outside**	**Observed HP in 1863**
Lower Austria	Vienna	1522.41	1770.54	-22.36	1750
Hungary	Buda-Pest (City)	761.20	560.02	0.20	1607
Austr. Littoral	Triest	450.35	250.91	-1.76	453
Galicia	Lwiw (City)	335.16	114.05	0.90	124
Styria	Graz (City)	328.87	441.89	12.40	544
Carniola	Ljubljana (City)	268.18	312.85	-5.60	139
Moravia	Brno (City)	264.05	456.08	4.50	1326
Croatia	Zagreb (City)	240.26	269.45	-22.54	60
Banat	Timisoara (City)	235.08	118.22	5.58	164
Venetia	Padua	225.66	118.97	-4.27	18
Panel B: Top 10 districts with greatest impact on neighbors					
Lower Austria	Vienna	1522.41	1770.54	-22.36	1750.00
Hungary	Buda-Pest (City)	761.20	560.02	0.20	1607
Moravia	Brno (City)	264.05	456.08	4.50	1326
Styria	Graz (City)	328.87	441.89	12.40	544
Silesia	Troppau (City)	212.14	321.92	134.61	204
Carniola	Ljubljana (City)	268.18	312.85	-5.60	139
Croatia	Zagreb (City)	240.26	269.45	-22.54	60
Austr. Littoral	Triest	450.35	250.91	-1.76	453
Carinthia	Klagenfurt (City)	140.53	172.20	-10.78	6
Hungary	Debrecen (City)	153.45	156.27	30.81	64
Panel C: Top 10 beneficiaries of outside impact					
Galicia	Jaworzno	-22.63	284.10	481.87	835
Silesia	Troppau (suburb)	-19.41	491.13	438.19	238
Silesia	Bielitz	45.08	342.74	369.53	390
Silesia	Biala	48.60	345.78	368.96	159
Bohemia	Friedland	6.45	267.34	333.03	97
Moravia	Mahrisch-Ostrau	7.04	279.66	324.54	1832
Silesia	Oderberg	13.11	270.22	323.62	2161
Bohemia	Schatzlar	-87.15	187.35	320.69	172
Silesia	Konigsberg	-11.29	279.03	320.68	28
Silesia	Freistadt	30.10	274.73	319.80	504
Note: In each panel, districts are ranked according to the values in the column that is shaded. Border effects are included under "Total impact from outside".					

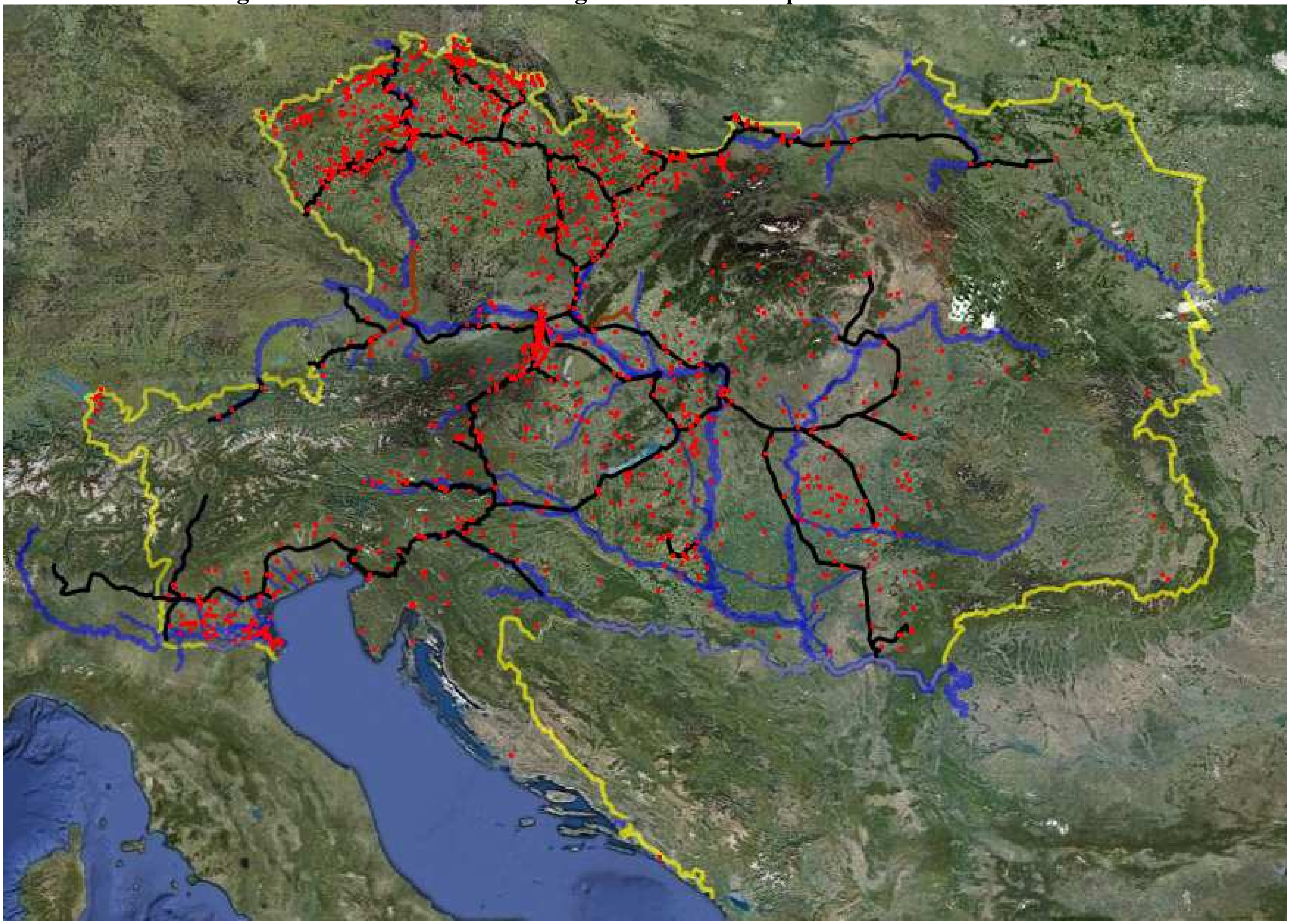
Figure 1 – Map of the Habsburg Empire in its 1914 borders



Province	**Capital**
Lower Austria	Vienna
Upper Austria	Linz
Salzburg	Salzburg
Tyrol	Innsbruck
Vorarlberg	Bregenz
Styria	Graz
Carinthia	Klagenfurt
Carniola	Ljubljana
Littoral	Trieste
Bohemia	Prague
Moravia	Brno
Silesia	Opava
Galicia	Lwow
Bukowina	Czernowitz
Dalmatia	Zadar
Hungary	Budapest
Transylvania	Cluj
Western Slovakia	Nitra
Eastern Slovakia	Košice
Croatia	Zagreb
Slavonia	Osijek
Banat	Timisoara
Bosnia-Hercegovina	Sarajevo

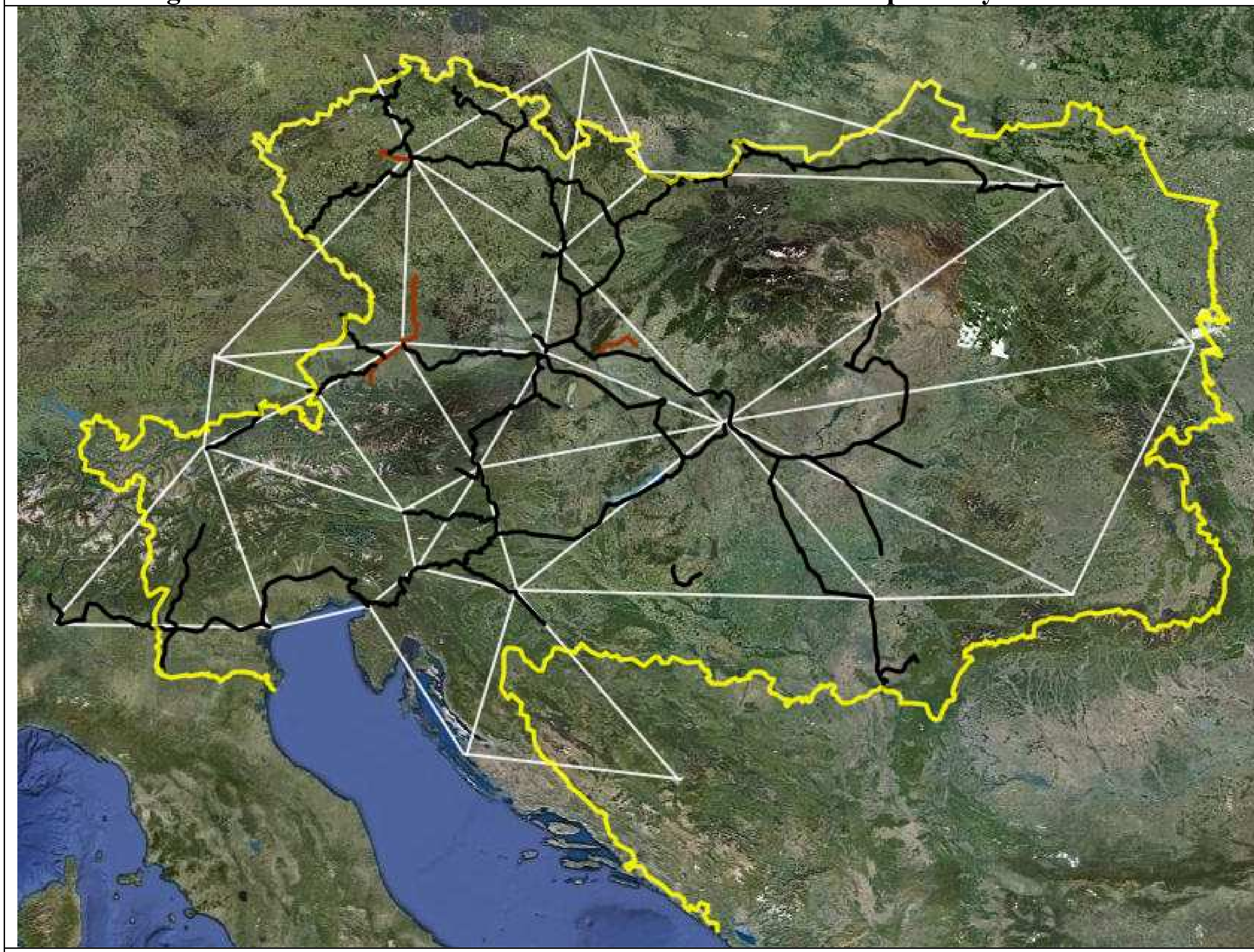
Note: Not all provinces were in existence at all times. Bosnia-Hercegovina was an Austrian protectorate between 1878 – 1908, after which it was annexed. Source: Wikimedia commons.

Figure 2 – Locations of steam engines and the transportation network in 1863



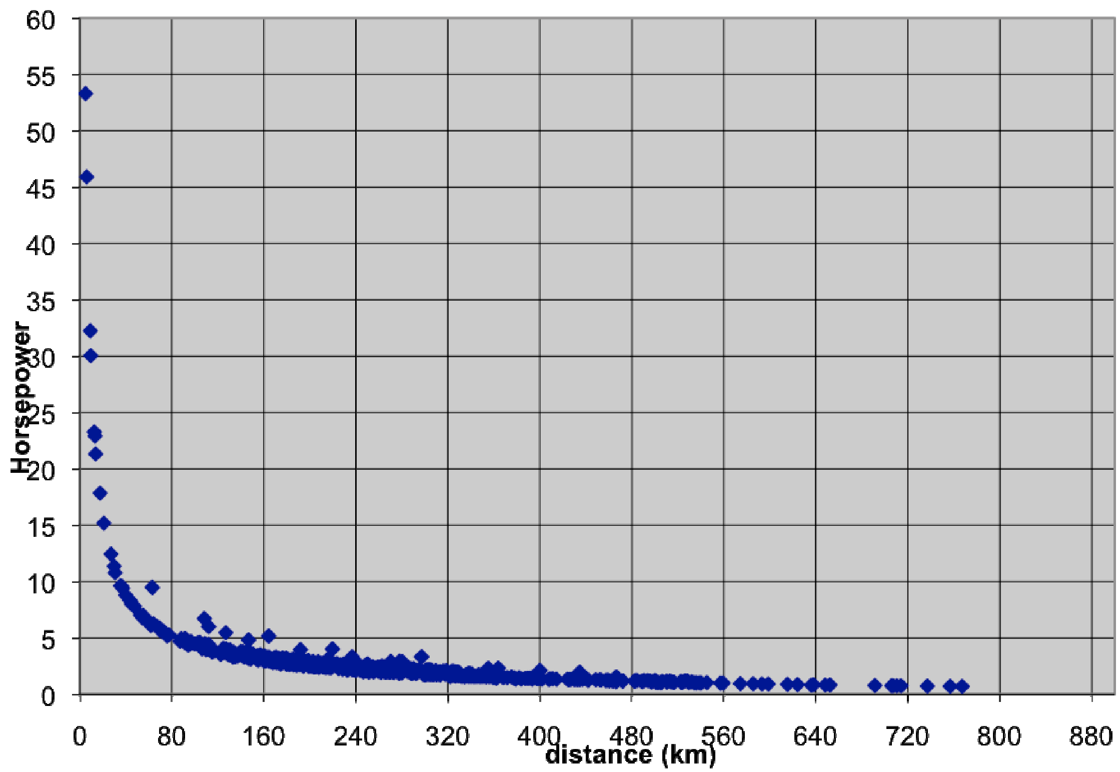
Note: Railroads are black, rivers are blue, steam engine locations red and borders yellow. Some railroads –the horse-drawn kind -are in brown, they were all converted to steam power by 1860.

Figure 3 – Railroad network in 1863 and its instrument – capital city connectors



Note: White lines connect provincial capitals "as the crow flies". Black and brown lines and curves are railroads as of 1863. Yellow is the border of the empire as of 1863.

Figure 4 – Distribution of Vienna's predicted indirect effect on other locations by distance



Note: See text for explanation.