If you build it, will they come? Using historical development patterns to better anticipate future development scenarios for cumulative effects assessment

by

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If you build it, will they come? Using historical development patterns to better anticipate future development scenarios for cumulative effects assessment

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Abstract

In Canada and the United States, as in many other jurisdictions worldwide, environmental impact assessments required as part of the permitting process for proposed resource development projects include cumulative effects assessments. These aim to predict a proposed project's environmental impacts in combination with those of past, present, and future projects. This last category of projects has been problematic for analysts. Detailed information about future projects is usually scant, and this limitation is often cited as a justification for excluding future projects from consideration. Conversely, a more speculative approach to estimating the potential economic benefits of future projects is widely accepted. Thus, the authorities responsible for permitting projects are often given restrictive assessments of environmental impacts and optimistic assessments of economic benefits.

The goal of this dissertation is to introduce a practical approach to balancing the asymmetry described above—a method for considering induced development in CEA in order to give potential environmental impacts the same weight that potential economic benefits currently receive. To do this, I use the historical record to discern patterns of development that followed infrastructure. I do so in a specific geographic context and so develop empirical evidence of how projects build on top of preceding projects' legacy of proximate services, labour, water and energy supplies, and routes to market. I then use this evidence to forecast the probable outcomes of permitting a proposed project in terms of likely future induced development. The initial iteration of the method uses British Columbia as a case study, and makes use of data on that province's historical development. This first iteration is intended as a means of exploring and

demonstrating the method’s value in a specific application, while providing a framework that can be refined and applied to other contexts.

Lay Summary

Many governments require a study called a cumulative effects assessment when a resource project is proposed. This study's goal is to predict how a project's environmental impacts might combine with those of past, present, and *future projects*. This last category is difficult to include, because details about future projects often do not exist. For this reason, analysis of future projects is a weak spot in cumulative effects assessments.

This thesis introduces a new way to include future projects in cumulative effects assessment. I argue that we can look at the history of a region to see if building certain types of projects is linked with building other types of projects nearby at a later date. If we can identify historical patterns, we can use them to help forecast what future projects are likely to be built. I show how this method could be applied using the example of British Columbia.

Preface

I designed the research described in this manuscript with valuable contributions and advice from Hadi Dowlatabadi. I assembled most of the data used in this research from publicly available government sources and databases or solicited them from the original collectors (as described in detail in Chapter 4), with the exception of the data collected from British Columbia Environmental Impact Studies (discussed in Chapter 7), which were collected by Francis Dowlatabadi under my supervision. I performed the analysis described in Chapters 5, 6, and 7 with guidance from Hadi Dowlatabadi and technical advice from Seong-Hwan Jun. I wrote the manuscript itself with editorial feedback and many suggestions from Hadi Dowlatabadi, Bram Noble, and Terre Satterfield.

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Acknowledgements

(This will be long; I've bolded names so you can more easily skim to the part that's about you.)

Thank you first to my committee: Hadi Dowlatabadi (who we'll get to in a minute), Bram Noble, and Terre Satterfield. I will one day get over giddily fan-girling that **Bram F. Noble** is on my PhD committee, but today is not that day. Thank you Bram, for cogent and thoughtful ideas on how to steer this thesis and for bringing your thorough understanding of cumulative effects assessment, in practice and in theory, to bear. Many thanks must also go to **Terre Satterfield**, for encouraging me in directions I would not have considered, for making me think more clearly and practically about environmental impact assessment while still keeping an eye on necessary academic objectives, and for welcoming me into graduate school in the first place!

I've had trouble writing anything about **Hadi Dowlatabadi** that doesn't sound like boilerplate thesis acknowledgement hackery or a eulogy. This is my best run at it: Hadi is my supervisor, my mentor, and my friend. He can tell immediately when I don't know what I'm talking about, and never hesitates to share that observation with me. To forestall this from happening, I've been forced to think much harder and more reflexively than I would have otherwise. This is not to say that Hadi is hypercritical. On the contrary, he always seems to have massive confidence in me, and I can't tell you how onerous and annoying it's been to try to live up to that confidence over the years. He has the ability to spin on an intellectual dime and vanish in a puff of smarts, but will continually insist, with apparent sincerity, that *he* is the one having trouble keeping up. Either he is delusional or he is right about me, and while I haven't yet come to a definitive

conclusion on that point, the intervals in which I've thought his belief in me at least partially justified have been wonderfully sustaining. Thank you, Hadi, for everything.

I am very grateful to the Social Sciences and Humanities Research Council, the University of British Columbia, and the National Science Foundation Center of Excellence in Climate and Energy Decision-Making at Carnegie Mellon for providing generous financial support while I was completing this research. In particular, the Vanier Graduate Scholarship program made things a *lot* easier for me at a key moment.

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Many thanks to my dear friend and fellow student, **Gerald Singh**, who I've summoned to my aid countless times to answer abrupt and often terribly vague questions by spamming his name in a chat window. *Gerald Gerald Gerald what is that word for when you sort of double-count things? Gerald Gerald Gerald is there any actual point in providing people with Pearson's r correlation co-efficients in a tabular form?* Thank you for your patience and for always trying to give me an answer even when I gave you only the spindliest bones of a half-question. Gerald Gerald Gerald you're a shining star, and one day your buffness will block out the sun; I know that idea probably

appeals to you, but just sit with it awhile G, and consider the implications to the children and the canola fields and things.

Thank you to my lovely mother, **Judy Lerner**, for personifying strength in the face of adversity and for being the first to cheerlead me in any endeavour. This page would be incomplete without also remembering my father, **Jeff Lerner**, who gifted me with two superpowers: (1) chill, and (2) the curiosity and drive to teach myself new skills as a means to an end. Thank you to **Joanna Wen** for being the very best of kid sisters—for acing the role of sisterhood to such an extent that I honestly can't think of a better one. I mean, was Amelia Earhart a good sister? No one ever mentions it. But you are sisterly perfection: hilarious, giving, quick, elegant, kind.

Jordan Tam abhors any indication that he's better than average and so I will just thank him for being my partner in every sense of the word. Actually, I just consulted an online thesaurus and I would not describe you as my *co-worker*, but in every other sense. Maybe also I would exempt *associate.*

Finally, thank you to my sweet daughter, **Fiona van der Eerden**, for believing that I was somehow saving the planet with my brain when she was just a wee girl, and for persisting in thinking that my work is pretty important (though super boring) now that she's older and more circumspect. You make me proud every day, my Fi.

Chapter 1: The asymmetrical treatment of the ecological and economic impacts of induced development in environmental impact assessment

> It's all the stuff that we're not allowed to talk about, that we know is coming when they build this line. They build this line, that opens the door for industry to say, "Well, they already built the line. You've got to let us do our tie-ins now." What was the point of letting them build the line? It feeds to their objective of development. We understand that. **But we need to assess that.**
>
> —Chief Roland Willson, West Moberly First Nation, presenting evidence relating to the Dawson Creek/Chetwynd Area Transmission Project (British Columbia Utilities Commission 2012, 518; emphasis added)

1.1 Introduction

The purpose of environmental impact assessment is to provide decision-makers with a reliable account of the environmental risks associated with a proposed project, to enable them to weigh a project's benefits—usually economic ones—against its ecological consequences. A key component of environmental impact assessment is to look beyond impacts that will be caused solely by a proposed project to those impacts it will produce in concert with other past, present, or future human activities and natural disturbances. These impacts are known as *cumulative effects*, and the associated analysis as *cumulative effects assessment*, or CEA.

Within the context of environmental impact assessment, CEA contemplates the many ways the impacts of development may be magnified (or attenuated) within the real-word context, where they will almost certainly cross paths with the stressors associated with natural and other anthropogenic drivers. Accurate prediction of the environmental impacts of one isolated project is itself a daunting task. Factoring other human activities into the analysis—particularly those that will occur in the future and thus may not be well-defined in the present—adds to the already considerable complexity and uncertainty. However difficult, such context is critical to proper assessment (Greig, Pawley, and Duinker 2004; Duinker et al. 2012).

A sub-category of future projects that may be considered in CEA is *induced development*: that is, additional projects or other human activities that are enabled by the project being proposed (Tidd et al. 2013). Induced development may result from the increased demand for inputs "upstream" of a proposed project or the increased feasibility of activities in parallel or "downstream." For example, consider a proposal to build a new natural gas pipeline. Additional exploration and drilling activities may be needed in order to keep the pipeline supplied with product (upstream), and easy access to a supply of gas may allow other industrial works to proceed along the pipeline route (downstream). Similarly, the supply of electricity to one mine may shorten the length of the transmission infrastructure required for another potential mine.

The need to consider induced development is recognized in some of the earliest literature on CEA and, as discussed later in this chapter, is supposed to be included in assessments conducted in Canada and the United States.

1.2 A taxonomy of Cumulative Effects Assessment

Much recent literature (e.g, Noble and Harriman 2008; Bragagnolo and Geneletti 2012; Bragagnolo, Geneletti, and Fischer 2012; Du et al. 2012) broadly conceptualizes approaches to CEA as either project-level or regional. *Project-level approaches* focus on an individual project or group of projects, while *regional approaches* attempt to systematically address cumulative effects at the planning level, typically over a larger area. Regional approaches do not replace the need for project-level approaches; rather, the two can complement one another, incorporating environmental concerns at multiple levels of decision-making, with regional approaches addressing the implications of decisions made above the individual project level (Partidário 2000). Regional approaches are sometimes described as being proactive, while project-level approaches are thought of as reactive (Vicente and Partidário 2006). The limitations of project-level approaches are broadly acknowledged, particularly their inability to sufficiently address cumulative effects (Dubé 2003; Duinker and Greig 2006; O'Faircheallaigh 2007; O'Faircheallaigh 2010; Parkins 2011), and there is wide consensus that a shift towards a strategic, regional approach to cumulative effects management is needed (e.g., Partidário 1996; Noble and Harriman 2008; CCME 2009; Gunn and Noble 2009; Wärnbäck and Hilding-Rydevik 2009; Johnson et al. 2011; Seitz, Westbrook, and Noble 2011; Fidler and Noble 2012; Gillingham et al. 2016; Noble and Nwanekezie 2017). However, most study of cumulative effects worldwide is currently undertaken at the project level, as a component of environmental impact assessments conducted for individual project permitting.

CEA approaches can also be classified another way, as *effects-based* methods, which monitor the response of the environment to anthropogenic and natural disturbances, and *stressor-based* methods, which model the drivers of disturbances and postulate the resulting environmental effects (Dubé 2003; Noble 2015). Effects-based methods are valuable because they provide a direct measurement of the real-world state of environmental components, inherently encompassing the cumulative effects of all stressors. However, any changes detected reflect an impact that has already occurred, forcing management to occur reactively. Use of this information for planning purposes is also made difficult because many cause-effect linkages are poorly understood. In addition, monitoring of effects-based indicators tends to be data intensive and highly context-specific (Dubé 2003). Stressor-based approaches are simpler to implement—as drivers can be more easily counted and measured—and can be proactively linked to management actions. However, incomplete understanding of cause-effect linkages also impairs analysts' ability to fully predict the effects produced by stressors. Stressor-based approaches tend to be limited in terms of their spatial and temporal scope, and thus are difficult to apply to regional assessments (Dubé and Munkittrick 2001). The two approaches can benefit from one another, with the accuracy of an initial prediction produced with stressor-based methods being subsequently tested and improved upon using effects-based methods (Dubé and Munkittrick 2001). In current practice of project-level CEA, stressor-based approaches are generally used in anticipatory exercises such as environmental impact assessment, while effects-based approaches are used in follow-up monitoring and management.

Broadly speaking, project-level approaches to CEA tend to contemplate the potential stressors associated with an individual project proposal and how those might interact with the stressors produced by other projects, while regional approaches consider the capacity of a region and the combined effects of all stressors in order to support decision-making.

1.3 The environmental impacts of induced development

1.3.1 In Canadian legislation, policy, and practice

Current Canadian federal legislation, in the form of Section 19(1)(a) of the *Canadian Environmental Assessment Act* (2012),[1] mandates that CEAs take projects that "will be carried out" into account. Unfortunately, it does not specify how these future projects are to be identified. As Greig and Duinker (2007, 5) point out, this ambiguity leaves analysts "in the awkward position of trying to predict the future, which is virtually impossible."

In the absence of more prescriptive legislation, CEA analysts can consult official operational policy and guidance documents prepared by the Canadian Environmental Assessment Agency (CEAA). The Agency's current operational policy statement advises that CEAs should represent the "most likely future scenario" by including projects that are "certain" or "reasonably foreseeable" (CEAA 2015, 5). The criteria for identifying these two categories of future projects, found in CEAA's current guidance document, are closely tied to permitting: *certain* projects have already received or are partway through the process of obtaining permits, while *reasonably foreseeable* projects have initiated permitting (Hegmann et al. 1999, 18–19).

The latter category includes projects with or without a direct relationship with the proposed project, which "may proceed if the [proposed project] is approved" or ones that are "conditional

[1] The Government of Canada plans to replace the *Canadian Environmental Assessment Act* (2012) with a new *Impact Assessment Act* under Bill C-69 (see Section 2.5). This new Act will still require consideration of cumulative effects.

on the [proposed project's] approval," termed *induced* projects (Hegmann et al. 1999, 19–20). The guidance explicitly notes that the "growth-inducing potential" of such projects can add to cumulative effects (Hegmann et al. 1999, 6). Similarly, draft guidance (updated to reflect the 2012 changes to the Act but still under review at the time of writing) describes induced projects as reasonably foreseeable, defining them as those projects that "the completion of the [proposed] project would facilitate or enable," or whose economic feasibility is contingent on the proposed project (CEAA 2018, 26).

The previous version of this guidance document also includes a third category—"hypothetical"—comprising situations where there is "considerable uncertainty" whether a future activity will ever proceed, and where only "a conjecture […] based on currently available information" is possible, suggesting that these projects also be included in CEAs "where appropriate" (Hegmann et al. 1999, 20–21). This third category of future project has been removed from the updated guidance. (This thesis will argue that it is possible to re-introduce these sorts of projects in CEA without engaging in highly speculative conjecture, but rather on the balance of probabilities estimated from past patterns of development.)

As noted earlier, Canadian policy and guidance has instructed practitioners to consider induced projects for over fifteen years, and appears poised to continue to do so in the future. In practice, however, these types of projects are rarely considered in Canadian CEAs. Indeed, only projects that would be considered *certain* according to the definitions above—projects that have either received permits or are in an advanced state of permitting—are generally included (Greig and

Duinker 2007). Occasionally, CEAs note that as there is much uncertainty about the exact nature of other future projects, their effects are impossible to assess, and suggest that such projects will be expected to adopt measures to reduce or eliminate cumulative effects, when and if they are approved and built. If regulatory agencies are dissatisfied with this apparent failure to adhere to federal guidance, it does not often manifest as a rejection of the project's permit application.[2]

1.3.2 In American legislation, policy, and practice

In the United States, consideration of "growth inducing effects" that are "reasonably foreseeable" is explicitly required by Section 1508.8(b) of the *National Environmental Policy Act* (NEPA 1969), as well as in guidance documents (United States Council on Environmental Quality 1997; also see Stanley 2006). As in Canada, neither NEPA nor related guidance documents specify the methods that should be used to identify induced development (Ewing and Bartholomew 2009). In what seems like a profoundly unhelpful tautology, reasonable foreseeability is consistently defined in guidance, white papers, and case law as "sufficiently likely to occur that a person of ordinary prudence would take it into account in reaching a decision" (e.g., The Louis Berger Group Inc. and National Cooperative Highway Research Program 2002; Prahler et al. 2014; Mandelker 2014; Mid States Coalition for Progress v. Surface Transportation Board 2003).

Thus, government agencies and courts still do not have concrete criteria for determining which

[2] There are notable exceptions; Ehrlich (2010) and Greig and Duinker (2007) discuss some examples from processes overseen by the Mackenzie Valley Impact Review Board, which would seem to have resulted from the more stringent requirements established by the *Mackenzie Valley Resource Management Act*.

projects must be considered, which has led to absent or inconsistent treatment of induced development in regulatory and legal proceedings (Mandelker 2010 and 2014; Moore, Allen, and Forman 2009). Some legal appeals of environmental impact assessments that did not include induced development have failed, with courts finding the requirement too speculative (The Louis Berger Group Inc. and National Cooperative Highway Research Program 2002).

On other occasions, federal courts have held that environmental impact assessments that failed to address induced development impacts were in violation of NEPA. In these cases, the proposed projects were major pieces of transportation infrastructure: typically highways (The Louis Berger Group Inc. and National Cooperative Highway Research Program 2002), but also airports (e.g., Carse 2012), water channels and ports (e.g., Moore, Allen, and Forman 2009), and railways (Sheargold and Walavalkar 2013). Mandelker (2010; 2014) suggests that government agencies should strengthen decision-making in this area and develop coherent criteria for determining when to include induced development in CEAs under NEPA.

1.4 The economic impact of induced development

Thus, while the potential for induced development to produce environmental impacts is often a required consideration in Canadian and American CEAs, in practice, it is largely missing in Canada and is inconsistently addressed in the United States. The potential for projects to induce future human activity is not entirely absent from environmental impact assessments, however. One can find it in most assessment documents, though not in any analysis of cumulative effects. Rather, induced impact is routinely accounted for as part of a project rationale or justification, and associated with its economic benefits.[3] Uncertainty does not appear to be a barrier to analysis here.

Analysts employ well-known macroeconomic methods to estimate the impact of an activity on an economy, with the largest impacts felt from the direct spending associated with the activity, and diminishing ripples of new spending occurring due to secondary or tertiary changes catalyzed by the activity. The application of these methods to estimate the potential "spin-off" or "knock-on" jobs, tax revenues, and business and development opportunities has long been a fixture of environmental impact assessment documents (James 1994; Leistritz 1994; Weisbrod and Weisbrod 1997; Gillespie and James 2002; Government of British Columbia 2007a; US EPA 2014; BC EAO 2015).

While these economic impact study methods are well-established and widely accepted, they have a controversial reputation. Outside the environmental impact assessment domain, many have argued that these studies do not provide a particularly exact or irrefutable measure of a proposed project's future economic impacts. Crompton (1994, 33) quotes experienced practitioners in this field as saying, "if you pick five consultants, you'll get five different numbers," and describing economic impact studies as "an inexact science." In addition, as Crompton (2006, 1) observes, these studies are often commissioned "to legitimize a political position rather than to search for

[3] Unlike the formal framework in the United States stipulating that the benefits of an initiative outweigh its costs (per Executive Orders 12866 and 13563), there is no systematic approach to evaluating costs and benefits in environmental impact assessment in either the United States or Canada.

economic truth," a factor that often results in the production of "large numbers that study sponsors seek to support a predetermined position."

Despite these limitations, the legitimacy of economic impact analysis's place in environmental impact assessment goes unquestioned, and indeed, it is not my intention to question it here. Assuming economic impact analysis is performed competently and interpreted cautiously and with integrity, it can provide a useful first-order approximation of the likely economic effects of a project. My concern is rather with our apparent comfort with uncertainty in estimates of economic benefits, in contrast to the high level of certainty we demand before we even acknowledge concomitant environmental impacts. The obvious risk inherent in this practice is that decision-makers charged with approving or rejecting a proposed project are habitually provided with cooked books: inflated tallies of economic gains accompanied by an understated evaluation of environmental consequences.

It is not surprising that accepted methods for modelling induced economic impacts exist, while equivalent environmental impact models do not. Economic benefits can be measured using familiar indicators (i.e., investment and employment); measuring environmental damage is much more complex, involving a vast suite of interdependent variables located across a broad spectrum of biophysical and socio-cultural disciplinary domains. Nevertheless, the difficulty of the task is not an adequate rationalization for shirking it.

As previously mentioned, Canadian and American laws do not mandate the use of any particular methodological approach to identifying induced future developments in CEA. However, both

CEAA (explicitly) and NEPA (implicitly; see Kleiss 2003) require governments to exercise their powers in a manner that applies the *precautionary principle*, which states that where there is a risk of serious or irreversible harm from a particular activity, the absence of full scientific understanding or certainty about the cause-and-effect relationships at play should not be used as a justification for inaction (Government of Canada 2003). According to this principle, it is precisely in instances like this, where we recognize a gap in our knowledge or understanding of environmental risk, that we are obligated to exercise the greatest amount of care and attention. Instead, we appear to be doing the opposite: using a lack of certainty as an excuse for ignoring an issue completely.

My own professional experience writing and reviewing over thirty environmental impact statement (EISs) for Canadian and international projects is that typical CEAs only include future projects that are in the late stages of permitting, with the result that the temporal cut-off for inclusion in a CEA is approximately the same as the usual timeframe for major project permitting: around two years, or five years at the outside. Some proponents (e.g., Western Canadian Coal 2005, 6; Kruger Energy 2009, 8–5) explicitly note this five-year window as being standard practice. Most major developments have lifespans—and produce cumulative impacts—that last decades or longer. Other elements of EISs include predictive models, analyses, and plans that contemplate the whole of the project's life, but current practice seems content with a much narrower view of future development and its implications on CEA.

To further illustrate the manner in which current practice in CEA seems to close its eyes to the reality of induced development, I present a case study from a recent environmental impact assessment of the Northwest Transmission Line in British Columbia, Canada.

1.5 Case study: The Northwest Transmission Line Project

In the fall of 2008, the Province of British Columbia announced the start of the regulatory process for the proposed Northwest Transmission Line (NTL) Project—a nearly 350-kilometre powerline connecting areas of northwest BC to the BC Hydro power grid. In its press release, the government made note of the project's potential "to generate billions of dollars in capital investment, create thousands of new jobs and open economic opportunities on a global scale in the Northwest" (Office of the Premier of British Columbia 2008), citing an economic impact study commissioned by the Mining Association of British Columbia (MABC 2008).

The MABC report had not only considered induced developments in its calculations, it had even cautioned against the dangers of ignoring them:

> In undertaking the cost-benefit analysis for the NTL project, the potential benefits that need to be assessed include ones that are difficult to quantify and/or involve significant uncertainty. In the financial evaluation of projects, potential returns can be underestimated by not taking into account their "option value" once a project is built, which often makes possible other projects that were previously unknown or considered uneconomic. (MABC 2008, 18)

BC Hydro[4] submitted an Environmental Impact Statement to the British Columbia Environmental Assessment Office (BC EAO) two years later (BC Hydro 2010a). The proponent's discussion of the NTL Project's potential benefits echoed the sentiments of the Premier's announcement and the MABC report, strongly emphasizing the project's capacity to induce development, and the associated windfall to the regional economy:

> Northwestern BC has substantial mining potential […] Without low cost grid power, the number and scale of mines would be limited. In addition, mines could produce many jobs during construction and operation. Mines have one of the highest employment multipliers of all industrial activity. Projects that could become viable as a result of access to grid power could more than offset the expected loss of jobs in the region caused by the anticipated closures of the Eskay Creek and Huckleberry mines. […] A transmission system extended to northwestern BC would open the opportunity for [independent power producers] to develop projects and deliver power through the grid. Such generators would be able to sell their output to BC Hydro, large industrial customers in BC, or other wholesale suppliers or markets. Such projects could also produce long-term, highly skilled, well-paying employment (BC Hydro 2010a, 1–23).

In response, the BC EAO initiated a standard 45-day review period, during which the agency collected hundreds of comments from the Nisga'a Nation and First Nations, industry, the public, and other government agencies. Opinions on the merits of the project were certainly mixed, ranging from vehement opposition to whole-hearted support.

[4] The proponent for the NTL Project was originally the British Columbia Transmission Corporation (BCTC), a crown corporation and separate entity from BC Hydro that was re-integrated by the time the public review began in 2010. To avoid confusion, I refer to the proponent as BC Hydro throughout this chapter.

However, as shown in Table 1.1, both opponents and supporters were in agreement on one thing: building the new transmission line was likely to set off a flurry of new development in the region.

Table 1.1. Selected comments on the Northwest Transmission Line Environmental Impact Statement.

Reviewer	Comment excerpt (emphasis added)
Nisga'a Nation and First Nations comments	
Tahltan First Nation (Rescan 2010)	The NTL is **the gateway to future mining development** in the territory (with both positive/negative impacts).
Nisga'a Lisims Government (BC Hydro 2010b, 26)	The NTL is **an enabling line which will actually make the development of projects more likely** by bringing grid power to the Northwest part of the Province. […] In fact, that is the publicly stated goal of the Provincial government in promoting the NTL project.
Industry comments	
NovaGold Resources Inc. (Rescan 2010)	Development of the NTL will foster critical economic development. […] **The ability to tie into the NTL will increase the viability of a number of resource projects in the region.**
Northern Metals (Rescan 2010)	We as a province and a country should be doing everything we can to foster industry and this project will do just that. **It will make the potential mines economically viable and bring growth to the whole Northwest.**
Public comments	
Campbell Stewart, Terrace (Rescan 2010)	Power is nothing less than vital infrastructure that will draw investment in the mining sector, creating jobs and resulting in cascading economic benefits throughout the region. **The proposed Northwest Transmission Line is a classic example of, "If you build it, they will come.**" We know there are proven mining developments ready to build - they just need power to bring these developments to fruition.
Kam Siemens, Terrace (Rescan 2010)	This project is clearly **the foundation required to fuel other major investment opportunities in the North**.
Josette Wier, Smithers (Rescan 2010)	Looking at the environmental impact of "the line" outside the implications for **the gold rush in the north which it will foster** is absurd. […] To look at the consequences of the line on the environment, one has to include all the environmental impacts of huge mines going at once, including acid-mine drainage, toxic tailings, increased greenhouse gas emissions and increased truck traffic disturbing long stretches of wilderness.
Government agency comments	

Reviewer	Comment excerpt (emphasis added)
Regional District of Kitimat-Stikine (Rescan 2010)	The Northwest Transmission Line (NTL) is a very good example where direct project impacts might not be significant but, by substantially altering the economics of mining and power development, **might bring about several other major projects** in the region.
BC Ministry of Environment (Rescan 2010)	The most significant cumulative effects will be **from future projects enabled by the NTL**. […] Cumulative effects from **offspring projects** over the next 50 years plus is the biggest issue involving the construction of this line as it pertains to impacts on environmental values.
BC Ministry of Environment (Rescan 2010)	The NTL, and the Galore Creek and KSM mine infrastructure (road, pipelines, mill, etc.) **will enable numerous projects in this area**. Many of these are below EAO thresholds.

Thus, the proponent, the government, industry, First Nations, and the public seemed to be in complete agreement that the NTL Project was highly likely to induce development. However, this broad consensus was not reflected in the CEA.

Under the BC EAO's terms of reference for the CEA, BC Hydro was required to consider "past, present and *imminent* relevant projects" and to explicitly provide the criteria for including or excluding relevant projects (BC EAO 2009, 10–1, emphasis added). The BC EAO listed six mines and one independent power producer as potential candidates for relevant projects. However, in its original CEA, BC Hydro only took three future projects into account: two mines and one independent power producer, using the criteria for selection that projects should be "at least as foreseeable as the NTL Project itself" (BC Hydro 2010b, 2–1). At the behest of regulators, the proponent later submitted a supplementary CEA that included five additional mines. BC Hydro strongly objected to being required to take this approach.

> The ability to successfully assess the magnitude and likelihood of potential residual effects becomes less and less reliable as more speculative future projects are taken into account. […] In order to conduct a supplemental CEA that takes into account the five additional potential mining projects […] BC Hydro is in the position of having to assume incorrectly that those projects are at least as likely as the NTL Project to proceed and that, consequently, they are as likely to result in residual effects. This assumption does not increase the reliability of the information about potential residual effects of those potential projects and, as a result BC Hydro is not confident in this analysis (BC Hydro 2010b, 2-1 to 2-2).

The proponent’s characterization of the five additional projects as “speculative” relative to the NTL Project is arguable, as all five had entered into the same regulatory process. Three of the five mines had also announced their intention to use the new NTL Project as their main power source.

Regulators granted the NTL Project its environmental impact assessment certificate in February of 2011, and the transmission line was powered up in the summer of 2014. By that time, BC Hydro’s confidence in the non-speculative growth-inducing potential of its project had been renewed: the corporation confidently blogged about its expectations that “with the transmission line in place, 10 new mines will be developed and seven independent power projects will be able to deliver clean energy back[5] to BC Hydro's electrical grid” (BC Hydro 2014).

[5] The use of the word “back,” implying that the NTL Project was somehow enabling the recovery of energy that belonged to the power system to begin with, is an odd choice.

1.6 Research objectives and structure of the dissertation

Many scholars and practitioners have called for a new approach to CEA that would better address the question of induced development. Several authors, including Baxter, Ross, and Spaling (2001), Duinker and Greig (2006), Greig and Duinker (2007), Hegmann and Yarranton (2011) and the Canadian Council of Ministers of the Environment (CCME; 2009) have suggested the creation of scenarios of future development alternatives as a solution (this topic is more thoroughly explored in Chapter 3). The sentiment was also notably echoed by the International Finance Corporation (2013). However, there has yet been no agreement on a specific approach to deriving future development scenarios for CEAs, though some attempts have been made at tackling subcomponents of this work. For example, Blaser et al. (2004) suggest a method for creating an Index of Development Attractiveness model, but only consider transportation infrastructure as a driver of future development. Dowlatabadi et al. (2004) propose a method for estimating the probability of all induced development types, but specify that their approach is unsuitable for densely developed areas.

The goal of this dissertation is to theorize, develop, and trial a method for addressing induced development in CEA. My aim is to balance or render symmetrical the asymmetry described in the preceding sections in order to give potential environmental impacts the same weight that potential economic benefits currently receive. To do this, I examine in detail historical development patterns in a specific geographic context. I use these to create empirical evidence of how projects build on top of preceding projects, including their footprints or legacies of proximate services, labour, water and energy supplies, and routes to market. I then use this evidence to forecast the probable outcomes of permitting a proposed project in terms of future induced development. The initial iteration of the method uses British Columbia as a case study, and makes use of data on that province's history of development projects and the outcomes that followed. This first iteration is intended as a means of exploring and demonstrating the method's value in a specific application, while providing a framework that can be refined and applied to other contexts.

I began this thesis with a discussion of the problem of accounting for induced development. Before diving into my proposed solution, I present two stage-setting chapters. In Chapter 2, I discuss the historical policy decisions that have made British Columbia a worthy context in which to examine induced development, while in Chapter 3, I survey some of the ways that projections of future development are generated in contexts outside of environmental impact assessment.

In the four succeeding chapters, I proceed through development of the methodology: the process of assembling the requisite historical data (Chapter 4), the statistical analysis of the data and identification of historical development patterns (Chapters 5 and 6), and "ground-truthing" of the patterns identified using the evidence of recent development (Chapter 7).

I conclude by providing guidance for use of this approach in other geographical contexts and attempting to anticipate—and provide pithy and convincing rebuttals to—some of the potential objections or barriers to adopting this method (Chapter 8).

1.7 A note on terminology

Confusingly, *environmental impact assessment* and a number of variants are often used to describe (1) the regulatory process involved in formally assessing impacts to the environment, (2) a significant document prepared as part of that process, and (3) the general concept of assessing environmental impacts. Throughout this manuscript, *regulatory process* means the regulatory process, *environmental impact statement* refers to the document, and *environmental impact assessment* is the general concept.

In addition, I use the adjective “environmental” not only in reference to the natural world but also to the human environment, including its social, economic, and cultural dimensions.

Chapter 2: The evolution of British Columbia's environmental policy

> Plus ça change, plus c'est la même chose.
> —Jean-Baptiste Alphonse Karr, *Messieurs les Assassins* (Karr 1885, II)

2.1 Introduction

In this chapter, I provide a chronology of the major policies put into place by the government in order to manage British Columbia's natural resources, with a focus on those policies relating directly to environmental protection and environmental impact assessment. In doing so, I identify the characteristics of the province's policy context that make consideration of induced development particularly important.

More recent developments in policy (i.e., the early 1990s to the present) are familiar to me because of my professional background. Relevant changes prior to the 1990s were found by reviewing the relevant legislation and policy discussed in Dorcey (1987) and listed at the end of Begg (2007, 223–33). Specific primary and secondary sources are cited throughout this chapter.

2.2 Early policy: Pre-Confederation to 1960s

Prior to the foundation of colonies on Vancouver Island and in mainland British Columbia, traditional First Nations systems of stewardship and caretaking were the only policies governing lands and natural resources in BC (Turner and Jones 2000; Turner and Turner 2008). In the mid-1850s, discovery of gold in the Fraser Canyon hastened the British government's need to establish sovereignty. Months after proclaiming Vancouver Island a Crown colony and taking office as Governor in 1858, James Douglas issued the *Land Proclamation* (1859), asserting Crown ownership of "all the lands in British Columbia, and all the mines and minerals" (Wolfenden

1871). Fearing the encroachment of the United States and recognizing mining as a potential source of the revenue and settlers needed to assert colonial authority, the new colony of British Columbia proclaimed a series of mining laws over the next decade to formalize and support the fledgling industry. These included the *Gold Fields Act* (1859), *Rules and Regulations for the working of Gold Mines* (1859), the *Mining District Act* (1863), and the *Ordinance to Amend and Consolidate the Gold Mining Laws* (1865). These Acts were closely patterned after laws that had been successfully implemented in other British colonies, such as New South Wales and Victoria in Australia (Underwood 1974; Gough 1975).

In 1867, British parliament granted British Columbia ownership and legal authority over its own lands and natural resources under Section 92 of the *British North America Act*. Over the next century, the provincial government developed policies and established agencies with the primary function of furthering BC's resource extraction industries. Early legislation from this period was explicit about this intent, both in its supportive language and proffered incentives: for example, the stated purpose of 1877's *Mineral Act* was to "develop the mineral resources of the province," while 1886's *An Act to Encourage the Erection of Smelting Works* and 1887's *An Act to Aid the Development of Quartz Mines* granted thousands of dollars to companies willing to construct mills and smelters. These Acts were designed to facilitate growth as a means of establishing settlement. The BC government saw resource development in general—and mining in particular—as a significant catalyst for settlement. In 1896, Minister of Finance George Foster summed up the government's position thusly:

> The object the Government have in view is to give an impetus to the mining and smelting industry… A mining population is particularly a consuming population. It makes nothing for its own wear, and for its own food, but it calls lavishly and constantly for the products of the

> manufacturer… The object is to give a stimulus to the development at once, to get capital to go in and set up establishments there, and commence operations, so as to give the benefits that are derived from a large industry. (Mouat 1992, 27)

With this sentiment, the government clearly identified miners as attractor colonists. The presence of miners was directly associated with demand for provisioning of services and establishment of self-sustaining settlements. Settlement patterns during this period were strongly influenced—as they continue to be influenced—by British Columbia's mountainous topography, which reduces the amount of land that can feasibly be settled and restricts major transportation networks largely to valley corridors.

However, the mining wealth of the province could not be developed without access to rail, both to transport mined ore to market and deliver the coking coal necessary to fuel smelters (McDougall 1968). Accordingly, between 1885 and 1905, the government gave a series of generous land and financial subsidies to railroad companies to create the network of intra-provincial railroads that would form the necessary foundation for large-scale mining efforts (Cail 1974).[6]

In 1891, the Province created the Mining Commission, a body dedicated to growing the mining industry and overhauling existing mining laws (Begg 2007). The Mining Commission rewrote and reorganized legislation into the *Placer Mining Act* and the *Mineral Act* (both 1891), establishing a

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[6] By 1903, about 10% of the province's land had been given to the Canadian Pacific Railway and other railroad companies, which sold most of the land for profit. The Canadian Pacific Railway, for example, built on 1,320 acres and sold the rest of its 25 million acre land subsidy (McDougall 1968).

regulatory system that remains largely unchanged to this day. A central tenet of early mining legislation was the right of "free entry," which gave priority to prospectors accessing land and carrying out mining exploration activities over most other land users or interests. The free entry system lives on in BC's current *Mineral Tenure Act* (1996).

As Dorcey (1987) notes, other Acts coming into force in this period were also precursors to present-day legislation regulating resource extraction in BC. In their original forms, most of these Acts dealt superficially, if at all, with environmental issues, as they were designed to encourage resource exploitation rather than exert any measure of government protection; it is arguable that at least some retain traces of their lineage to this day. When the *Game Protection Act* (1897), with its preoccupation with game animals and birds, eventually became the *Wildlife Act* (1996), it was still primarily concerned with hunting. Similarly, the provincial *Fisheries Act* (1901), which established a system of licenses for the fishing industry but did not provide other protections for fish or fish habitat, has much in common with the current *Fish and Seafood Act* (2015). The *Land Act* (1875), like its modern counterpart (1996), focused on levying government fees in exchange for quantities of provincial Crown land, and provided little guidance on environmental matters. The *Water Act* (1909) went virtually unchanged for over a century; the new *Water Sustainability Act* (2014) requires industrial groundwater users to acquire licences for the first time in the province's history, but retains some of the 1909 Act's colonial flavour, such as a controversial "first in time, first in right" model of prioritizing water rights based on how long users have held licenses instead of according to environmental needs or types of water use.

2.3 Origins of environmental impact assessment: 1960s to mid-1980s

As we have seen, during the first half of the nineteenth century, the governmental departments responsible for administering environmental policy served primarily as promoters rather than regulators of industrial development, in line with the Province's policy of encouraging rapid settlement and "improvement" of rural land (Pearson 1971). By the mid-1960s and early 1970s, however, protection of the environment was attracting widespread attention (Harrison 1996b). Rachel Carson's *Silent Spring*, published in 1962, both reflected and amplified the anxiety of the time over habitat destruction and pollution of air, water, and land. The Science Council of Canada (1972) summed up Canadian public opinion this way:

> Canadians have acquired an environmental conscience.[7] It is important that this new awareness be neither forgotten as a passing mood, nor exaggerated into a national panic. With forgetfulness, we would run the risk of coming closer to the extreme of converting a natural wilderness into another, maybe artificial, kind of wilderness in exchange for a transient prosperity. With hysteria, we might so react to environmental concerns that we unnecessarily deprive ourselves of the material benefits of modern technology. Somewhere between these extremes is the constructive median of orderly development…

When the issue of pollution became a major discussion point during Canada's 1968 election, the federal government passed nine pieces of environmental legislation over the next four years, creating the Department of Environment to oversee them (Dwivedi 1973). Following the United States' adoption of the *National Environmental Policy Act* in 1969, Canada's Federal

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[7] This sentiment rather overlooks earlier conservation ideals and First Nations' traditions. Presumably the Council was suggesting that a widespread shift in views was occurring among Canadians who had not previously been concerned about the environment.

Environmental Assessment Review Office was established to serve a similar function in regulating proposals involving federal lands or funds. Reporting directly to the Minister of Environment, this agency performed an initial review to determine if a proposed project had the potential to cause environmental impacts; proposals were then referred to the Minister for a public review (Sadar and Stolte 1996; Department of the Environment Act 1971). In an important deviation from the American example, Canada did not enshrine any requirements for environmental impact assessment in law at this time.

In the early 1970s, BC joined other provinces following the federal government's lead in beginning to develop its own environmental impact assessment process, and in signing a bilateral agreement with Ottawa to take the lead in enforcing federal environmental standards, along with the Province's own (Fafard and Harrison 2000). In 1971, the Social Credit government passed the *Environment and Land Use Act*, creating the Environment and Land Use Committee (ELUC), which brought together ministers from governmental departments relating to natural resources.[8] The Committee's directive was to:

> …ensure that all the aspects of preservation and maintenance of the natural environment are fully considered in the administration of land use and resource development commensurate with a maximum beneficial land use, and minimize and prevent waste of those resources, and despoliation of the environment occasioned by that use. (*Environment and Land Use Act*, 1971)

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[8] The ELUC members included the Ministers of Lands, Forests, and Water Resources; Agriculture; Mining and Petroleum Resources; Recreation and Conservation; Economic Development; Health; Highways; and Municipal Affairs.

After their election in 1972, the New Democratic Party[9] established a Secretariat for the ELUC, substantially increasing both the size and influence of the Committee (Dunn 1995). To the handful of Ministers serving on the original ELUC, the ELUC Secretariat added over a hundred new staff to handle resource analysis, resource planning, and special projects. The newly augmented ELUC developed what was arguably British Columbia's first formal process for environmental impact assessment of mines, energy projects, highways, and other linear developments: a multi-stage procedure that included a justification for the project itself, a detailed description of the selected project site with an evaluation of alternative sites, and a plan for mitigating environmental impacts (Duffy 1990). However, the requirement for environmental impact assessment was at the discretion of the ELUC, and was not embedded in law.

In 1975, the provincial government established the provincial Department of Environment (renamed the Ministry of Environment in 1977), which absorbed the ELUC Secretariat. The agency was greatly expanded and reorganized over the next five years, adding branches for fish, wildlife, and marine resources, and creating eight management regions and forty strategic planning units to more efficiently implement provincial environmental policies. Plans developed by each unit were intended to serve as a guide for operational decision-makers in order to ensure the long-term preservation of lands and resources (Duffy 1990).

Though there was still no unified process for provincial environmental impact assessment, two pieces of legislation—the *Utilities Commission Act* (1980) and the *Environment Management Act*

[9] The BC New Democratic Party of the 1970s did not run on an environmental platform, and were more interested in social reforms at that time.

(1981)—were introduced that established separate processes. The former required proponents to document any impacts by the project on the physical, biological, and social environments and propose mitigation measures, while the latter gave the Minister of Environment authority to require an assessment of anyone who proposed to do anything that would have a detrimental environmental impact.

A booming resource-based economy and the expectation of a number of large impending projects supported this prolonged period of institutional growth. However, in the early 1980s, a global recession caused many proponents to dramatically scale back their plans for development. The need for environmental impact assessment virtually dried up as most project proposals were suspended. The government responded by dissolving the ELUC Secretariat, reducing the role of the Ministry of the Environment, removing its regional planning roles, reducing the number of management regions, and cutting a third of Ministry staff (Dorcey 1987).

2.4 BC's first Environmental Assessment Act: Mid-1980s to 2000s

In response to renewed public concern about the environment (Hansen 2010), in 1984, Ottawa created the Canadian Environmental Assessment Research Council to advise on ways to improve the scientific, technical, and procedural basis for environmental impact assessment (Bowden and Curtis 1988). The Council was established based on the recommendations of a 1983 study that emphasized the importance of methodologies for successful environmental impact assessment (Beanlands and Duinker 1983). At the same time, Cabinet formalized the review process that had been established in the 1970s in the Environmental Assessment and Review Process Guidelines Order (1984). This Guidelines Order was still not a federal law requiring environmental impact assessment; however, in the early 1990s, court decisions relating to the Rafferty-Alameda and Oldman dams unexpectedly revealed that the Order could be legally binding (Boyd 2003). Canada responded by introducing the *Canadian Environmental Assessment Act* (1992), finally enshrining environmental impact assessment in federal law in Canada.

Similar developments were occurring in BC. In 1991, the new NDP government, which had run a decidedly pro-environment campaign (Harrison 1996a), introduced the *Commission on Resources and Environment Act* (1992), establishing the Commission on Resources and Environment (CORE). CORE was a permanent advisory body entrusted with the design of a provincial land use strategy to guide resource and environmental management through consensus-building exercises among local communities, industry, First Nations, and many other types of stakeholders (Mason 1997; Ruff 1996).

Meanwhile, the *Mine Development Assessment Act* (1990) had formalized the review process that had been in use since the ELUC's innovations in the mid-1970s, and established a threshold that triggered an assessment (production of 10,000 tonnes of coal or ore per year; British Columbia Ministry of Energy, Mines and Petroleum Resources 1992). A few years later, the NDP combined the latter process with those established in the *Utilities Commission Act* and the *Environmental Management Act* into British Columbia's own *Environmental Assessment Act* (1994), to be regulated by the newly established British Columbia Environmental Assessment Office (BC EAO). The Act was originally introduced in 1992, but underwent two years of revisions before being passed into law. The new Act came with a longer list of thresholds (in the form of the *Reviewable Projects Regulation* [1995]) to trigger the requirement for an environmental impact assessment, applying not only to mines but also to energy projects, waste management facilities, transportation infrastructure, and other types of developments. At the same time, the threshold for assessment of mines was raised significantly, to 100,000 tonnes of coal or 25,000 tonnes of ore produced per year.

The stated purpose of the 1994 *Environmental Assessment Act* was the "thorough, timely and integrated assessment of the environmental, economic, social, cultural, heritage and health effects of reviewable projects." The associated regulatory process included creation of project committees with representatives from federal, provincial, regional, local, municipal, and First Nations governments; public advisory committees, four public comment periods; and public hearings. Like the *Canadian Environmental Assessment Act*, the BC Act required assessment of the probable cumulative effects of projects.

At around the same time, the government set about regulating the province's forestry practices, establishing a multi-agency steering committee with representatives from CORE and the ministries responsible for forests, fisheries, mining, energy, oil and gas, and the environment. Under the resulting *Forestry Practices Code of British Columbia Act* (1996), forestry companies were required to complete assessments of impacts to cultural heritage, scenic areas, soil conditions, terrain stability, and several other environmental components. The code also prohibited any practice that caused "significant damage" to the environment… but only if the damage was to a watercourse and was caused by "deposit of a petroleum product or a fluid used to service logging equipment," a definition that clearly does not encompass all or even the most obvious potential environmental impacts of logging. In order to further mitigate the impacts of their own legislation on the forestry industry, the government placed a 6% cap on the amount by which the code could restrict the logging rate (Boyd 2003).

Close on the heels of these new pieces of legislation came the recession of the early 1990s, which dampened the government's appetite for environmental reform. CORE was abandoned as a failed collaborative planning experiment—not without good reason, as the head of the Commission had been burned in effigy to protest logging in the Cariboo, and thousands of protesters had invaded the Legislature to show their disapproval for CORE's forest land use proposals (Blake, Guppy, and Urmetzer 1997; Harrison 1996a). The Commission was dissolved in 1996, four years after being formed and two years after delivering its multi-volume Provincial Land Use Strategy. None of the recommendations in CORE's strategy documents, including a call to pass its land use objectives into law, were ever acted upon, and no institution was established to take its place (Thielmann and Tollefson 2009).

2.5 BC's second Environmental Assessment Act: 2000s to present

After unseating the NDP in 2001, the Liberals promptly repealed and replaced BC's *Environmental Assessment Act* (2002) in order to establish "more streamlined and flexible environmental impact assessment procedures for major projects," (British Columbia Hansard Services 2002, 1715). Boyd (2003, 157) writes that this move replaced "one of the country's most progressive provincial [environmental impact assessment] laws with one of the weakest." The new Act completely removed some requirements and made discretionary parts of the process that had originally been mandatory. Cultural effects and cumulative impacts were no longer mentioned explicitly. First Nations and local governments had no required representation on project committees, and the BC EAO—not public advisory committees—took responsibility for steering project reviews.

In place of the old Act's prescribed terms of reference for environmental impact assessments, the Executive Director of the BC EAO now decided the procedure and methods for each assessment on a project-by-project basis, a determination that the new Act stipulated should "take into account and reflect government policy" (*Environmental Assessment Act* 2002). Some feared that this point could lead to politicization of the review process (West Coast Environmental Law 2002; Carrier Sekani Tribal Council 2007). The *Reviewable Projects Regulation* accompanying the Act was no longer the sole trigger for environmental impact assessment; projects exceeding thresholds in the Regulation were referred to the Executive Director for a decision on whether an assessment was necessary. In addition, many thresholds in the Regulation were again raised (for mines, production thresholds increased to 250,000 tonnes of coal or 75,000 tonnes of ore per year).

The government also passed the *Forest and Range Practices Act* and *Forest Statute Amendments Act* (both 2002), effectively erasing the minimal environmental protections established by the NDP's forestry code. As forestry was absent from both iterations of BC's *Environmental Assessment Act*, this move resulted in one of the province's largest industries being entirely exempt from environmental impact assessment.

Although not directly relevant to environmental impact assessment policy, the 2007 BC Energy Plan had a significant role in shaping natural resource development trends, particularly with respect to hydroelectric projects. The Plan, which emerged during the brief policy window between the release of Al Gore's *An Inconvenient Truth* (both book and documentary) in 2006 and the global financial crisis of 2008, was part of a larger suite of initiatives to establish British Columbia as a leader on climate change (Government of British Columbia 2007b). Under the BC Energy Plan, the Province set ambitious targets for power acquisition and opened production to private corporations (breaking BC Hydro's long-standing near-monopoly) in the interests of self-sufficiency.[10] The Plan established a standing offer program requiring BC Hydro to buy power from any small hydroelectric project at rates based on the Crown corporation's latest energy call. One significant result of this policy was a dramatic proliferation of new run-of-river power projects across the province (Cohen 2017).

While BC legislation relating to environmental impact assessment has been largely unmodified since 2002, other mechanisms have resulted in significant changes to the regulatory process. In 1996, BC joined other provinces in signing an agreement-in-principle for the Canada-wide Accord on Environmental Harmonization, a national initiative intended to prevent "overlapping activities and inter-jurisdictional disputes" between provincial and federal environmental regulatory processes (Canadian Council of Ministers of the Environment 1996, 1). The agreement would be formally approved in 1998 (Fafard and Harrison 2000). This move marked the beginning of an on-going quest for greater efficiency that would characterize much of the political conversation about environmental impact assessment until the present day (e.g., Government of Canada 2013). Six years later, in 2004, BC made an agreement with Ottawa to harmonize the provincial and

[10] Several writers, including Cohen (2017), argue that the government's definition of self-sufficiency, which obliged BC Hydro to acquire all its power from producers within the province even in rare dry years, was costly and inefficient.

federal environmental impact assessment processes in cases where projects triggered both *Environmental Assessment Acts* (Canadian Environmental Assessment Agency 2004). The agreement was renewed in 2009. The stated purpose of the harmonized process was to encourage cooperation between levels of government and to eliminate unnecessary duplication and expense, issues that had been repeatedly cited, especially by industry proponents, virtually since the passing of the original BC *Environmental Assessment Act*.

There are some indications that both of these problems may have been overstated. For example, an audit of 25 environmental impact assessment cases conducted by the Commissioner of Environment and Sustainable Development (1998) found more evidence of federal-provincial cooperation than duplication of effort. Another study produced for the BC EAO showed that environmental impact assessment costs represented 1.4% of total project costs, on average (Rescan 1999). A study of a decade of environmental impact assessment timelines uncovered no backlogs between the provincial and federal processes, and noted that Canadian reviews were generally quicker than their American equivalents (de Kerckhove, Minns, and Shuter 2013). As a report prepared by Environment Canada concluded:

> The impression that there is large scale duplication of effort and the implication that there are large cost savings and improved environmental performance which can be achieved by removing overlap and duplication is largely a myth unsupported by any data. (Krahn 1998, 40)

In my professional experience as a consultant preparing environmental impact statements for British Columbian projects between 1997 and the present, the onerousness of the regulatory process is certainly not the only or even the most common reason that projects languish in permitting limbo. Significant changes to the project design can cause considerable delays, and market fluctuations and changing investment priorities often lead industry proponents to place projects on hold for months or even years at a time.

Nonetheless, the incumbent Liberals expressed continuing dissatisfaction with the efficiency of environmental impact assessment in a 2010 Speech from the Throne, calling strongly for a new *Canadian Environmental Assessment Act:* one that would do away with the "redundancy and unnecessary costs" associated with duplication between the two processes, leaving billions of dollars' worth of BC projects "stranded in the mire" of "Byzantine bureaucratic practices" (British Columbia Hansard Services 2010, 1415). The provincial government did not propose any changes to its own legislation to eliminate duplication with the federal process.

However, two years later, Ottawa appeared to answer BC's call, rewriting the *Canadian Environmental Assessment Act* as part of omnibus Bill C-38 (*Canadian Environmental Assessment Act* 2012). Under this Act, the requirement for a federal environmental impact assessment is at the discretion of the Minister of the Environment. Many projects designated as reviewable by the Minister do not go through a federal assessment if they are also subject to an equivalent provincial review. Effectively, this has delegated much of the decision-making power and jurisdiction to the provinces, and greatly increased the number of projects that do not undergo any type of environmental impact assessment. As shown in Table 2.1, the total number of projects assessed within the provincial and federal regulatory processes in 2014 was 82, as compared to the 561 assessments in 2011, immediately before the passing of Bill C-38. Most of this reduction was in the number of projects assessed under the federal process, which fell from nearly 500 in 2011 to just 2 in 2014.

Table 2.1. Comparison of British Columbia projects in provincial and federal review processes, November 2011 vs. November 2014.

	Number of British Columbia projects in regulatory processes			
As of (date)	**Provincial assessments**	**Joint provincial-federal assessments**	**Federal-only assessments**	**Total assessments**
November 2011	29	42	490	561
November 2014	49	31	2	82

(Source: Government of British Columbia 2011; BC EAO 2016; Canadian Environmental Assessment Agency 2014.)

A plan to reform the *Canadian Environmental Assessment Act* was part of the 2015 election platform of the federal Liberal party. At time of writing, these plans had progressed to the stage of draft legislation (Bill C-69) that has been passed in the House of Commons and is now making its way through the Senate. The federal government anticipates formally publishing regulations in early 2019. Bill C-69 makes no significant changes with regards to cumulative effects assessment, despite the recommendations of the expert panel tasked with informing the government's review (Expert Panel for the Review of Environmental Assessment Processes 2017).

On the provincial front, in 2015, the BC Auditor General issued a report concluding that the Province was "not adequately addressing cumulative effects in its recent natural resource use decisions" (Bellringer 2015, 3). In response, the BC government began development and implementation of a cumulative effects management framework to guide the periodic evaluation of cumulative effects at a broad, strategic scale, co-led by the Ministry of Forests, Lands and

Natural Resource Operations and the Ministry of the Environment (BC MFLNRO and BC MOE 2016). As articulated thus far, this framework takes a reactive, effects-based approach, mapping and collecting data on key environmental components rather than identifying drivers. At the time of writing, an interim policy is in place, limited to three environmental components: aquatic ecosystems, grizzly bear, and old growth forest (BC MFLNRO and BC MOE 2016). The framework is focussed on monitoring and management, and not on impact prediction; at present, it is unclear what, if any, application it will have to environmental impact assessment.

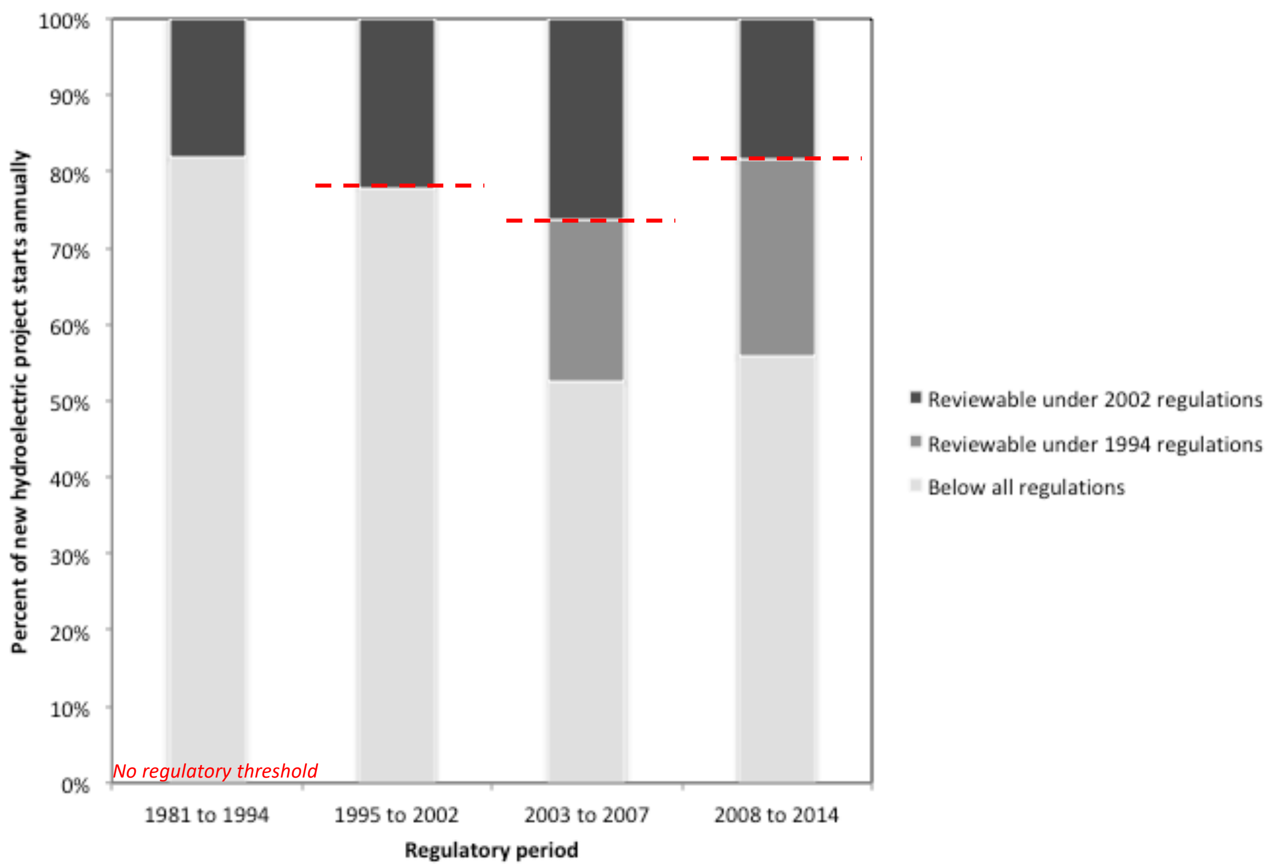
In March of 2018, the BC government announced its intention to review the provincial environmental impact assessment process with the stated goals of enhancing public confidence, promoting reconciliation with First Nations, and “protecting the environment while supporting sustainable economic development” (Government of British Columbia 2018; BC EAO 2018c). This review is in an early stage and has as yet produced a summary of public engagement and a short, high-level discussion paper (BC EAO 2018b; BC EAO 2018a), with specific reforms to the process expected to be introduced in the late fall of 2018.

2.6 Development during modern assessment policy changes

As BC’s environmental assessment policy transformed, there were noticeable shifts in development patterns. In the following paragraphs, the cases of hydroelectric projects and mines built during the previously discussed periods of policy change are examined. This analysis was done using the database of projects compiled as described in Chapter 4 (Section 4.2.2 for mines and 4.2.4 for hydroelectric projects), which included the dates in which projects were permitted and built, as well as their designed capacities.

In Figure 2.1, I compare the generating capacities of projects commissioned during four periods: 1981 to 1994, when there was no requirement for environmental impact assessment for hydroelectric projects; 1995 to 2002 under the original BC *Environmental Assessment Act*, when the threshold requiring an environmental impact assessment was 20 MW; 2003 to 2007 under the revised Act, when the threshold was raised to 50 MW; and 2008 to 2014 under the same regulation and after passage of the 2007 BC Energy Plan.

Figure 2.1. New hydroelectric projects commissioned between 1981 and 2014 in British Columbia, with regulatory thresholds for environmental impact assessment indicated by dotted red lines.



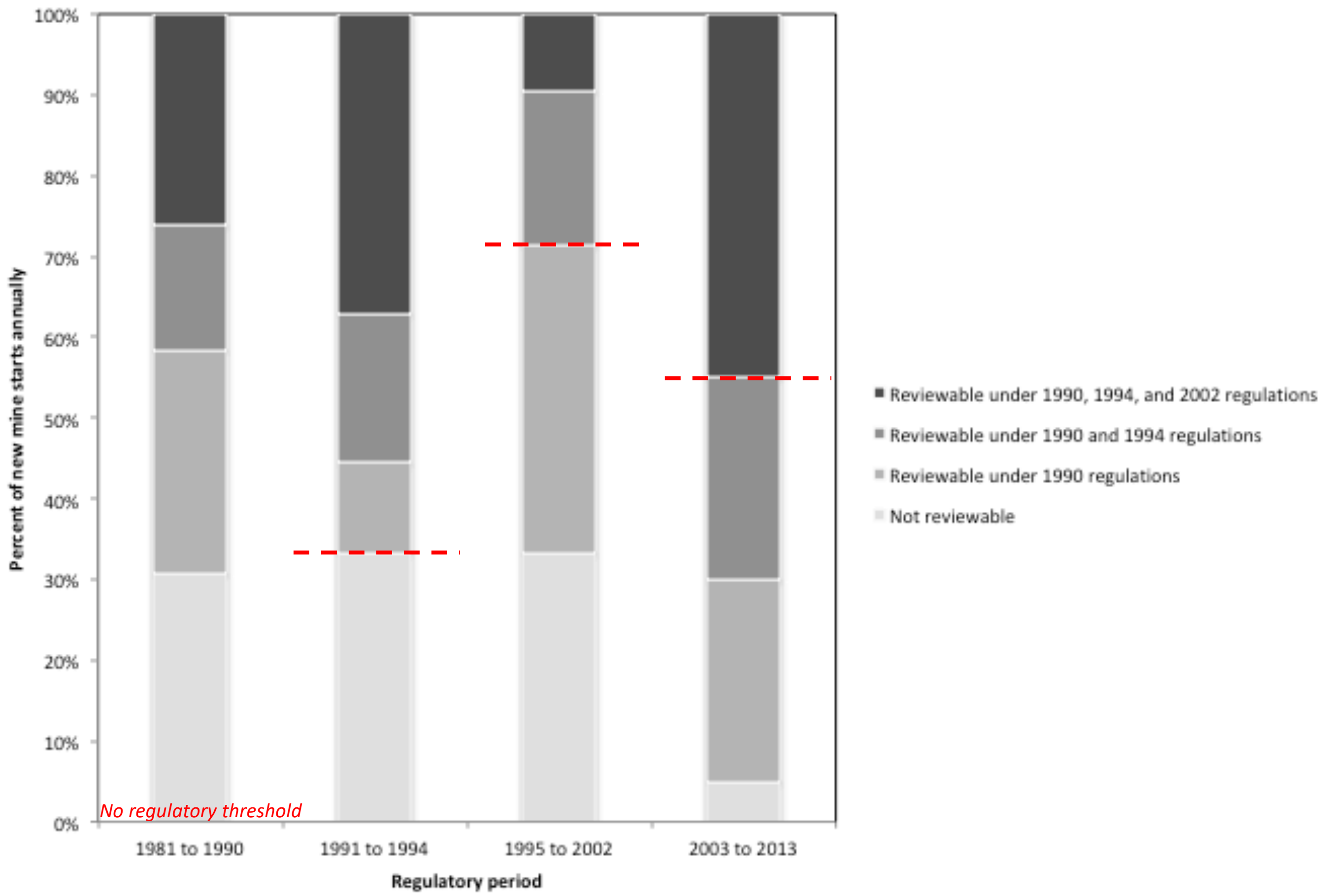
Sources: BC Hydro (2011; 2015); DMTI Spatial Inc. (2016); Cameron Chung [BC Hydro], pers. comm., May 31, 2013; and Rosa Munzer [BC Hydro], pers. comm., December 4, 2015.

As we can see, the percentage of projects above 50 MW stayed relatively consistent throughout (roughly 20%). However, after the threshold was raised in 2002, the composition of new projects shifted; an additional 20 to 25% of new projects now had generating capacities large enough that they would have required assessment under the previous Act.

The case of mining is explored in Figure 2.2, where I compare another four regulatory periods: 1981 to 1990, before environmental impact assessment requirements for mining; 1990 to 1994 under the *Mine Development Assessment Act*, when the threshold requiring an environmental impact assessment was 10,000 tonnes of coal or ore per year; 1995 to 2002 under the original BC *Environmental Assessment Act*, when the threshold was 100,000 tonnes of coal or 25,000 tonnes of ore, and 2003 to 2014 under the revised Act, when the threshold was 250,000 tonnes of coal or 75,000 tonnes of ore.

Again, we can see that the composition of new projects shifted in 2002, with a greater percentage of mines having larger production capacities than the previous period, and mines with capacities below the 1990 regulations all but disappearing by 2014.

Figure 2.2. New mines commissioned between 1981 and 2014 in British Columbia, with regulatory thresholds for environmental impact assessment indicated by dotted red lines.



Sources: Stewart and Barazzuol (2003), Barazzuol and Stewart (2003), BC MEMNG (2015), BC EAO (2016), BC MJTST (2018).

While, as Boyd (2003) suggests, lowered thresholds may encourage developers to design projects just short of the size that would trigger an environmental impact assessment, other factors may have contributed to the increasing size of new projects: for example, technological innovations or economies of scale. One can also make the inverse inference, that thresholds have been lowered *in response* to anticipated increases in industrial scale, perhaps to avoid a glut of assessment work while government capacity remains static. However, the fact remains that as regulations have relaxed, larger projects have become more prevalent.

In addition, many project types are either exempt from assessment entirely or have regulatory thresholds that have remained high throughout the evolution of BC policy. As discussed previously in this section, both iterations of the *Environmental Assessment Act* have been silent on the topic of logging, logging roads, and most other forestry activities, despite the inherent risk of environmental impact, and there are other notable omissions, such as exploration activities for the mining and oil and gas industries—including road-building, blasting, drilling, and deforestation. The threshold for powerlines has always been 500 kV, high enough to exclude 67% of the province's industrial transmission circuit, regardless of line length or the environmental sensitivity of the location.[11]

2.7 Discussion

British Columbia's natural resource policies are inextricably linked with its environmental policies. Over the years, as the legislation originally designed to foster industry has been rewritten to protect the environment, the legislation originally designed to safeguard the environment has been rewritten to protect industry. In this push-pull between competing interests, it appears that policy has largely favoured industrial development over environmental concerns (though recent movement toward regulatory reforms are encouraging).

[11] Since 2002, lines greater than 500 kV have been exempted as well, as long as they are shorter than 40 kilometres in length.

Introduced at a peak in public environmental awareness and concern, environmental impact assessment requirements have since been modified such that larger and larger projects are not obliged to undergo assessment. It is difficult to say with precision how these policy decisions have shaped resource development in British Columbia, as we cannot know which projects would have proceeded if policy and legislation had been other than they were. However, patterns in new hydroelectric and mining development over the past several decades are perhaps indicative of the influence of these policy changes.

The historical fluctuation of British Columbia environmental policy, with its cycle of regulation and deregulation, is not unique, and provides a case study of a policy context with interesting implications for cumulative effects assessment. Careful attention to the potential impacts of future development, especially development that may be induced by the projects authorized today, is particularly critical when there is considerable likelihood that much of that future development will never undergo any assessment of its own.

Chapter 3: Anticipating tomorrow

> The goal of futuring is not to predict the future but to improve it. We want to anticipate possible or likely future conditions so that we can prepare for them. We especially want to know about opportunities and risks that we should be ready for. (Cornish 2004, 65)

> I'm not sure what 2010 will look like, but I'm sure that it will be very little like we expect, so we should plan accordingly. (Wells 2001, 2)

3.1 Introduction

Cumulative effects assessment (CEA) assumes a temporal dimension: a contemplation of how the effects of past, present, and future human development will amass and interact over time. However, as the first chapter in this dissertation has argued, the way we conceptualize future development is rather limited in CEA practice. Canadian and American guidance, policy, and case law on CEA also call for consideration of future development though without articulating methods for doing so.

A review of environmental impact assessment literature revealed a similar—and perhaps related—dearth of recommendations for identifying future development projects for inclusion in CEA. This literature is discussed on the following pages. However, in order to provide a better understanding of the state of the art for projecting future development at a regional scale, a broader net was cast, encompassing the fields of futurology, geography, and economics. This chapter also provides a broad overview of different approaches developed in these fields.

3.2 Foreseeing the future in environmental impact assessment literature

The environmental impact assessment literature, as noted above, is remarkably silent on proposing ways for identifying foreseeable future development. While almost every treatise on cumulative effects mentions future development as a part of temporal scope, little attention is paid to how this should be operationalized.

Over twenty years ago, in Cooper and Canter's (1997) survey of 225 American assessment professionals, respondents reported that one of the most common difficulties they faced was defining what constituted a reasonably foreseeable future project. Cooper and Canter concluded that, as an appropriately conservative approach and to enhance credibility, CEAs should have a wider test for inclusion of future development, and recommended that a "master plan projection" for development in the study area be created (Cooper and Canter 1997, 29). The authors did not offer any specific suggestions for how this projection might be generated.

A few years later, in a report prepared for the Canadian Environmental Assessment Agency, Duinker, Pawley, and Grieg (2004) noted that the problem of accounting for an uncertain future in an analysis is not unique to CEA, and accordingly looked outside of environmental impact assessment literature to review how methods developed in other fields might be applied. Many of the approaches Duinker, Pawley, and Grieg reviewed are discussed later in this chapter, and the authors' conclusions on their suitability for application in environmental impact assessment are summarized, where applicable. Duinker and Grieg published three subsequent papers on this topic: the first echoed Cooper and Canter's sentiments that the treatment of future developments was one of the chief failings of CEA practice (Duinker and Greig 2006), while the other two reiterated the methodological recommendations of the 2004 report in the specific case of an environmental review taking place in Canada's north (Greig and Duinker 2007), and to environmental impact assessment practitioners in general (Duinker and Greig 2007).

Finally, Ehrlich (2010) also argued against the limited scope of future developments considered in CEA, presenting a case study of multiple uranium mine proposals in an area with extensive recent claim stakings and other development applications, many known mineral showings, and a history of analogous development patterns. The author suggested that a weight of evidence approach—in which a range of factors is collectively evaluated to determine possible future outcomes—would be preferable to typical practice.

3.3 Foreseeing the future outside environmental impact assessment literature

Researchers in several other fields have also designed approaches for exploring the future of regional industrial development. The approaches reviewed in the following section all seek to answer at least one of the following three questions:

1. What locations will be affected by land use changes?
2. At what rate will these changes occur?
3. What variables best explain these changes?

3.3.1 Futurology

Several approaches developed by futurologists have direct applicability and even precedent for creating projections of future development. The following section briefly summarizes some of these approaches.

3.3.1.1 Delphi method

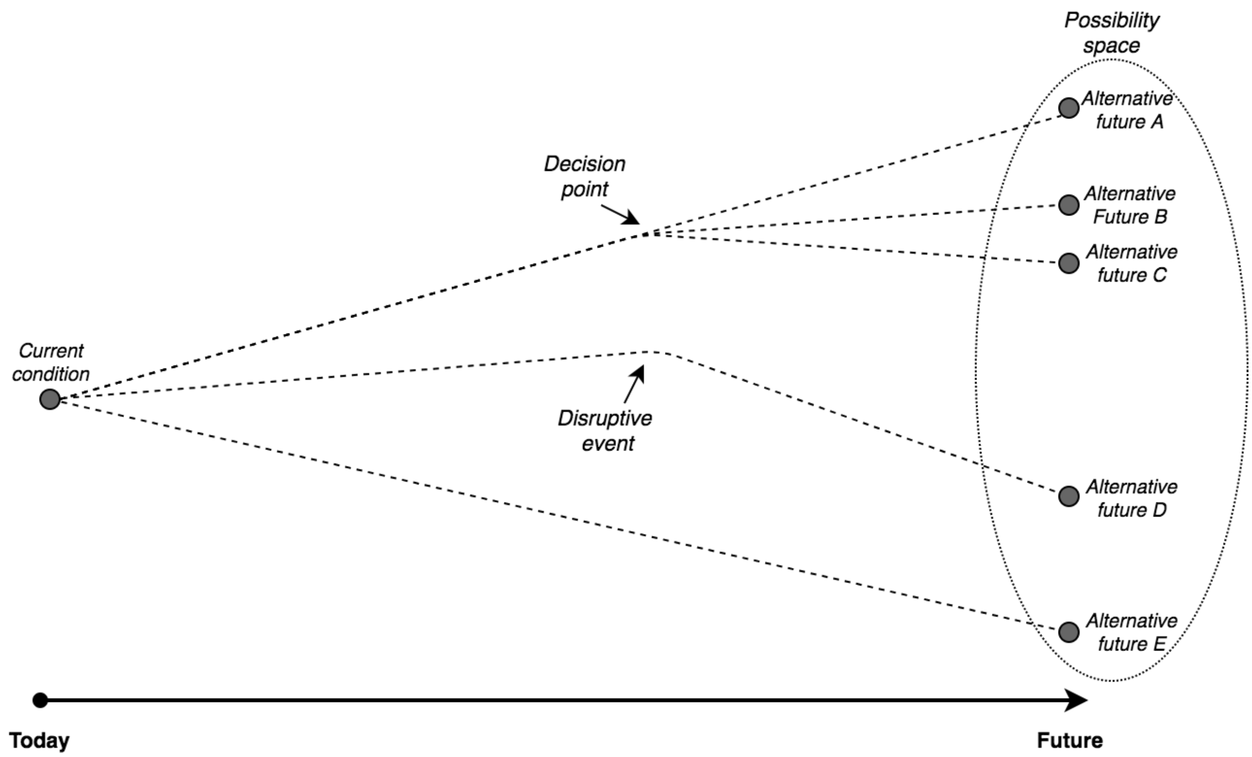
An intuitive way of anticipating the future is to poll a group of individuals with great familiarity with the subject matter. The Delphi method is a popular protocol for deriving this kind of expert opinion. The method involves questioning a group of experts—usually using a series of anonymous surveys—about a topic, giving them the opportunity for justifying their expressed opinions and evaluating each other's responses (Brown 1968). Feedback from this process is then shared with all respondents, and over several iterations a general consensus is developed. The Delphi method provides structure and removes the element of face-to-face confrontation that might otherwise sway the outcome of a group elicitation. However, it requires much time and effort and, as with all expert opinion-based methods, the quality of the results depends heavily upon the knowledge of the participating experts (Greig, Pawley, and Duinker 2004; Brown 1968). Greig, Pawley, and Duinker (2004) note that the Delphi method is most successful at providing insight into the relatively near future (i.e., fewer than five years).

3.3.1.2 Scenarios

Scenarios are descriptions of hypothetical sequences of events that lead to multiple alternative futures (Cornish 2004). These descriptions can be developed directly through expert opinion, or via an intermediary model which derives its assumptions about how causal processes will act on components from expert input (Shearer 2005). One such model is the ALCES® model, which (with its Mapper module) simulates future land use based on user inputs (Francis and Hamm 2011). Scenarios generally do not describe certain or probable futures, but instead provide a set of plausible futures varying in the degree of influence different variables have on one other (Aligica 2005; Xiang and Clarke 2003). As they must rely on expert opinion to a great extent, scenarios have the same drawbacks noted in the preceding paragraph in terms of the time, effort, and knowledge resources required.

In addition, as Greig, Pawley, and Duinker (2004) report, users may be tempted to interpret scenarios as predictions of the future, or to favour a particular scenario as the most correct or probable one. Nevertheless, the authors identify scenario-building as the approach most consistent with realistic objectives for cumulative effects assessment. Instead of attempting to develop a single picture of future development (and almost certainly getting it wrong), they encourage analysts to use scenarios to delineate a "possibility space" encompassing the scope of several plausible alternative futures (Greig, Pawley, and Duinker 2004, 20). These alternative futures do not necessarily proceed from current conditions in a linear fashion, but may change course abruptly at a decision point (such as a policy change) or due to a disruptive event (such as a natural disaster or market fluctuation; Timpe and Scheeper 2003). In addition, alternative futures may become more widely divergent with increasing distance from the present, as shown in Figure 3.1.

Figure 3.1. Concepts in scenario-building. Adapted from Timpe and Scheeper (2003) and Mahmoud et al. (2009).



3.3.1.3 Trend extrapolation

Trend extrapolation is one of the simplest and most popular futuring methods: a basic assumption that what has happened in the past will continue to happen going forward. The approach involves recording changes to specific variables in a region to determine shifts in the speed or direction of those changes, and using these data to create a future projection (Skumanich and Silbernagel 1997). The greatest shortcoming of trend extrapolation is, of course, that the future does not always replicate the past. As Hermann Kahn, one of the preeminent futurologists of the last century, is reported to have said, “The most likely future isn’t” (Bishop, Hines, and Collins 2007, 11). Another lesser but still important drawback of this approach is the requirement for long and detailed time series data and statistical analysis (Greig, Pawley, and Duinker 2004). However, while surprises may change some aspects of the future, they are unlikely to change *all* aspects of the future; thus, trend extrapolation is still a useful method of deriving a plausible projection.

3.3.1.4 Cross-impact analysis

Cross-impact analysis is a systematic framework for quantitatively considering how multiple conditions or events may influence one another to shape future development. Each condition or event is placed in both a row and a column of a square matrix, and the probability of impacts to future development given each possible pair combination is estimated (Bishop, Hines, and Collins 2007). Probabilities are usually derived using expert judgement, potentially via the Delphi method described earlier. Greig, Pawley, and Duinker (2004) suggest that this approach is most useful in contexts where data is unavailable or where relationships between variables are not well understood.

3.3.2 Geography

Geographers have also developed methods for evaluating and projecting changes to landscapes over time. Much of the literature within this discipline is concerned with land use and land cover changes in general, not just those changes triggered by human interventions. Two approaches that have been used to anticipate human development are discussed below.

3.3.2.1 Cellular automata models

In cellular automata models, a set of deterministic transition or growth rules (usually derived from expert knowledge, but also sometimes using machine learning) is applied to predict land use changes at a particular location, or cell, based on the location's attributes and land use conditions at neighbouring locations (Veldkamp and Lambin 2001; Pontius Jr. et al. 2008). Thus, these models simulate how development could occur over time as a succession of state changes, with each cell's new state being a function of the states in its neighbourhood at the previous time interval. Examples of cellular automata models of land use change include SLEUTH and Environment Explorer (Pontius Jr. et al. 2008). Cellular automata models have also been used to model a wide variety of spatial processes, including urban growth, vegetation dynamics, and the evolution of spiral galaxies (Irwin and Geoghegan 2001).

3.3.2.2 Empirical modelling in Geographic Information Systems (GIS)

Empirical models developed in GIS have also been used to predict land use changes. In these models, explanatory variables—often remotely sensed distance and other measures calculated using GIS—are analysed with reference to dependent variables, past transitions in land cover and use. Serneels and Lambin (2001), for example, used this approach to estimate where land use changes in the Narock District of Kenya were most likely to occur, though the authors note that the model was not able to predict the timing of such changes.

Several software packages have been developed to aid in this type of modelling, including Lucas (Berry et al. 1996), CLUE (Veldkamp and Fresco 1996), and CLUE's variants (i.e., CLUE-s, Dyna-CLUE and CLUE-Scanner). Irwin and Geoghegan (2001) argue that while these types of models can often simulate the processes and outcomes of land use changes well, they fail to adequately explain the human behaviour behind such changes.

3.3.3 Economics

Economists are also interested in identifying patterns of land use change over time. Much of the work in this field has concentrated on urban areas (Waddell 2002). Research outside of cities has mainly focused on modelling agricultural land use and anthropogenic deforestation (Irwin and Geoghegan 2001), as reviewed in the following section.

In the mid-nineteenth century, farmer and amateur economist Johann Heinrich von Thünen developed an economic model of agricultural land use. In von Thünen's model, proximity to a central market is the main determinant of agricultural land use in the surrounding region because of its direct effect on land values and transportation costs. The closer a farm is located to a market, the lower the transportation costs to the farmer will be, and therefore the higher the cost that can be charged for the land. Absent other complicating factors (for example, variations in land fertility, or geographic obstructions like rivers), von Thünen envisioned that farms would develop in concentric rings around the market, with farmers producing more valuable goods with higher transport costs (due to weight) being willing to pay for the pricey land closest to the market, and farmers with lower value and more cheaply transported goods working farther afield (Chisholm 1961; O'Kelly and Bryan 1996).

von Thünen's work has been hugely influential, underpinning much research since its translation into English in 1966, and is the foundation of location theory. Many empirical studies have generalized von Thünen's observations outside of traditional farming applications. The resulting models rely on statistical techniques, mainly regression, using historic data on land use change to assess the relationships between land use changes and location-based drivers. For example, Chomitz and Gray (1996) found that greater deforestation occurs with greater proximity (in terms of travelling time) to urban centres in Belize, while Mertens and Lambin (1997) showed that in Cameroon, most deforestation occurs within 10 kilometres of towns and 2 kilometres of main roads.

3.4 Conclusion

Current practice in identifying future development for the purposes of CEA is the simplest kind of trend extrapolation. Essentially, analysts search for any other development proposals in close proximity (defined, for example, by distance or discharge into the same ecosystem) with an implicit assumption that these will be the only new developments in the region over the project's life.

To produce more robust models of likely future development patterns, we could adopt any of the methods described above. However, many pose significant challenges, and may be beyond the scope of a project-level assessment. Most of these approaches rely on context-specific expert opinion and/or have onerous data requirements that make them too expensive and impractical as a prerequisite to individual environmental impact assessments. Rather, these types of analysis would be best suited to the regional level of environmental impact assessment, running in advance of or parallel to a project-level study.

The approach I propose in this dissertation and explore in the next four chapters combines elements of several of the methods described in the preceding pages, but has the advantage of being practicable at the project level of environmental impact assessment, in addition to being scalable to the regional level. In contexts where historical data on past development is already available, it may be possible to leverage that data to produce a more sophisticated picture of future alternatives than the current trend extrapolation model. I am proposing a scenario-based approach that takes statistical analysis of historical development data, informed by empirical modelling in GIS, as its data input, delineating a "possibility space" within which future development will most likely occur. As its central premise, this approach borrows from von Thünen's observations about the role of location—and specifically proximity—as a key driver of development.

Chapter 4: Data collection and refinement (or, Why I wear glasses now)

> Our discussion will be adequate if it has as much clearness as the subject-matter admits of, for precision is not to be sought for alike in all discussions, any more than in all the products of the crafts… for it is the mark of an educated man to look for precision in each class of things just so far as the nature of the subject admits…
> —Aristotle, *Nicomachean Ethics* 1.3 (2009, ll. 12-14 and 23-24)

> This Abstract, which I now publish, must necessarily be imperfect.
> —Charles Darwin, *The Origin of the Species* (1876, 1–2)

4.1 Introduction

A prerequisite step to exploring my central premise—that historical development patterns can provide insight into development futures—was assembling a database of historical resource projects in my case study region of British Columbia. A retrospective study of this nature came with several inherent challenges. While much data on past development did exist in various forms, the original collectors obviously did not have my particular application in mind when they designed and carried out their work. Building the database therefore involved combining a number of datasets that were collected for many different reasons and according to diverse protocols, some documented by their originators and some not. In addition, these data were collected over a period of great technological change, with paper record-keeping giving way gradually—and sometimes quite ungracefully—to digital formats.

Thus, tracing a century and a half's worth of resource development patterns across the full extent of the province has been, by necessity, an exercise in patchwork. The availability, quality, and detail of historical data on different development types varied widely. These data were imperfect in ways that I noticed immediately, in ways I noticed after months of working with them, and in ways I probably missed entirely. To mend gaps and stitch all my data into a unified format for analysis, I employed the techniques and made the assumptions described in the following chapter.

4.2 Data sources

4.2.1 Screening criteria

Keeping in mind that my goal was to look for patterns in how new projects build on top of earlier projects by leveraging legacy facilities or proximate services, I had five criteria for including or excluding project types. One criterion had to do with the characteristics of the project type itself, while the other four concerned qualities of the available data. This section summarizes those criteria, while a longer discussion of each of the project types considered can be found in the following sections.

The first criterion had to do with whether the project type was likely to have power as an attractant: in other words, do projects of that type have any facilities or proximate services to leverage? One project type (forestry) was excluded from consideration on this basis.

My second requirement was for data on the project type to include both a temporal and a spatial dimension. To determine spatial proximity, I needed to know the location for each project, and to be able to place projects in sequence, I needed to know when they were constructed. Where either of these dimensions was missing, I attempted to infer it from other sources, but if this too failed (as in the case of placer mines), I excluded the project type.

Thirdly, a probabilistic analysis of development patterns requires a sufficient number of observations for the different development types. A number of developments within the categories discussed in the following sections have occurred so infrequently (fewer than 30 times) in British Columbia that they could not be included in the analysis. These project types were gemstone mines, biomass plants, wind generation facilities, tidal energy facilities, and waste heat facilities.[12]

My fourth criterion was for data on the project type to be of reasonable quality and largely complete, in order to provide a reliable basis for establishing historical patterns. If inspection of the data revealed obvious inaccuracies that could not be resolved, or that a significant share of the data was missing (as was found for placer mines and resource roads), I excluded the project type from the analysis.

Fifthly, some data on linked sub-components of larger projects were available, and I considered the implications of treating each of these as separate new developments. However, the scale of analysis for this research is the project, regardless of the size of the environmental disturbance. To consider all kinds of new disturbance as wholly new projects, I risked artificially inflating the numbers within certain project types. I therefore decided to exclude gas wells, platforms, and pipelines—sub-components of larger gas projects—from my analysis.

[12] Technological innovation produces new project types. For a reflection on how projects without a long historical legacy (such as biomass plants, wind farms, and tidal energy facilities) might be incorporated into this type of analysis, see Chapter 8.

4.2.2 Mines

Since the mid-1800s, the vast majority of mining in BC has extracted metals (primarily copper, gold, silver, lead, and zinc); there have also been a large number of coal and industrial mineral mines, and a handful of gemstone mines. In 2000, the British Columbia Ministry of Energy and Mines initiated an inventory of historic mine sites, which catalogued a total of 1,923 producing deposits dating back as far as 1852 (Stewart and Barazzuol 2003; Barazzuol and Stewart 2003).[13] Start-of-operation dates were recorded for only 1,482 of these mines, and the inventory was not updated after 2007. I was able to obtain 190 of the 441 missing dates from other sources, including the MINFILE mining database (BC MEMNG 2015),[14] newspaper articles, and archived corporate news releases. Information on six additional mines built after 2007 were acquired from provincial government sources—namely, the e-PIC database (BC EAO 2016) and the Major Projects Inventory (MPI; BC MJTST 2018)—for a final total of 1,678 mining projects: 1,426 metal mines, 165 mineral mines, 74 coal mines, and 13 gemstone mines. As the gemstone mines did not meet the minimum observation threshold, gemstone mines was excluded as a project type.

Some operation dates from the Stewart and Barazzuol inventory initially appeared to have been entered in error: several mines were reported to have opened and closed in the same year after producing an improbable amount of ore for such a short period. This was because the dates had

[13] Stewart and Barazzuol's published dataset, which accompanies their report, includes the locations of individual deposits, and in some instances multiple deposits were developed as part of a single mine (Sarah Meredith-Jones [BC MEM], pers. comm., March 6, 2017). In these instances, the records were combined, with the start- and end-of-operation dates respectively set as the year work on the first deposit began and the year work at the last deposit was completed.

[14] This database was also a primary source for the Stewart and Barazzuol inventory.

originally been collected using information from the Annual Census of Mines, which has changed in format several times since its initiation in 1888. During some periods, the start-of-operation for mines reflected the year mining or milling began, and in others, it represented the year ore or concentrate was sold and reported as mining proponent revenues (BC MEMRCR 1991). As the inventory did not include the census dates that were the source for each mine record, it was difficult to tell which mines had been affected by this variation in reporting, other than the mines that had caught my attention in the first place (i.e., those that started and ended operations in a single year). In 11 such cases, new start-of-operations dates were obtained from MINFILE or newspaper sources. It may well be that some of the remaining start-of-operation dates are lagged by one or more years, but I was unable to find a way of rectifying this issue.

The Stewart and Barazzuol inventory contained the spatial positions of the mines (i.e., their georeferenced latitudes, longitudes, and elevations), and this was used to convert the data into point features in ArcGIS. The locations of the six additional mines were found in e-PIC and the MPI. To confirm that mine locations had been accurately captured in this process, positions for the mines that are currently operating or have closed within the past ten years were verified using satellite imagery (Environmental Systems Research Institute 2017).

4.2.3 Placer mines

Small and large-scale placer mining in BC goes back to the 1850s and Fraser and Cariboo gold rushes (Griffin 2009; AME BC 2012). Two relevant datasets are available from the Ministry of Energy and Mines: one contains historical data for nearly 27,000 placer tenures but no temporal metadata (BC MEM 2016a), and one contains about 8,000 currently held placer tenures, along with various dates associated with tenure application and issuance (BC MEM 2016b). The earliest tenure in this latter dataset was issued in 1972, but the vast majority are less than twenty years old. If the Tenure ID numbers in both datasets were issued consecutively, all of the historical placer tenures were issued *after* the oldest currently held placer tenure (i.e., post-1972); in other words, neither dataset includes placer tenures issued prior to this date, and the previous 80 years of placer mining activity in BC is unrepresented.

The placer data were thus already revealed as incomplete. An even greater difficulty is that issuance of placer tenure is not evidence that actual mining, mining exploration, or any other activity occurred at that location. Barriers to obtaining mineral and placer title in British Columbia have historically been trivial (unless you were of First Nations descent, in which case you were out of luck from about 1860 to 1948; Moss and Gardner-O'Toole 1991). In the 1930s, for example, unemployed men could make placer claims for free (AME BC 2012). In modern times, the process has been streamlined with an online staking system allowing users to acquire a miner's license for $25 and buy mineral rights for a few cents an acre. Anecdotal reports indicate that some placer claims are staked by individuals with no intent to develop a mine (e.g., Salcito 2006). Therefore, it is entirely possible that little or no mining activity occurred at many of the issued tenures.

In an attempt to identify placer claims that had been actively mined, I explored two avenues. First, since 1917, employers in BC have been legally required to insure their workers with the Workers' Compensation Board of British Columbia (now operating under the name WorkSafeBC). If an employer purchased coverage for workers at a placer claim over a certain period, it might reasonably be assumed that mining took place there during that time. While the (mercifully few) records of insurance *claims* for injuries to placer mine workers do include the locations where the injuries took place, the records of insurance *coverage* are not linked to any specific locations (Melissa Medearis, [Population Data BC], pers. comm., May 3, 2017), and thus cannot be used to ascertain activity at a mine. Second, miners are currently required to submit a Notice of Work application before embarking on exploration or development, and these applications could conceivably be matched up with placer tenures. However, this information is not available to the public, and it is unclear how far back the government's records of these applications extends. As I could find no record showing which claims had actually been developed into placer mines, I excluded placer mines from my database.

4.2.4 Energy projects

Information on 106 energy projects was collected from BC Hydro (including the utility's list of independent power producers), and other major power producers, such as Innergex, Capital Power, and Fortis BC. While the resulting list of projects includes facilities built as far back as 1905, it seems limited to those that remain in operation today or were decommissioned within the past two decades. I was unable to find records of energy projects that were decommissioned prior to 2002, and am skeptical that this is because none exist. The large majority (95) of these facilities were hydro projects, though the dataset also includes biomass (5), wind generation (4), tidal (1), and waste heat (1) projects. The latter four project types did not meet my minimum observation threshold criterion, and were consequently excluded from the analysis.

4.2.5 Powerlines

BC Hydro reports that British Columbia's bulk transmission system consists of over 18,000 kilometres of line and submarine cables (BC Hydro 2017). Information on powerlines was assembled by combining vector data (BC Hydro 2011) and georeferenced digitizations from maps produced by BC Hydro (BC Hydro 2015) with nationwide data available in CanMap Content Suite v2016.3 (DMTI 2016), supplemented with routing information from e-PIC and the MPI. With the exception of two lines running from the Arnott substation to Vancouver Island, the entirety of BC's transmission system is composed of higher-capacity three-phase lines (Cameron Chung [BC Hydro], pers. comm., May 31, 2013). Line segments with voltages of lower than 138 kV were excluded from the database as unsuitable for transmission to or from resource development projects.

In-service dates for line segments were furnished by BC Hydro (Rosa Munzer [BC Hydro], pers. comm., December 4, 2015). This temporal data was the product of a report queried from BC Hydro's maintenance database, and came with several caveats: in particular, that the utility's historical practice (prior to the computer age) was to recycle circuit designations. For this reason, line segments with in-service dates earlier than 1980 had to be checked manually against historical system diagrams to ensure that the correct segment was being referenced. In addition, several segments had missing in-service dates; these were found by searching for statements regarding line construction in e-PIC, newspaper articles, and news releases, or more commonly by inferring a date based on nearby features. For example, where a segment with a missing in-service date formed a connection between two segments with different in-service dates, an in-service date midway between the two neighbouring segment's date was selected. Where a segment's metadata indicated that it had been built as a tap to a specific project (e.g., Brenda Mines, Fording Coal), it was assumed that the segment and the associated project were built in the same year, unless documentation could be found to show that the line was a later add-on (e.g., the Gibraltar Mine tap).

Contiguous segments with identical in-service dates were merged to form a single feature. A total of 390 of such features were thus derived, collectively forming over 18,300 kilometres of high-tension powerline.

4.2.6 Gas works

After Alberta, BC is Canada's second largest natural gas producer; with the only commercial production occurring in plants in the province's northeast.

4.2.6.1 Gas plants

Information on 106 operating gas plants were available as part of the BC OGC's facility location dataset (filtered by facility class code), and included temporal metadata relating to permit approvals and operations (BC OGC 2016b). The oldest of these gas plants was built in 1965, but the majority of have been built since 2001. Additional metadata on plant production was obtained from statistics published by the Government of British Columbia (2016).

4.2.6.2 Gas pipelines

Information on over 7,100 segments of pipeline, complete with permitting dates, is available from two BC OGC sources, both providing data collected on or after October 2006: a record of approved pipeline right-of-ways (BC OGC 2016c), and a record of applications for ancillary facilities, some of which include approved pipeline right-of-ways (BC OGC 2016a). There is little overlap between the pipeline data obtained from these two sources, and it is unclear why they are kept separately. A pipeline layer is also available as part of the CanMap Content Suite (DMTI Spatial Inc. 2016), but this contains no temporal metadata and appears to be incomplete: there are fewer than 700 segments, and again, few overlap with the BC OGC data. Other potential sources for pipeline data were investigated—including AbaData, the Canadian Energy Pipeline Association, Natural Resources Canada, and the National Energy Board—without success.

4.2.6.3 Gas production wells and platforms

Oil and gas wells are concentrated densely in northeastern BC, particularly in the 150 kilometres closest to the Alberta border. Surface locations of nearly 32,000 wells and production platforms are available from BC OGC (2016d). Metadata for these facilities include a permitting date, the name of the proponent, and the type of fluid being produced (e.g., gas, oil, water). While each new platform undoubtedly represents an incremental increase in development, it seems inappropriate to view them as separate projects; rather, they are component parts of larger oil and gas projects, analogous to a new facility at an existing mine. I attempted to group these facilities by the gas plants they might feed into. However, changes in ownership subsequent to permitting, other variations in reporting, and the incomplete pipeline dataset discussed previously made this difficult to do without considerable guesswork, and left me doubtful as to the accuracy of the results.

Rather than place undue weight on oil and gas development by considering platforms individually, or risk making potentially spurious assumptions by combining gas platforms with plants, I elected to use gas plants alone as the unit of development for the oil and gas industry.

4.2.7 Forestry

As noted in Chapter 2, forestry projects are not required to undergo environmental impact assessment in British Columbia, despite undoubtedly being a major source of environmental impacts. About 60% (or 55 million hectares) of British Columbia is currently classified as productive forest. The Government of BC owns the majority (94%, or about 52 million hectares) of this forested land. About 13% (or nearly 7 million hectares) are set aside as protected areas, and the government grants licenses to harvest timber on the remainder (PricewaterhouseCoopers 2017). Current data on timber harvests are based on forestry tenure applications and reporting, as well as on change detection from satellite imagery (Data BC 2016). While historical data on harvested areas go back to 1990, data custodians report only the most recent decade of data is reliable (Data BC 2016).

While forestry is certainly a prominent part of the province's development history, it is unlike the other resource development types discussed in this chapter. One of the main reasons for this is its lack of a fixed spatial location: once an area is harvested, it will not be ready for re-harvesting for at least 60 years and likely many more (BC MOF 2003). Timber harvests in a particular area also do not serve as an obvious attractant for more forestry or other types of industry except in one important way: access. Approximately two-thirds of British Columbia has at least one-tenth of a kilometre of forestry service road for every square kilometre of land, with the greatest road density in south, central, and northeastern parts of the province (BC MOF 2003). This road network facilitates access and exploration in terrain that would otherwise necessitate a greater investment. Thus, while I excluded forestry as a project type, I gave further consideration to including forestry service roads in the analysis, as described in the next section.

4.2.8 Roads

Data on two types of roads were investigated: resource roads—including forestry service roads (GeoBC 2014) and oil and gas development and access roads (British Columbia Oil and Gas Commission 2015) —and major public roads (Data BC 2013),

4.2.8.1 Resource roads

The Forest Practices Board (2015) estimates that there are over 600,000 kilometres of resource roads in British Columbia: over 75% of these roads are forestry service roads and most of the rest are oil and gas roads. However, government data on all BC roads, particularly resource roads, is known to be incomplete and out of date (Forest Practices Board 2005; Forest Practices Board 2015). Roads are generally one- to two-lane, with paved or gravel surfaces depending on whether they were needed for short- or long-term use, and some may be overgrown (by design or otherwise). Government records regarding these attributes were last updated in the mid-1990s (Forest Practices Board 2015).

Combined, the forestry service road and oil and gas road data from GeoBC and the BC OGC comprise just over 330,000 kilometres of road. Roughly two-thirds of the road records included permitting dates (and, in fewer cases, abandonment dates). However, these temporal data represented the *latest* permitting dates of road segments, not necessarily the *initial* permitting dates. As there were over 220,000 individual road segments, it was impractical to attempt to find commissioning dates from other reliable sources (and it seemed unlikely that there even *were* other reliable sources).

To summarize: by combining all sources of road data, I was still missing nearly 50% of BC's resource roads; of the roads I could find information about, one-third had no temporal dimension at all, while the remaining two-thirds had potentially misleading temporal data. With a heavy heart and bleeding eyes, I therefore decided to exclude resource road data from my database (though the roads with commissioning dates were used in the transportation network analysis model discussed later). In contexts where better records of road-building have been kept, I would strongly recommend they be incorporated into the analysis.

4.2.8.2 Major roads

The major public road data had no temporal information associated with it at all, but had the advantage of (1) including fewer individual segments and (2) consisting of major transportation corridors whose construction dates were much easier to discover from the British Columbia Ministry of Transportation (n.d.), Harris (1983), and BC Hansard transcripts (Government of British Columbia 2014). As with the transmission line data, contiguous road segments that were built in the same year were merged, to produce a total of nearly 12,000 kilometres of road divided into 104 segments.

4.2.9 Railroads

Railway track, train type, and junction data were taken from the National Railway Network (Natural Resources Canada 2013) and CanMap Content Suite v2016.3 (DMTI 2015). Railway construction dates were extracted from Trainer, Antonson, and Antonson (2015), Harris (1983), the Historical Atlas of Canada (Gentilcore 1993; Kerr and Holdsworth 1990), and Andreae and Matthews (1997). As with transmission line and road data, contiguous track segments built in the same year were merged, yielding over 8,500 kilometres of railroad divided into 170 segments.

4.3 Working with the data

4.3.1 Temporal categories

I assumed that development patterns have not remained consistent over the past 150 years, but have changed with technological innovations. In order to explore this hypothesis, I separated the database into three temporal categories: the colonial and post-confederation period of 1852 to 1899, the progressive period of increased industrialization from 1900 to 1949, and the post-war boom and modern period from 1950 to 2015.

The make-up of the final database, compiled as described in the preceding paragraphs, is summarized in Table 4.1.

Table 4.1. BC resource development through history

Project type	Total date range	Average number of projects/decade			Total no. of projects
		1852 to 1899	1900 to 1949	1950 to 2015	
Coal mines	1852 to 2013	3.2	7.6	3.5	74
Gas plants	1965 to 2015	-	-	21.2	106
Powerlines	1922 to 2015	-	2.6	56.0	390
Hydro projects	1905 to 2014	-	4.1	12.0	95
Metal mines	1859 to 2012	52.5	203.1	35.6	1,426
Mineral mines	1896 to 2009	3.3	11.0	18.6	165
Major roads	1926 to 1990	-	17.0	16.3	104
Railroads	1870 to 1982	13.8	22.2	6.6	170
Total	**1852 to 2015**	**72.8**	**270.2**	**169.1**	**2,525**

4.3.2 Transportation network analysis model

Transportation networks are important to industrial development for two reasons: 1) proximity of workforce to project locations and 2) transport of bulk commodities to distant markets. Projects that are relatively close to one another as the crow flies may be prohibitively far apart in terms of travel time because of geographical barriers (such as mountains or rivers). Thus, distance along transportation corridors, rather than simple Euclidean or Manhattan distance, was used as one measure of spatial proximity.

A transportation network analysis model for British Columbia was developed in ArcMap 10.4 (Environmental Systems Research Institute 2016) using the road and railway data described in the preceding sections. (A 15-kilometre buffer of road and rail segments in Alberta, the Yukon, and the Northwest Territories was also included to account for routes that cut across the BC border; this was not done for Alaska or Washington State, with the rationale that spatial proximity along routes that require international border crossings would exert less influence on development patterns.) To create this model, each transportation route segment was assigned a travel time value calculated using the segment's length and an estimated travel speed. The travel speeds for the segments were derived as described below.

4.3.2.1 Travel speeds

Transportation in British Columbia has, of course, changed significantly over the last century and a half in both speed and carrying capacity. The period of study is characterized by travel on foot and bulk movements powered by horses to increasingly more capable use of railroads and steam engines and roads and the internal combustion engine. In order to calibrate the transportation network analysis model to account for this change, two sets of travel modes were created: one for the "horse-and-buggy" era and one for the post-automobile era.

The transition from horse-drawn coaches and wagons to automobiles was gradual, and the poor condition of resource roads meant that horses were still used to move workers and freight in rural areas long after automobiles had been adopted in urban centres (British Columbia Ministry of Transportation, n.d.; Nikiforuk 2013; Harris 1983). For the sake of simplicity, all road travel prior to 1940 was assumed to have been via horse-drawn modes. Detailed information about specific road conditions and travel speeds possible during the "horse-and-buggy era" in BC was not available, so travel times were roughly estimated using indices from Gorton (1989) and examples from Harris (1983) as follows: 15 kilometres per hour for the few highways in existence at that time, 8 kilometres per hour for all other road types, and 30 kilometres per hour for rail.

Modern travel times required fewer assumptions. Rail speeds, train types, and junctions were included in the railway data, and the model limited rail travel to track segments classified as suitable for freight. Road travel times were inferred by adapting logic suggested by DMTI (2012), by combining road classifications (known as "carto values") with proximity to populated areas, as shown in Table 4.2.

Table 4.2. Road classifications and estimated travel time (after 1940).

		Travel time (km/hr)	
Carto*	**Road Type**	**Populated**	**Sparsely Populated**
2	Highway	80	80
3	Arterial	60	80
4	Collector	50	80
5	Local	30	50
n/a	Resource	40	40

* Carto 1 (expressway) is missing from this table because this classification is not assigned to any BC roads.

A thoughtful reader might point out that travel speeds would not have remained constant during either of these eras, and would actually have increased as technology improved, with the transition from horse to engine merely representing one significant surge in an overall upward trend. The simplification of this dynamic change as two distinct modes is an acknowledged limitation of this model.

4.3.2.2 Elevation adjustment and turn modelling

Travel speeds were adjusted for changes in elevation for both the "horse-and-buggy" and automobile eras. These adjustments were made by calculating the average slope of transportation route segments using a digital elevation model of BC, and then applying the travel time multipliers suggested by Price (2008) to penalize segments with steeper slopes.

Following Price's (2008) methodology, turn delays were defined for the automobile era to account for slowdowns in travel speed associated with changes in direction. Penalties for different turn types were selected using standard logic suggested by Price (2008): 2 seconds for right turns (minimum turn angle of 30 degrees), 4 seconds for left-turns (minimum turn angle of 210 degrees), 20 seconds for a U-turn (minimum turn angle of 150 degrees), and 1 second for each crossroad. Turns were not modeled for the "horse-and-buggy" era. Given the sparse network of roads in rural BC, the addition of turn and crossroad delays did not have a significant impact on the calculations.

4.4 Discussion: Reflection on collection

Information is valuable. *The Economist* (2017, 17) recently called data's relevance to this century "what oil was to the last one: a driver of growth and change." Innovations in data collection and sharing technologies have opened up a world of new possibilities for researchers.

The analysis conducted in this thesis would not have been possible two decades ago—maybe even one decade ago—because the data required to support it would not have been published in accessible formats. Today, many public and some private institutions make digital resources relating to BC's development history available. Most notably, open data initiatives at both the provincial and federal level provide access to an abundance of government data, as well as detailed descriptions of those datasets restricted to government use.

Nevertheless, before turning to the use of this data (in my next chapter), an observation on the foregoing collection process: it was extremely challenging. Setting aside the historical scope of what I wanted to assemble, the gaps in data on British Columbia's resource development industry and associated infrastructure *as it currently stands* are disquieting. Even in the last twenty years, information on some topics has been housed in separate, non-contiguous datasets that are difficult to reconcile with one another; this is usually the result of revisions to collection protocols or to database structures. Some datasets are maintained as a rolling snapshot of current conditions, with old records overwritten as new information becomes available, and a resultant loss of historical dimension. Temporal data (other than the date a particular record was created or last revised) simply does not exist for many datasets. Some datasets are acknowledged by their publishers as incomplete (e.g., the previously discussed resource roads), while others were found to be incomplete when projected spatially or when their metadata were closely examined.

Planning for developments that are not yet built is a tough task: dealing with the future is inherently complicated. It is therefore somewhat alarming to note that we seem to have a rather patchy picture of developments that have been built already, which is the part of the analysis that ought to be easy.

Possibly some growing pains were inevitable, given the pace at which the technologies for amassing and storing information have developed over the past few decades. It is important to recognize that those gaps impair our ability to perform stressor-based CEA (where projects and project-related activities represent key stressors). For example, we know that linear disturbances result in habitat fragmentation and concomitant impacts on wildlife and plant species, yet we do not know where many resource roads are, even ones authorized by government permit.

To improve stressor-based approaches in environmental impact assessment, I argue that two things are necessary. First, going forward, it will be critical to properly inventory and monitor stressor projects: to retain complete records of both their spatial and temporal attributes, and to ensure connectivity with older methods of record-keeping on an on-going basis. This seems like such an obvious and sensible solution that I have to note it first, but it will take time and resources to amass data that meets these higher expectations for quality. For this reason, I actually believe the second item is more important: we must be prepared to be innovative with the information we have at our disposal today. While being mindful of the real limitations of our current datasets, we can construct frameworks to better incorporate stressors into predictive exercises like environmental impact assessments. In the following chapters, I demonstrate what might be achieved even with the data limitations I have complained at length about in this one.

Chapter 5: Travel time analysis

> The word is about, there's something evolving.
> Whatever may come, the world keeps revolving.
> They say the next big thing is here,
> that the revolution's near,
> but to me it seems quite clear
> that it's all just a little bit of history repeating.
> —Propellerheads, *History Repeating* (1998)

5.1 Introduction

The intent of this chapter is to introduce a methodology for exploring how project developments may be related to one another in time and space. The weak form of such a pattern is a statistical association. A strong form would provide evidence of causality. The difference between causation and association is important to note here. Causation is when one event instigates a second event: when I turn on an electric kettle, the diode lights up showing there is power and, unless the element is broken, the water inside heats up. Association is when there is a demonstrable relationship between two events: in my home, the French press is usually operating at around the same time as the toaster. One should obviously not infer causality from a mere statistical association, and in my coffee/toast example, one would be unwise to do so. According to Singleton and Straits (1999, 155–59), three additional criteria are typically required: (1) the cause precedes the effect in time (time precedence), (2) the manner by which the cause produces the effect is known (causal mechanism), and (3) the effect cannot be explained by a third variable (non-spuriousness).

In the case of resource development in BC, we can meet the time precedence and casual mechanism criteria for causality, but cannot rule out other factors shaping the patterns of development through time and space; as a non-experimental study, it is not possible to control for all variables. However, if (in addition to time precedence and causal mechanism) we can show relatively stable associations across temporal and spatial indexes, and furthermore demonstrate that these associations can produce more accurate projections of future development scenarios than those found in current cumulative effects assessments, then I argue that this is sufficient support for regarding these associations as proxies for causation in the limited context of CEA. (In Chapter 7, I draw a more explicit link between projects using a subset of the data.)

In this chapter, the approach presented is based on the premise of location theory reviewed in Chapter 3 about the role of proximity as an attractant to development, as proposed by von Thünen (Chisholm 1961; O'Kelly and Bryan 1996), and specifically conceptualizing proximity in units of travel time, as suggested by Chomitz and Gray (1996). The analysis presented does not consider the heterogeneity of landscapes in terms of resource availability, but only timing heterogeneity borne of changes in technology and demand for economic development. In alignment with stressor-based methods, this simple approach measures the potential for a proposed project to induce future development, which could be compared to the existing state of development in the context of project-level CEA.

As discussed in the preceding chapter, I assembled a database of British Columbia's past and present resource development projects and created a two-mode transportation network analysis model for the province. I used the projects in the database to create a suite of spatial variables—

classified as gas plants, coal mines, hydro projects, powerlines, metal mines, mineral mines, major roads, and railroads—that I evaluated for their potential association with subsequent development patterns. This chapter presents both the methods used in this analysis and the results.

5.2 Methods

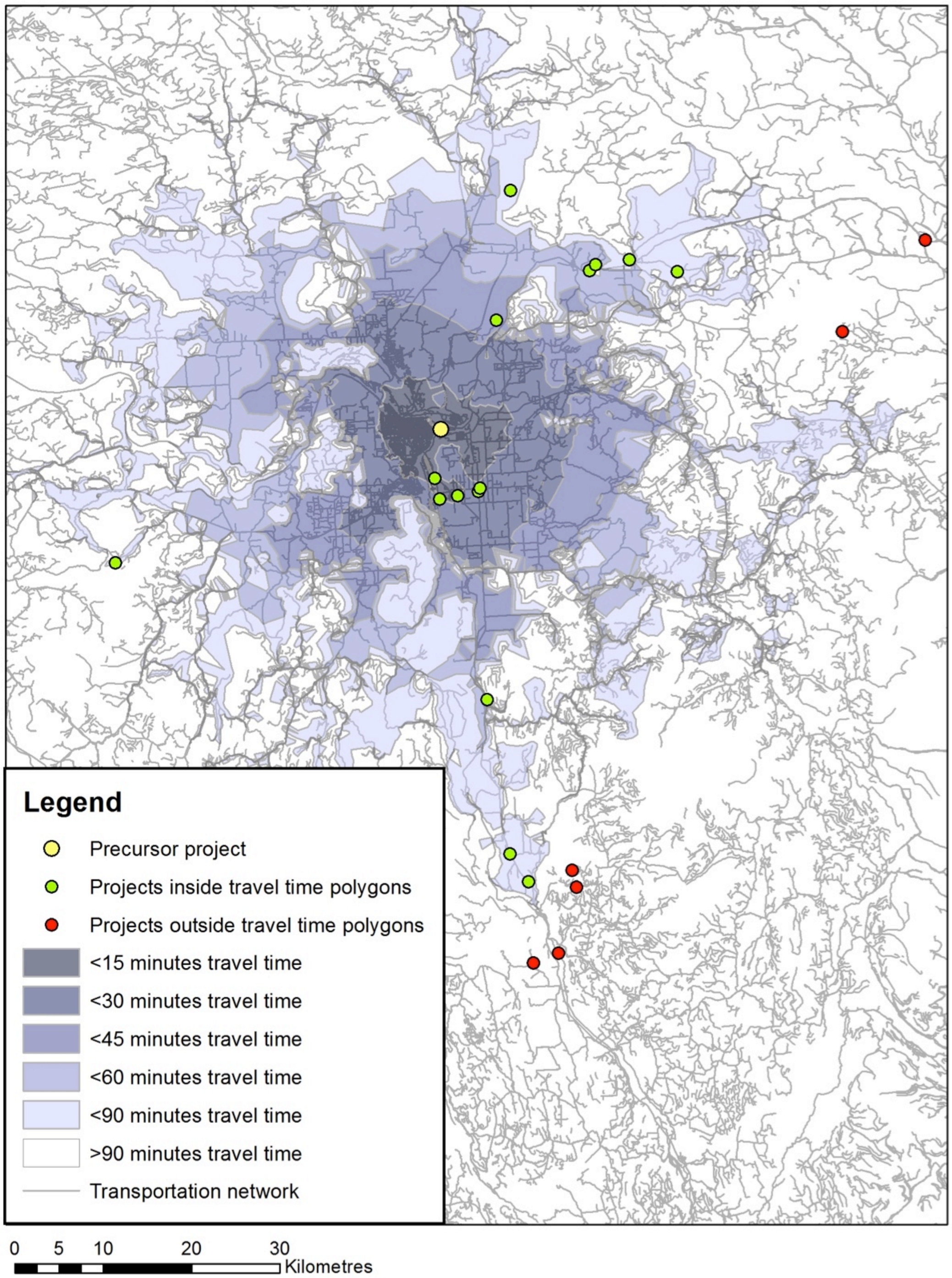
The data and transportation network analysis model described in the preceding chapter were used to examine the potential connections between developments co-occurring within specific spatial and temporal limits. Exploring the frequency at which new projects of specific types (which I call *follower projects*) occurred within a certain number of years and within a set distance of earlier projects (which I call *precursor projects)* then followed. To do this, I used a Python script developed for ArcGIS by Sevtsuk and Mekonnen (2012), taking inputs from the network analysis model described in the previous chapter to calculate the travel times between all projects in the database.

By calculating the travel time from the starting point of a precursor project to the end point of all other projects, I could identify potential precursor-follower project pairings (i.e., follower projects within a reasonable proximity of precursor projects along the existing transportation network). Travel times were calculated from the existing centroid point locations for coal, metal, and mineral mines, hydroelectric projects, and gas plants. Linear features—powerlines, major roads, and railroads—were first converted to sets of points spaced a maximum of 100 metres apart. These points were then geoprocessed to select those closest to entry points along the greater transportation network, to a distance of five kilometres.

From both types of points, follower projects that occurred 30 or fewer years after precursor projects were identified. Projects built within the first year of precursor project commissioning were excluded from this analysis, with the rationale that these projects were likely contemplated at the same time as the precursor project, and would have gone ahead with or without it. It is interesting to note that these types of projects are often the only ones considered as “future projects” in typical cumulative effects assessments. Spatial limits were set as the maximum distances that could be travelled along the contemporaneous transportation network within 15, 30, 45, 60, and 90 minutes. Figure 5.1 illustrates this concept. The yellow marker indicates a sample precursor project. The polygons shown in progressively lighter shades of purple indicate the areas in which a vehicle could travel (from a starting point at the precursor project) within 15, 30, 45, 60, and 90 minutes. To reach the area shown in white would require more than 90 minutes of travel. The green markers indicate projects that fall within the purple travel time polygons, and would thus have been counted as follower projects; the red markers indicate projects that were outside the travel time polygons and would have been excluded as follower projects.

The different possible combinations of these spatial and temporal limits are hereafter referred to as *space-time cells* (for the purposes of this travel time analysis, there are 145 space-time cells, representing all possible combinations of 5 spatial and 29 temporal limits).

Figure 5.1. Example of travel time analysis, showing travel time polygons emanating from a sample precursor project, with potential follower projects inside and outside the polygons.

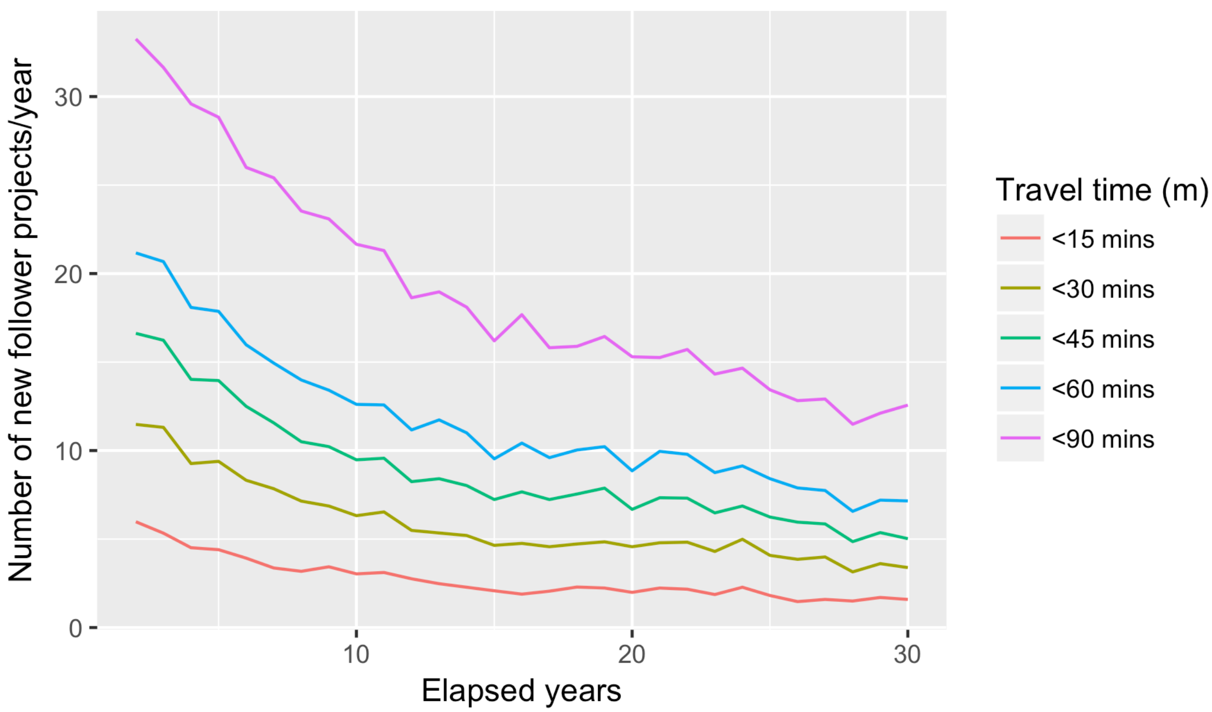


5.3 Results

5.3.1 Overall trends

The travel time analysis produced a list of potentially linked precursor and follower projects within each of the spatial limits, distributed over time as shown in Figure 5.2. All values shown are cumulative, encompassing all lesser travel times.

Figure 5.2. Potential follower projects occurring within travel time spatial limits, 1852 to 2015.



Within each spatial limit, the highest rate of follower projects/year occurs in the first few years after precursor project commissioning, with a gradually declining rate thereafter. The annual number of new follower projects only declines to half of this initial rate in the 13- to 23-year window, depending on the spatial limit (note this pattern changes when sub-periods are examined, as shown in Figures 5.3 to 5.5 below). This first analysis supports the argument that a longer time horizon (certainly greater than two years from precursor project commissioning) is necessary to capture a more accurate projection of future development.

Carrying out this analysis separately for each temporal category (summarized in Figures 5.3 to 5.5),[15] we see that the highest rates of project-building occurring between 1900 and 1949, the second highest between 1852 and 1899, and the lowest between 1950 and 2015. This reflects the modern shift from numerous small projects toward larger project sizes and capacities (as discussed in Chapter 2) due to technological innovation and economies of scale. Some of the trends discussed previously held true, in that the first few years after precursor project commissioning tend to be the period in which the greatest numbers of follower projects occur and an overall decline is observable thereafter.

However, that decline is most precipitous in the earliest of the three temporal categories, and becomes markedly less so in each of the ensuing periods, particularly within travel times of 60 minutes or less. Between 1852 and 1899, it took 12 years for the rate of follower projects per year to decline to half of the peak rate within all spatial limits; between 1900 and 1949 that number had risen to 20 years, and between 1950 and 2015 it took up to 28 years.

[15] Note that the rates shown in this sequence of figures show the number of follower projects linked to precursor projects built over the entirety of each period. The x-axes refer to the number of years that elapsed after *each* precursor project was built, and not to a 30-year period. For this reason, the rates indicated at the right-hand side of the 1852-1899 graph (Figure 5.3) do not match up with those on the left-hand side of the 1900-1949 graph (Figure 5.4), and so on.

Figure 5.3. Potential follower projects occurring within travel time spatial limits, 1852 to 1899.

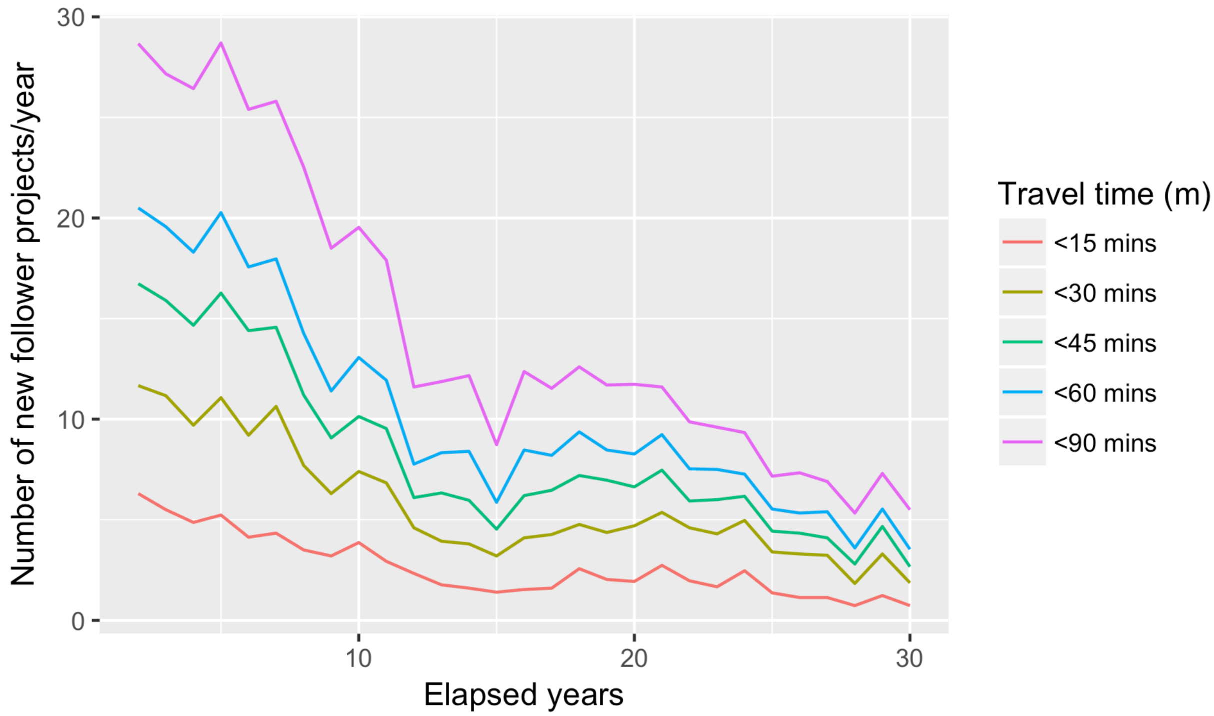


Figure 5.4. Potential follower projects occurring within travel time spatial limits, 1900 to 1949.

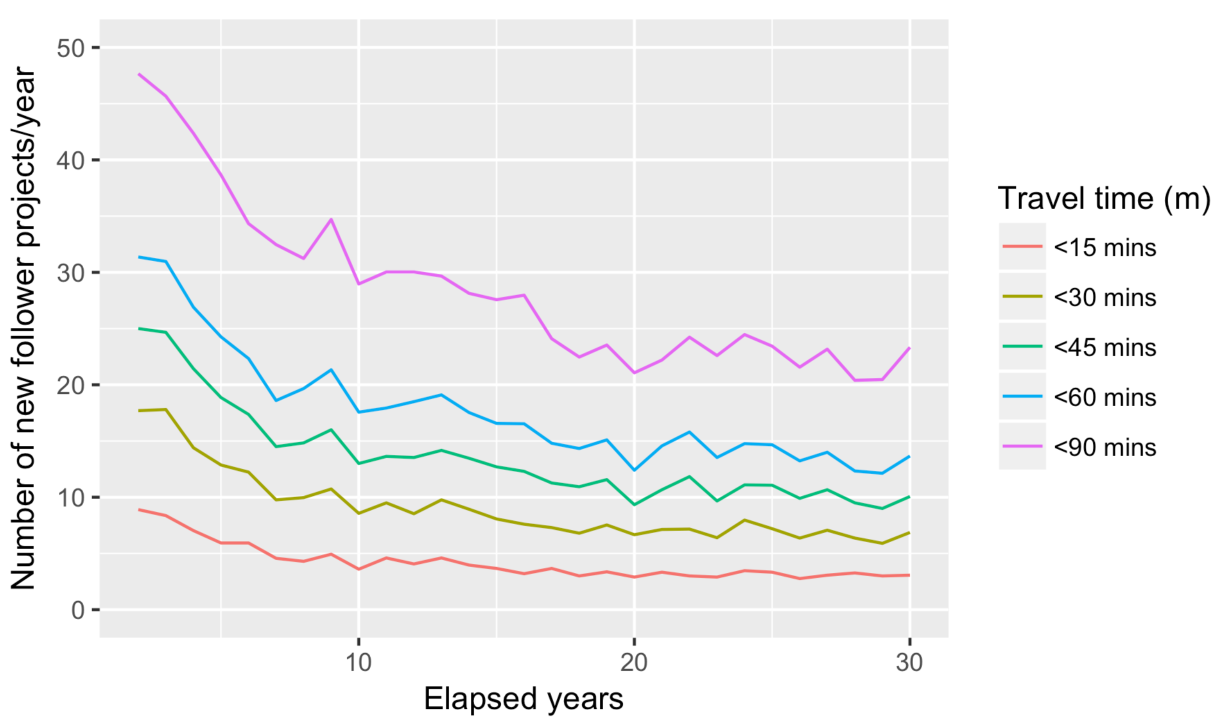
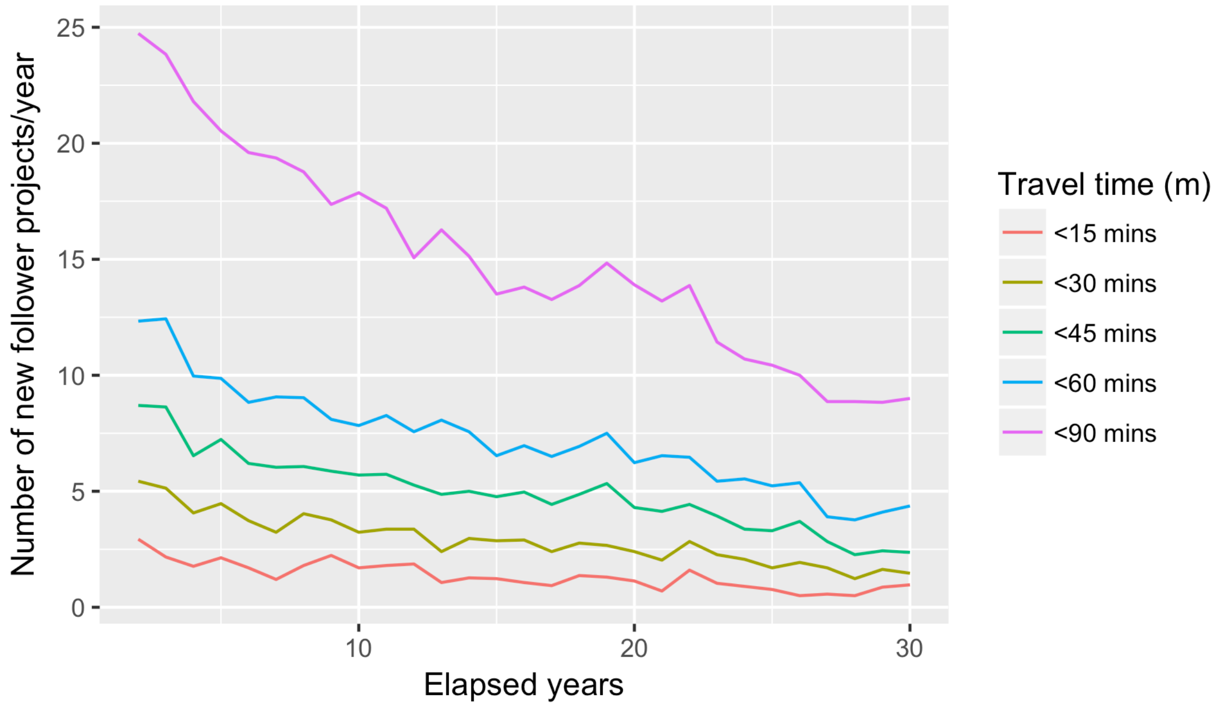


Figure 5.5. Potential follower projects occurring within travel time spatial limits, 1950 to 2015.



We can also observe a shift in the numbers of follower projects built at greater distances from precursor projects; between 1852 and 1899, the number of follower projects at 90 minutes' travel time was roughly three times the number of follower projects within 15 minutes, between 1900 and 1949 the multiplier was five, and between 1950 and 2015 it was nearly ten. (This is already taking into account the faster modes of transportation available during the later periods).

5.3.2 Trends by project type

Other trends emerge when we examine the frequency at which projects of specific project types have historically followed others. A sample of the output of this calculation is provided in Table 5.3, showing the mean number of metal mines that followed between 15 and 25 years of precursor coal mines during the most recent temporal category. Again, all values in Table 5.1 are cumulative (i.e., encompass all lesser spatial and temporal means). As shown in this example, coal mines commissioned during this period were followed by a mean of 0.88 metal mines within 60 minutes' travel distance and 16 years' time. At 90 minutes' travel distance and 25 years' time, the mean increased to 4.88 metal mines.

Table 5.1. Sample: Mean number of metal mines following a precursor coal mine, 1950 to 2015.

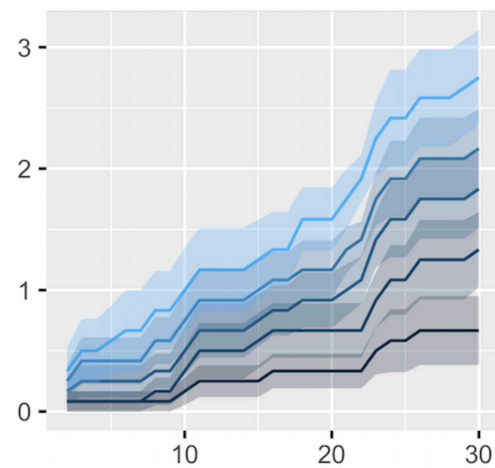
Elapsed years since precursor project commissioning	Travel time (minutes)				
	<15	<30	<45	<60	<90
15	0.00	0.25	0.75	1.25	3.13
16	0.00	0.25	0.88	1.38	3.38
17	0.00	0.25	0.88	1.38	3.38
18	0.00	0.38	1.00	1.50	3.75
19	0.00	0.38	1.00	1.50	3.88
20	0.00	0.38	1.00	1.63	4.00
21	0.00	0.50	1.13	1.88	4.38
22	0.00	0.63	1.25	2.00	4.50
23	0.00	0.63	1.25	2.00	4.63
24	0.00	0.63	1.25	2.00	4.75
25	0.00	0.63	1.25	2.00	4.88

The calculated means are presented in *space-time spillover* (STS) graphs presented in Figures 5.6 to 5.13. These STS graphs convey information about rates of development, their areal distribution, and the adequacy of the space-time framework in characterizing patterns of follower project development. The STS graphs contain separate panels for each relevant development type. Graphs with fewer than eight panels reflect the fact that one or more combinations of precursor and follower project types did not occur within the travel time distances depicted.

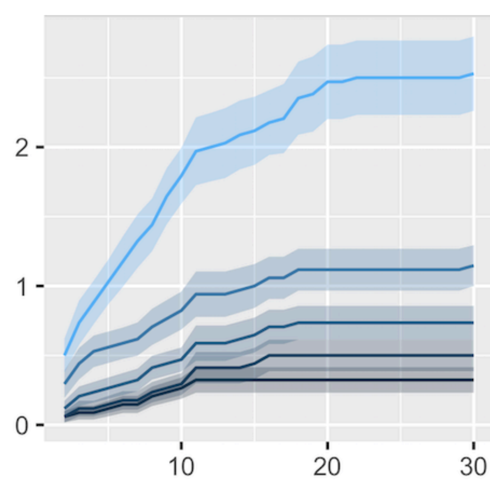
The horizontal axis of an STS graph shows the timing of follower projects, from 2 to 30 years after the precursor project. The blue lines differentiate follower projects by their distance from the precursor project (distances are in terms of minutes of travel between the centroids of precursor project locations (i.e., from 15 to 90 minutes' distance). The vertical axis shows the mean number of follower projects occurring after precursor project commissioning.

The trajectory at a specific time intervals (plotted on the x-axis) provides information about rates of follower project development. Graph trajectories fall into three patterns and their hybrids. These patterns are:

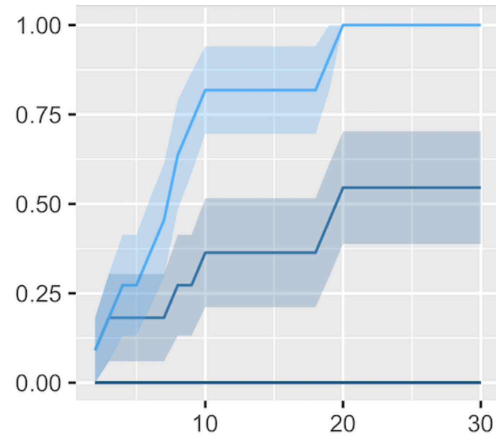
- *Linear*: where the lines are fairly straight with gradients that grow steeper by distance. These depict a relatively constant rate of project development that has remained fairly steady through time (e.g., precursor coal mines and follower coal mines, shown at right);



- *Asymptotic*: where the pattern is a rapidly rising line that then flattens at all distances (and error bands do not widen; see later note on error bands for more on this topic). This is typical of a saturation effect where rapid development quickly approaches or reaches an upper limit of

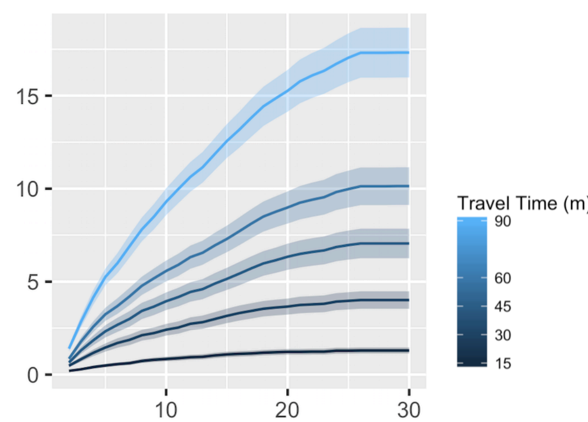


what is possible or needed (e.g., precursor hydro projects and follower major roads, shown at right); and



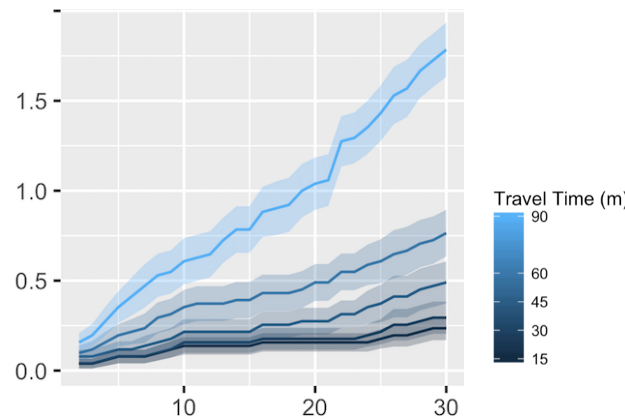
- *Stepped:* where the trajectory rises, is flat, and rises again after some time has elapsed. This is more likely when there are very few follower projects and each is followed by a period of hiatus (e.g., precursor metal mines and follower railroads, shown at right).

Comparison of trajectories at different travel times (depicted using different shades of blue lines) provides information about the spatial distribution of development. How the development trajectories fan out at different distances falls into three categories:

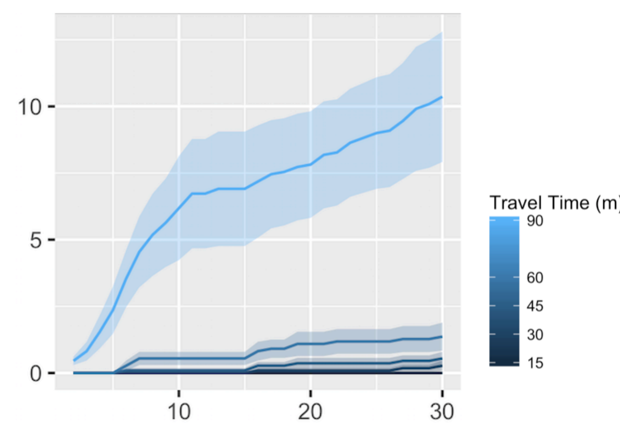


- *Radial*: where the project development opportunities are along a limited number of linear pathways radiating away from the initial project. In such cases, the potential for projects rises linearly with distance. In other words, if there is one project within 15 minutes' travel time, one expects 2 within 30 minutes and 6 within 90 minutes (e.g., precursor gas plants and follower gas plants, shown at right).

- *Areal*: where project development is distributed across the landscape. In this case, if we expect one project at 15 minutes' travel time, there would be 4 within 30 minutes' and 16 within 90 minutes (e.g., precursor powerlines and follower coal mines, shown at right).



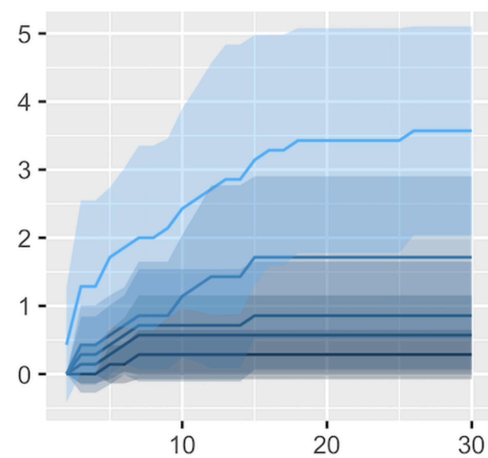
- *Clustered*: where projects effectively create focal points of activity. This is best illustrated with precursor coal mines and follower gas plants (shown at right), where plants are located strategically to collect and process over large areas; hence roughly 1 gas plant within 60 minutes' travel time, and yet 10 within 90 minutes' distance.



Project counts at the shortest travel time intervals are representative of one more real-world constraint. The extent of a precursor project (or its follower projects) can be larger than can be crossed in 15 minutes of travel. This leads to a zero count of follower projects for specific development type pairings at that distance.

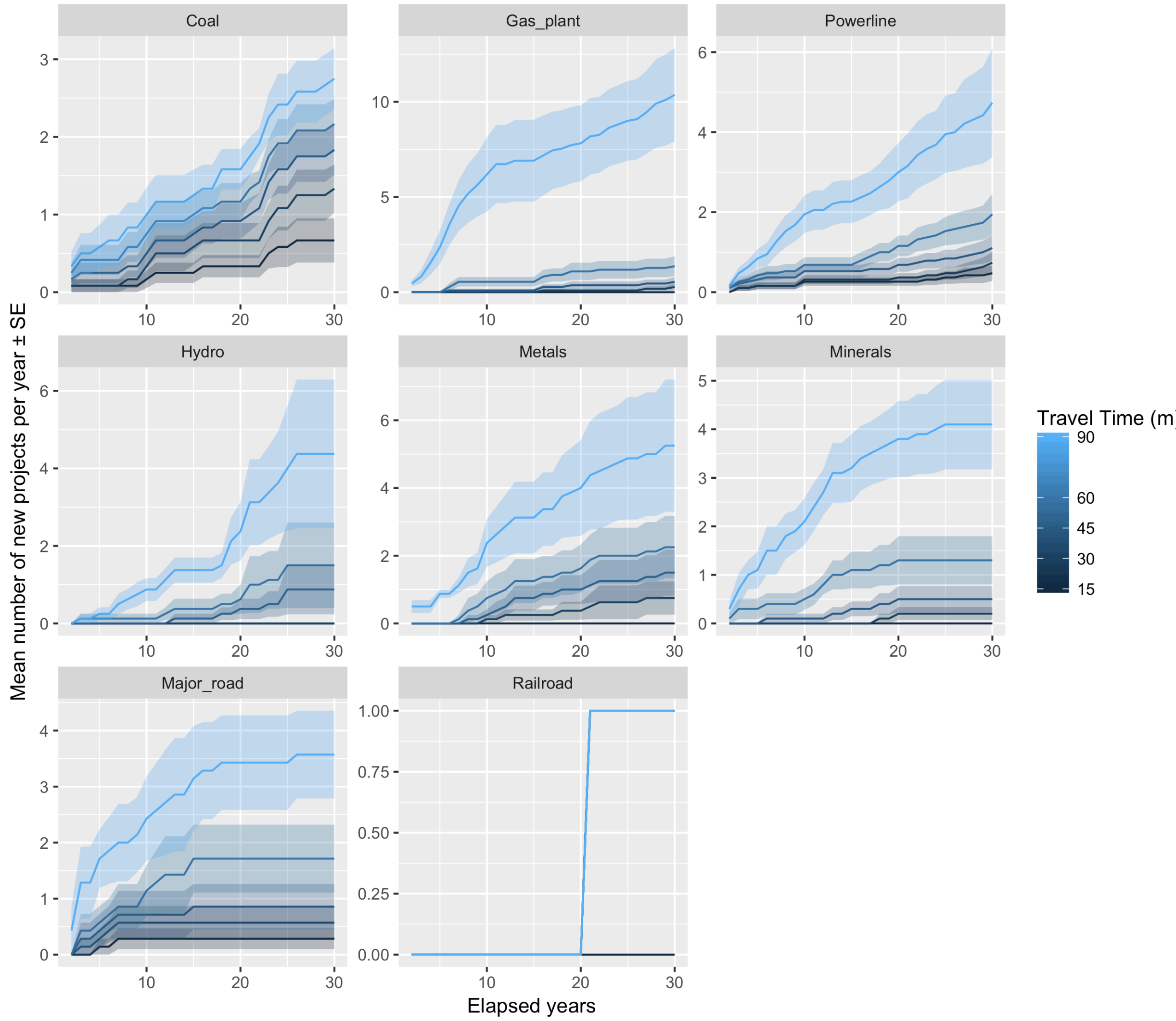
The width of the error band at each point along the trajectories indicates the confidence with which the approach can be used to create projections of follower project development. The STS graphs have been estimated over many space-time cells centered on a specific precursor project and informed by subsequent follower project development around it. This will, of course, vary across each space-time cell instantiation; hence, the graphs are averages across all observations and the error bands have similarly been calculated across all observations. Where bands are relatively narrow, projections for that particular development type pairing have a higher confidence level than when the bands are wide, hinting at other contextual factors (that vary in space and time) that are not explicitly used as an axis in STS graphs.

One final note about error bands pertains only to the STS graphs for the most recent temporal category (1950 to 2015). For precursor projects built subsequent to 1985, the full 30 years of data on all potential follower projects do not yet exist. This is reflected in lines that flatten long before the end of the graphed period as observations become sparser (e.g., precursor coal mines and follower major roads, shown at right). This pattern can be distinguished from the asymptotic pattern described above because the error band widens as the line flattens; in a true asymptotic pattern, the error band should stay relatively narrow.



The following pages contain the STS graphs for the most recent temporal category, 1950 to 2015; graphs for the other two temporal categories are presented in Appendices A and B.

Figure 5.6. Space-time spillover graph of travel time analysis results for precursor coal mines, 1950-2015.



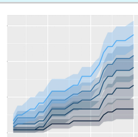
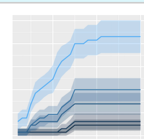
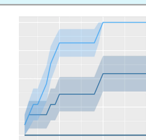
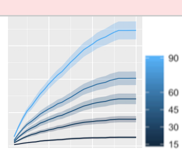
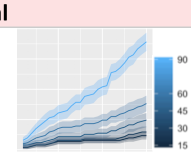
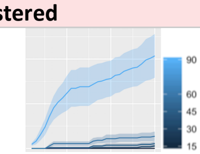
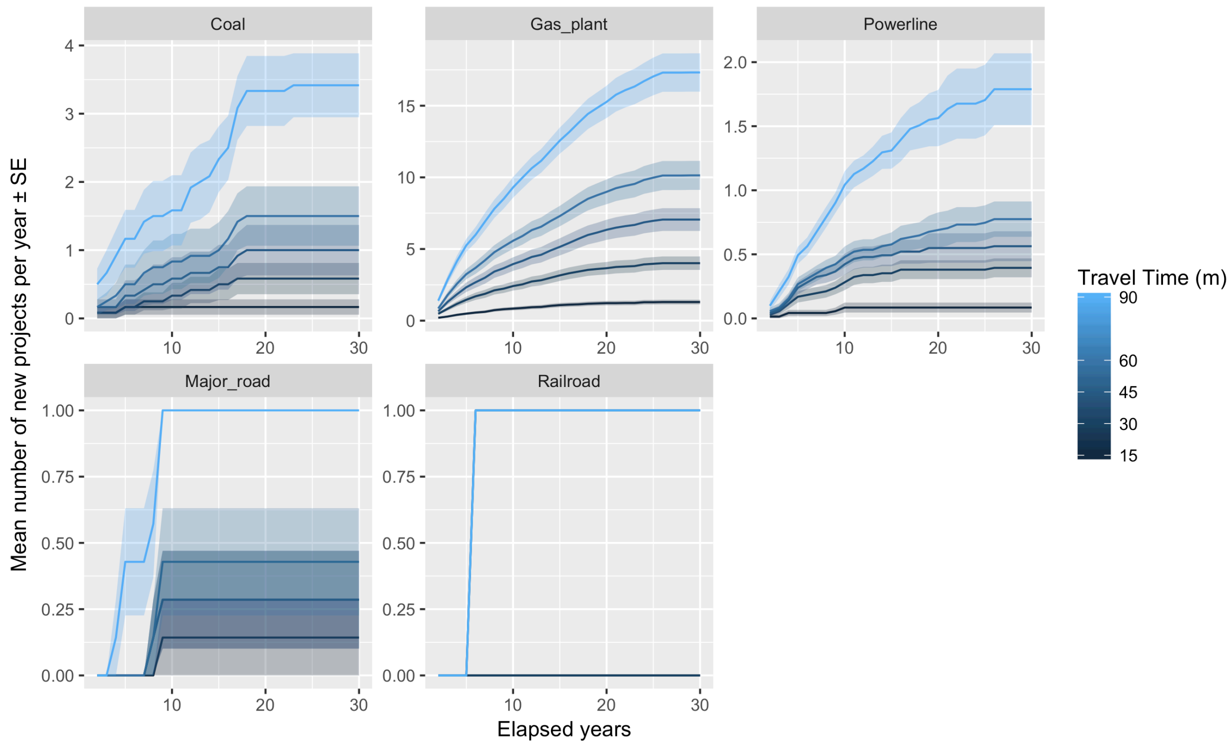
KEY (see text above for a more detailed guide to interpreting this graph.)		
Trajectories at different *time intervals* describe follower project development rates:		
Linear	**Asymptotic**	**Stepped**
A relatively constant rate of project development that has remained fairly steady through time. 	A saturation effect where rapid development quickly approaches or reaches an upper limit. 	Characterized by few follower projects, each followed by a period of hiatus. 
Fanning out of trajectories at different *distances* describes the spatial distribution of development:		
Radial	**Areal**	**Clustered**
Project development opportunities are along a limited number of linear pathways radiating away from the initial project. 	Project development is distributed across the landscape. 	Where projects effectively create focal points of activity. 

Figure 5.7. Space-time spillover graph of travel time analysis results for precursor gas plants, 1950-2015.



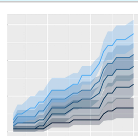
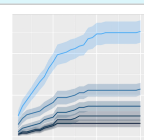
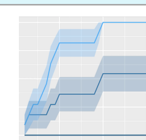
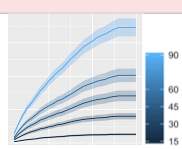
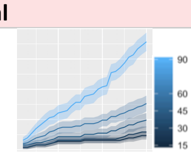
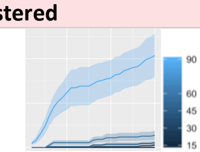
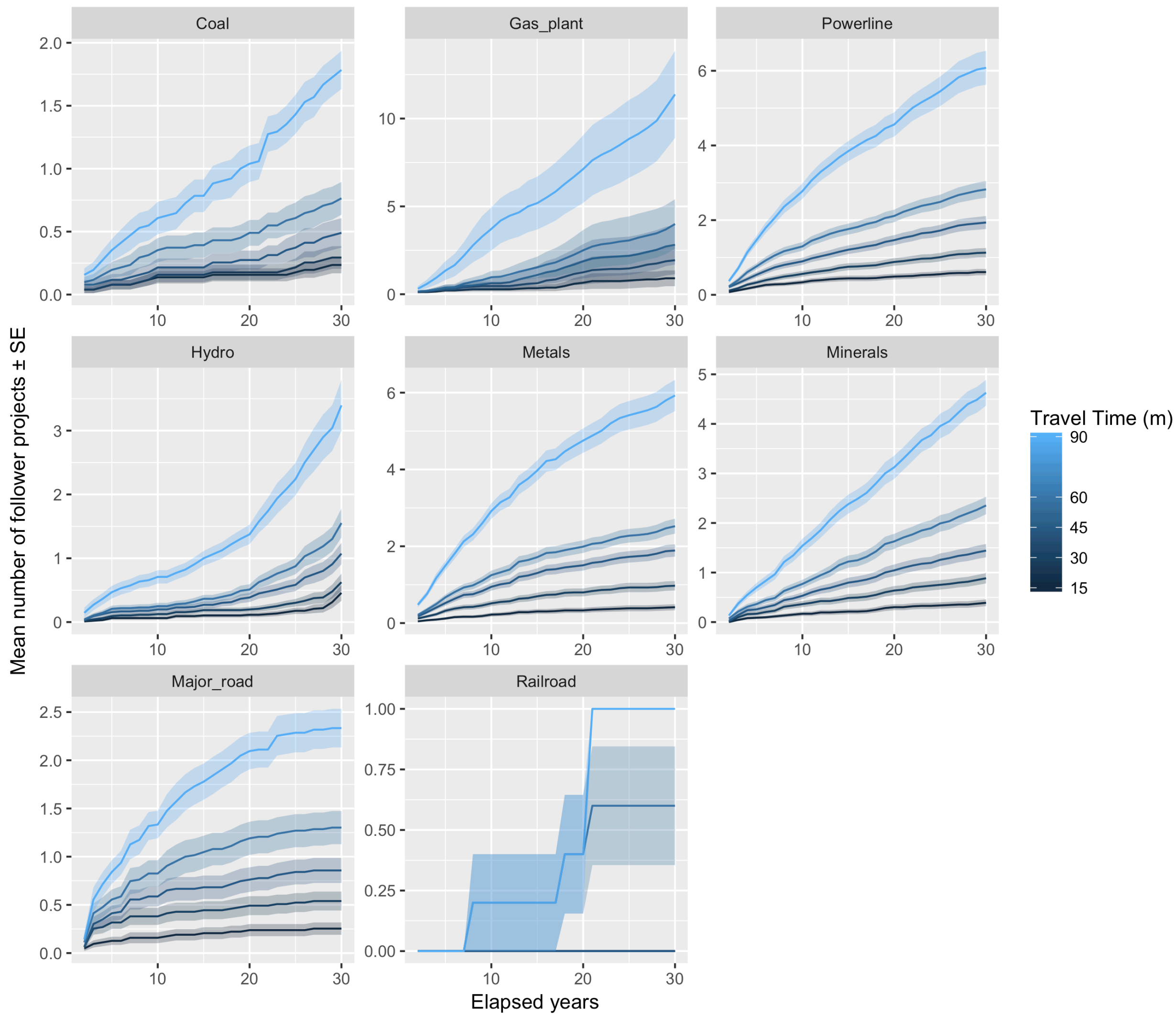
KEY (see text above for a more detailed guide to interpreting this graph.)		
Trajectories at different *time intervals* describe follower project development rates:		
Linear	**Asymptotic**	**Stepped**
A relatively constant rate of project development that has remained fairly steady through time. 	A saturation effect where rapid development quickly approaches or reaches an upper limit. 	Characterized by few follower projects, each followed by a period of hiatus. 
Fanning out of trajectories at different *distances* describes the spatial distribution of development:		
Radial	**Areal**	**Clustered**
Project development opportunities are along a limited number of linear pathways radiating away from the initial project. 	Project development is distributed across the landscape. 	Where projects effectively create focal points of activity. 

Figure 5.8. Space-time spillover graph of travel time analysis results for precursor powerlines, 1950-2015.



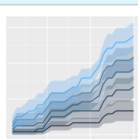
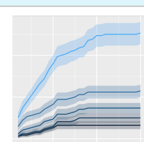
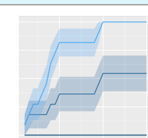
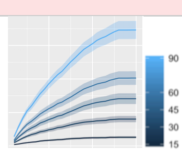
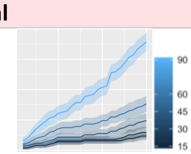
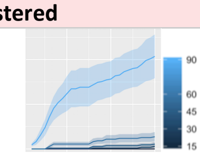
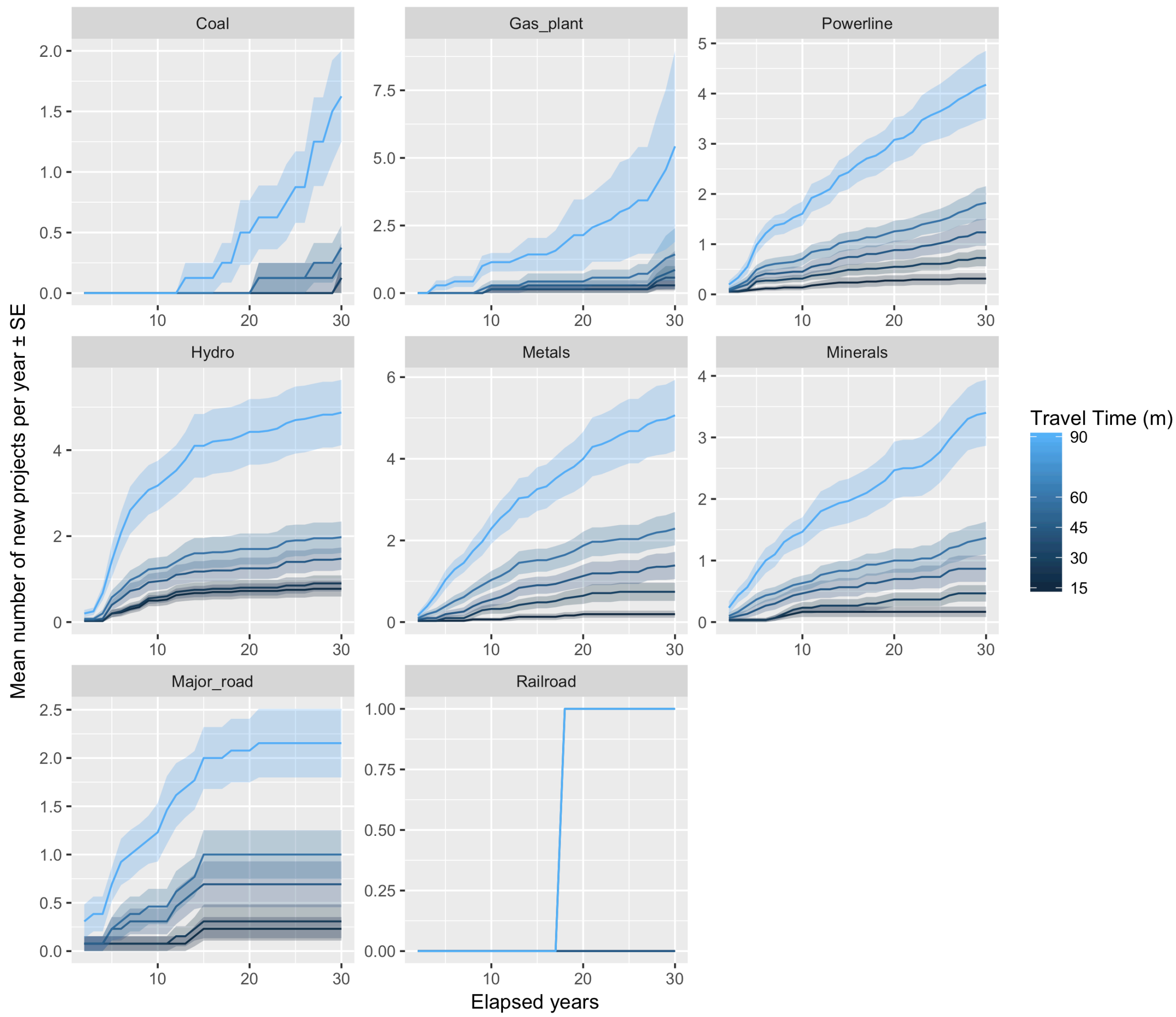
KEY (see text above for a more detailed guide to interpreting this graph.)		
Trajectories at different *time intervals* describe follower project development rates:		
Linear	**Asymptotic**	**Stepped**
A relatively constant rate of project development that has remained fairly steady through time. 	A saturation effect where rapid development quickly approaches or reaches an upper limit. 	Characterized by few follower projects, each followed by a period of hiatus. 
Fanning out of trajectories at different *distances* describes the spatial distribution of development:		
Radial	**Areal**	**Clustered**
Project development opportunities are along a limited number of linear pathways radiating away from the initial project. 	Project development is distributed across the landscape. 	Where projects effectively create focal points of activity. 

Figure 5.9. Space-time spillover graph of travel time analysis results for precursor hydro projects, 1950 to 2015.



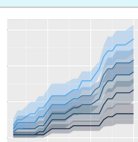
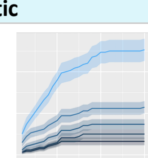
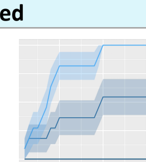
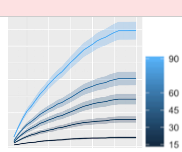
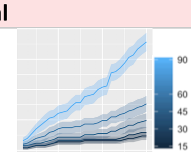
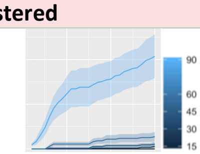
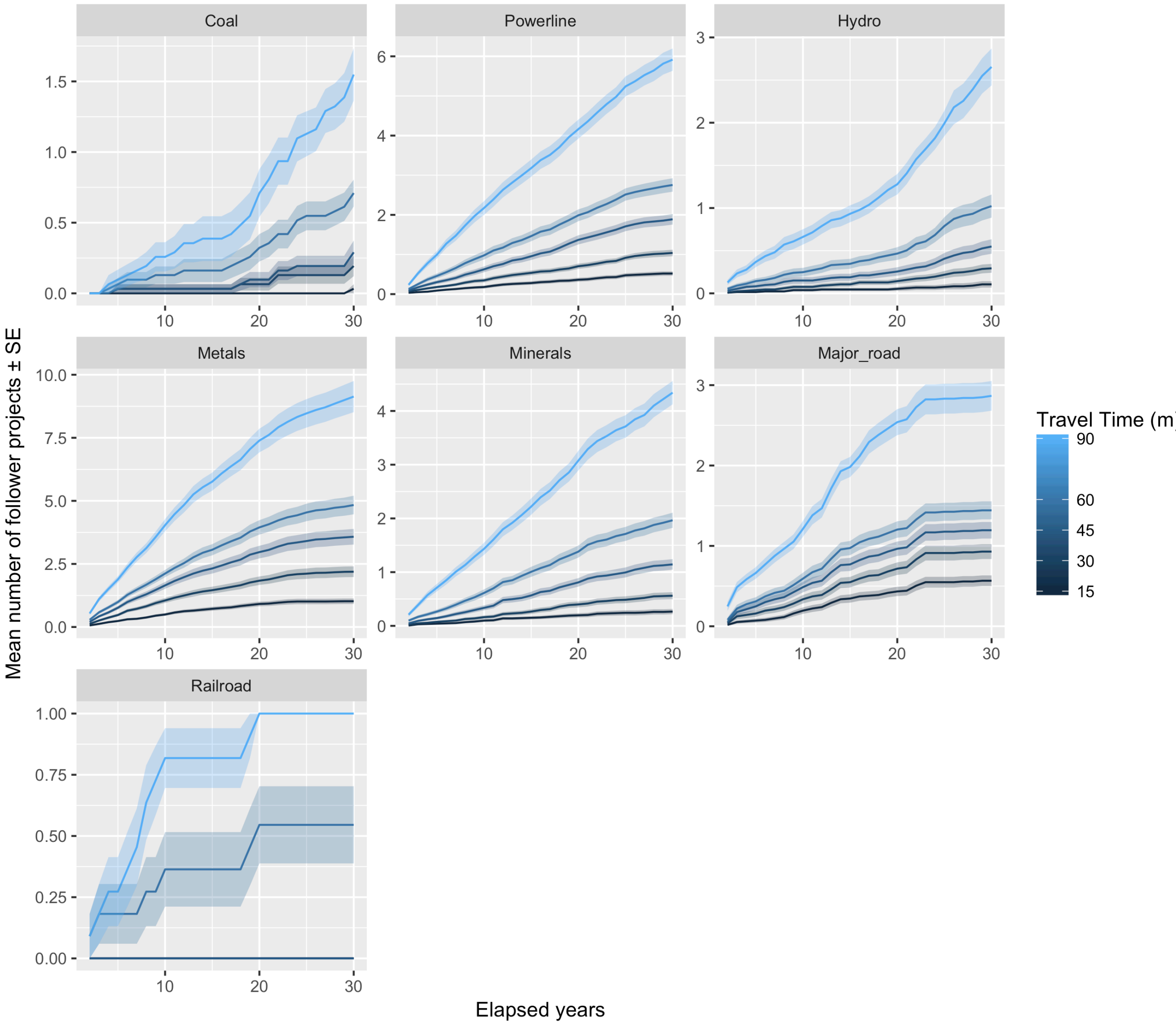
KEY (see text above for a more detailed guide to interpreting this graph.)		
Trajectories at different *time intervals* describe follower project development rates:		
Linear	**Asymptotic**	**Stepped**
A relatively constant rate of project development that has remained fairly steady through time. 	A saturation effect where rapid development quickly approaches or reaches an upper limit. 	Characterized by few follower projects, each followed by a period of hiatus. 
Fanning out of trajectories at different *distances* describes the spatial distribution of development:		
Radial	**Areal**	**Clustered**
Project development opportunities are along a limited number of linear pathways radiating away from the initial project. 	Project development is distributed across the landscape. 	Where projects effectively create focal points of activity. 

Figure 5.10. Space-time spillover graph of travel time analysis results for precursor metal mines, 1950 to 2015.



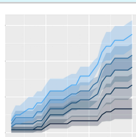
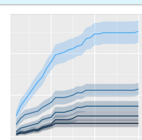
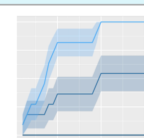
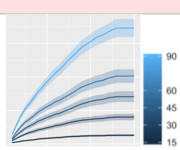
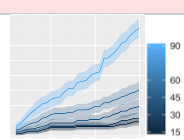
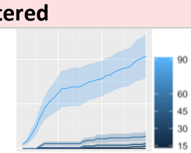
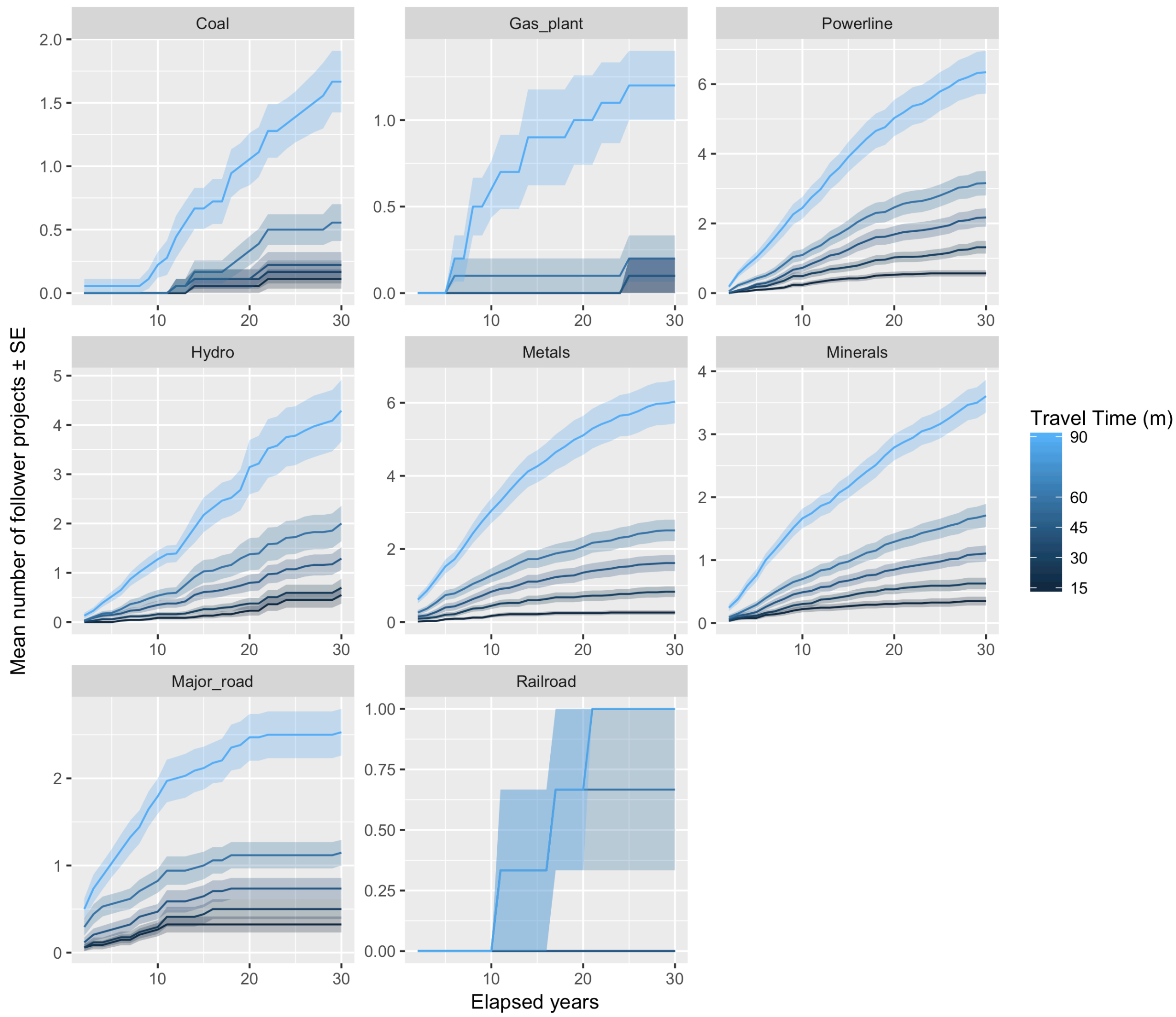
KEY (see text above for a more detailed guide to interpreting this graph.)		
Trajectories at different *time intervals* describe follower project development rates:		
Linear	**Asymptotic**	**Stepped**
A relatively constant rate of project development that has remained fairly steady through time. 	A saturation effect where rapid development quickly approaches or reaches an upper limit. 	Characterized by few follower projects, each followed by a period of hiatus. 
Fanning out of trajectories at different *distances* describes the spatial distribution of development:		
Radial	**Areal**	**Clustered**
Project development opportunities are along a limited number of linear pathways radiating away from the initial project. 	Project development is distributed across the landscape. 	Where projects effectively create focal points of activity. 

Figure 5.11. Space-time spillover graph of travel time analysis results for precursor mineral mines, 1950 to 2015.



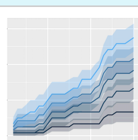
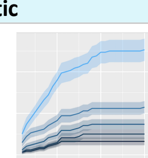
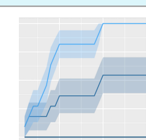
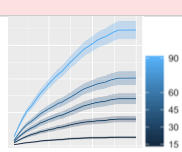
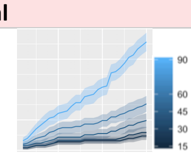
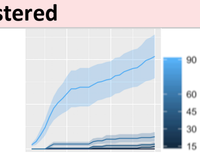
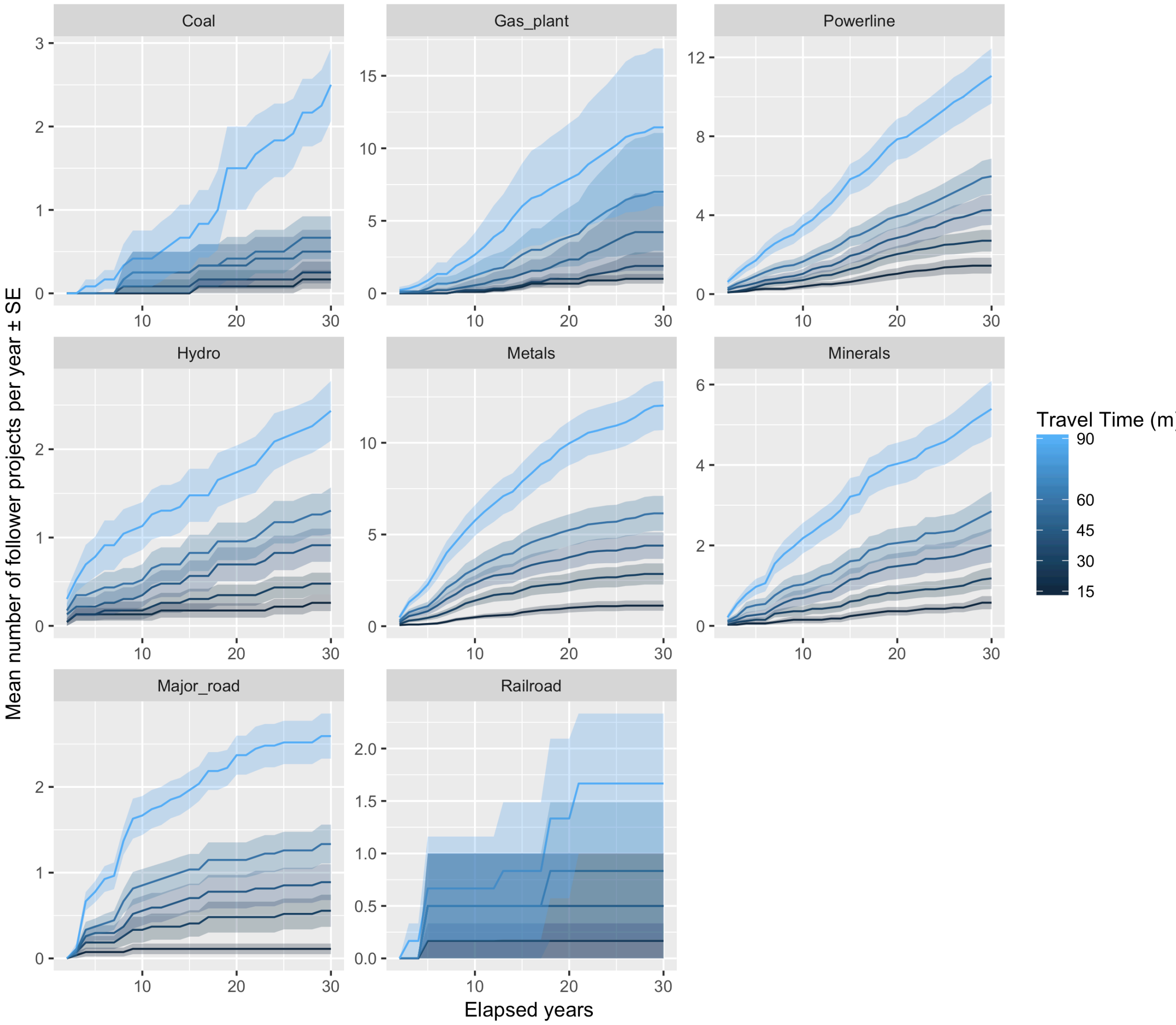
KEY (see text above for a more detailed guide to interpreting this graph.)		
Trajectories at different *time intervals* describe follower project development rates:		
Linear	**Asymptotic**	**Stepped**
A relatively constant rate of project development that has remained fairly steady through time. 	A saturation effect where rapid development quickly approaches or reaches an upper limit. 	Characterized by few follower projects, each followed by a period of hiatus. 
Fanning out of trajectories at different *distances* describes the spatial distribution of development:		
Radial	**Areal**	**Clustered**
Project development opportunities are along a limited number of linear pathways radiating away from the initial project. 	Project development is distributed across the landscape. 	Where projects effectively create focal points of activity. 

Figure 5.12. Space-time spillover graph of travel time analysis results for precursor major roads, 1950 to 2015.



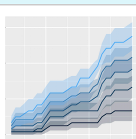
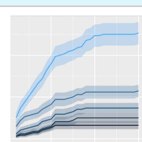
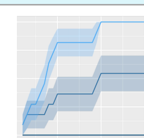
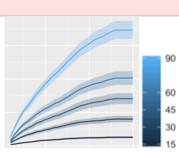
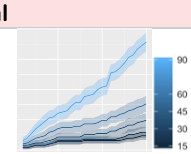
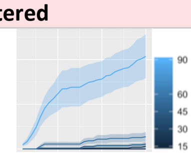
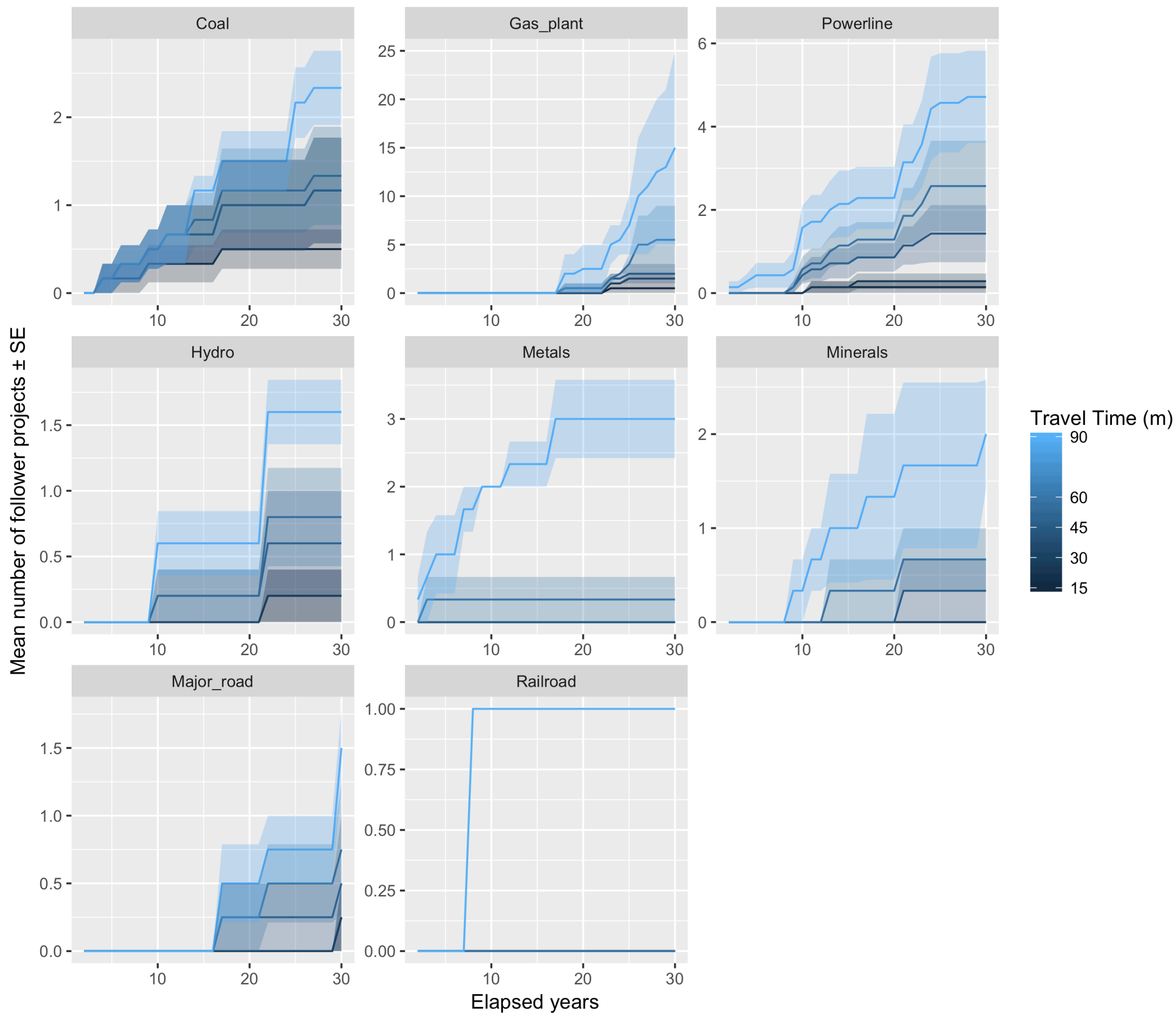
KEY (see text above for a more detailed guide to interpreting this graph.)		
Trajectories at different *time intervals* describe follower project development rates:		
Linear	**Asymptotic**	**Stepped**
A relatively constant rate of project development that has remained fairly steady through time. 	A saturation effect where rapid development quickly approaches or reaches an upper limit. 	Characterized by few follower projects, each followed by a period of hiatus. 
Fanning out of trajectories at different *distances* describes the spatial distribution of development:		
Radial	**Areal**	**Clustered**
Project development opportunities are along a limited number of linear pathways radiating away from the initial project. 	Project development is distributed across the landscape. 	Where projects effectively create focal points of activity. 

Figure 5.13. Space-time spillover graph of travel time analysis results for precursor railroads, 1950 to 2015.



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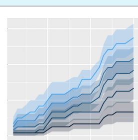
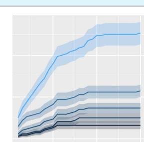
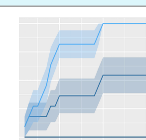
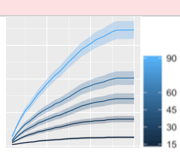
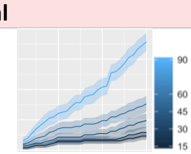
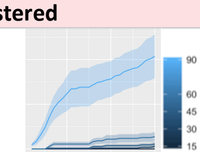
<tr><th colspan="3">KEY (see text above for a more detailed guide to interpreting this graph.)</th></tr>
<tr><td colspan="3">Trajectories at different time intervals describe follower project development rates:</td></tr>
<tr><th>Linear</th><th>Asymptotic</th><th>Stepped</th></tr>
<tr><td>A relatively constant rate of project development that has remained fairly steady through time. </td><td>A saturation effect where rapid development quickly approaches or reaches an upper limit. </td><td>Characterized by few follower projects, each followed by a period of hiatus. </td></tr>
<tr><td colspan="3">Fanning out of trajectories at different distances describes the spatial distribution of development:</td></tr>
<tr><th>Radial</th><th>Areal</th><th>Clustered</th></tr>
<tr><td>Project development opportunities are along a limited number of linear pathways radiating away from the initial project. </td><td>Project development is distributed across the landscape. </td><td>Where projects effectively create focal points of activity. </td></tr>
</table>

5.4 Discussion

I will refrain from a detailed discussion of the patterns displayed in all 60 STS graph panels generated from the data, and instead focus on a few examples.

On major roads: As a precursor project type, major roads are associated with the highest number of follower projects over the greatest number of follower project types. The STS graphs for major roads (Figure 5.8) display linear trajectories, suggesting that follower projects are being built on a fairly regular pace (i.e., not one that is rapidly escalating or diminishing over time). The trend lines fan out in mainly radial patterns, indicating that follower projects are occurring along limited linear pathways from the precursor road projects. An exception to this last observation is follower coal projects, which display a clustered pattern. Coal mining activities clearly can only occur in areas underlain by coal. In the last 65 years, most new coal mines have been built in either the Peace River Coalfield in BC's northeast or the East Kootenay coalfield in the southeast. The coal mines that exploit the same resource are therefore in proximity to one another. However, they may still be separated by a considerable distance, as modern mineral tenures for a single mine can be upwards of 60 kilometres from end to end. This represents a change from the coal mining of the 1800s and early 1900s, which tended to be at a smaller scale and more densely grouped (Matheson 1950; Muise and McIntosh 1996). Thus, the number of follower coal mines rises only slightly as travel distances increase from 15 minutes to 60 minutes, but nearly triples by the 90-minute interval. A similarly clustered pattern can be seen for any combination of precursor project and follower coal mines where there are many observations (i.e., precursor gas plants, hydro plants, metal mines, mineral mines, and powerlines), as indicated by the relatively narrow error bands.

On gas plants. The lack of panels in Figure 5.3 reflects the fact that BC's gas plants are bunched together both temporally and spatially, precluding several possible combinations with different follower project types. BC's natural gas industry is relatively new phenomenon; nearly all of the province's gas plants were built after 1989, and over two-thirds began operating in the last 15 years of the data set. In addition, gas plants are even more localized than coal mines, as they are found exclusively in the northeastern part of BC. As we can see in Figure 5.3, the most significant follower project types for gas plants are (1) more gas plants, capitalizing on the same resource, (2) coal mines, found in the same part of the province as the gas reserves, and (3) the powerlines required to meet the electricity demands of both the mines and natural gas exploration and development.

On the strange case of railroads: Only a handful (eight, to be exact) of railroad segments in the dataset were built within the last 65 years. This is reflected in the wide error bands and in the jagged trajectory of the graphed lines found in any STS graph panel involving a railroad as either a precursor or follower project. That the STS graphs did not show railroads leading to coal mines or vice versa came as a surprise, as many of the province's operating coal mines had rail spurs purpose-built to serve them (e.g., the Quintette mine, per Gunton 2003), either prior to or concurrently with their construction. However, closer examination showed that these spur segments were not included in the original data. In this analysis, then, projects with associated supportive infrastructure—such as major coal, metal, and mineral mines—may perhaps be seen as proxies where information about that supportive infrastructure is scant.

Chapter 6: Thinking topographically: Watershed analysis

6.1 Introduction

Travel distance is a logical spatial index for understanding the proliferation of development reliant on movement of people and materials. However, in some applications, it might be preferable to model the impacts of stressors using ecologically significant boundaries, such as an airshed, watershed, or eco-region. Furthermore, landscapes are not homogenous; different areas have distinct features (geological, hydrological, topographical) that make certain types of resource development possible. In the following chapter, I make two refinements to the approach introduced in Chapter 5: first, I use ecologically derived spatial boundaries (watersheds), and second, I classify landscapes according to their suitability for different kinds of resource development. These refinements broaden the focus of the analysis to a scale more appropriate for a regional CEA.

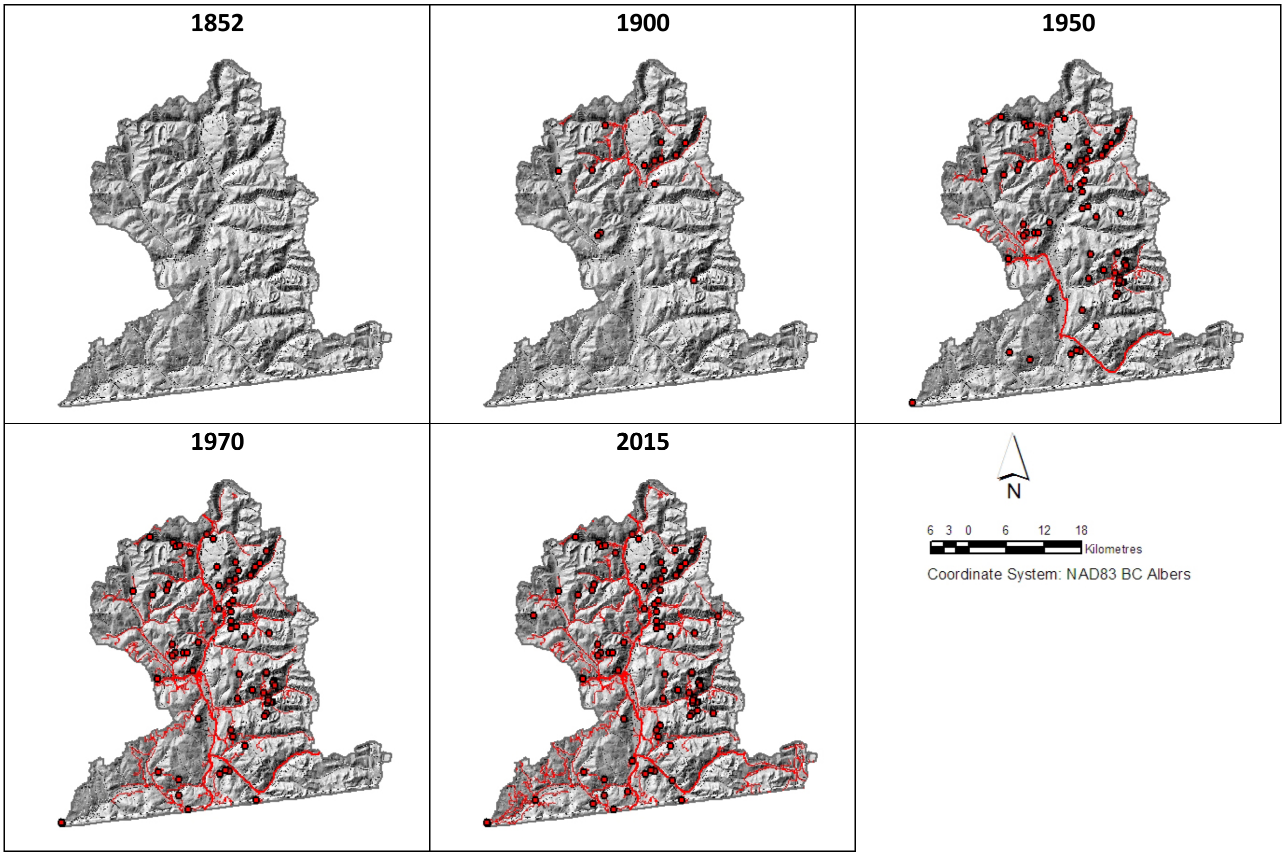
As was noted in Chapter 2, in hilly or mountainous terrain (like British Columbia's), roads and railways are typically built along riverbanks at valley bottoms, where gradients are flattest, and proximity to water and water transportation promotes human settlement (Forman 2003, 298–99). Road and railway construction over the high points and ridges that characterize the edges of major watershed systems is avoided, except when necessary. While a few major arteries provide transportation connectivity over greater distances, the majority of roads branch into lacy networks within basins, like the minor veins on a leaf. By dividing rail and major road routes from the database into 90-minute travel segments, we see that most of BC's transportation corridors conform to this pattern and stay within watershed system boundaries: about 87% of rail and 90% of major road segments never cross a boundary.

My premise is that in topographies like BC's, where the transportation network has been effectively shaped by the landscape, this characteristic could be leveraged to translate heuristics based on travel distances to ones based on watershed boundaries. Watersheds are the most common spatial boundaries used in cumulative effects assessments of terrestrial environments (Burns 1991; FEMAT 1993; Jamieson and Chew 2000).

6.2 Methods

To see if there was any consistency between development within travel distance boundaries and those within watershed boundaries, the analysis described in the previous chapter was repeated, using watershed system boundaries as the only spatial limit, resulting in 29 space-time cells for each development type pairing. Watershed systems were defined as third-order watersheds as classified in the BC Watershed Atlas (GeoBC 2015). An example of development over time within one such system—the Pend d'Oreille River watershed group—is depicted in Figure 6.1.

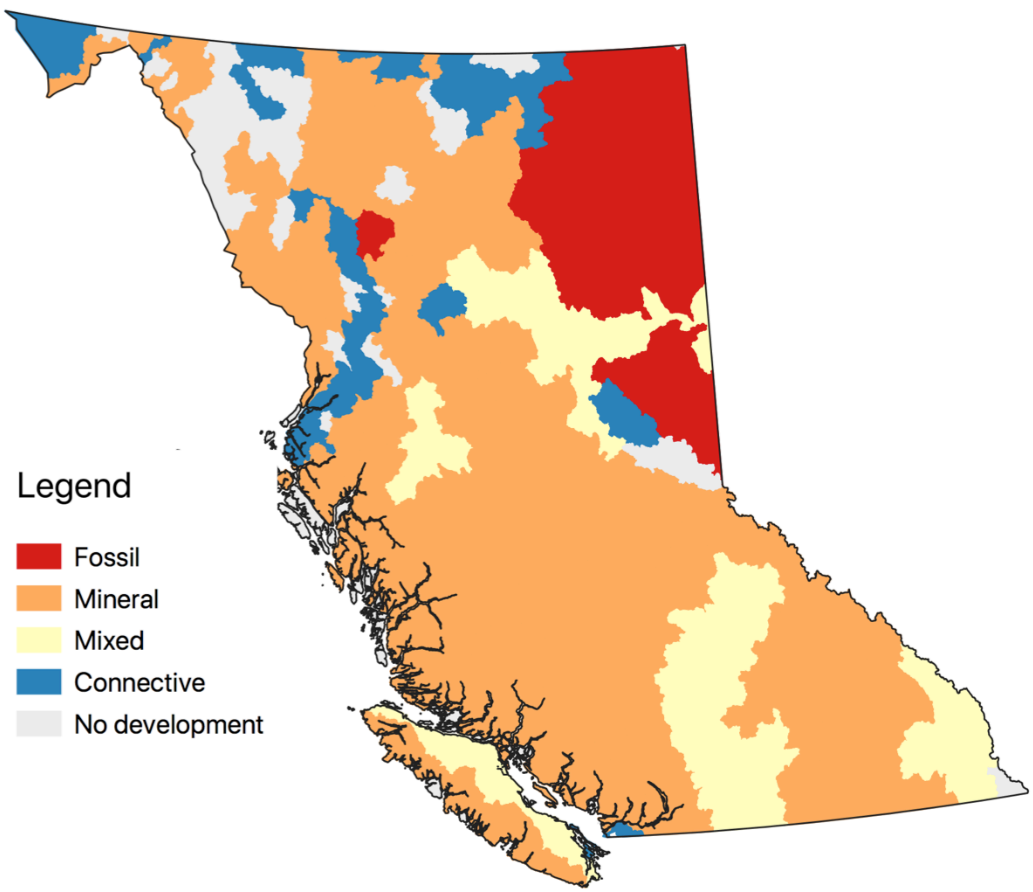
Figure 6.1. Resource development (all types shown in red) within the Pend d'Oreille River watershed group in southeastern British Columbia, 1852 to 2015.



Not every landscape has the same potential for resource development: for example, if there are no coal deposits in an area, there is no reason to expect that anyone will build a coal mine there. Linear features (major roads, railroads, and powerlines) provide connectivity between resource extraction points and markets. To credibly connect precursor and follower projects of all other types (mines, hydro projects, and gas plants), this analysis was augmented by classifying the major watersheds according to their resource potential. This was accomplished using spatial queries in ArcGIS to determine the project types built in each watershed over the entire 163 years of development history. Watersheds were differentiated as belonging to one of five categories, as follows (and shown in Figure 6.2):

1. **fossil watersheds** – containing predominantly coal mines and gas plants;
2. **mineral watersheds** – containing predominantly metal and mineral mines as well as hydro projects;
3. **mixed watersheds** – containing a combination of the above project types;
4. **connective watersheds** – containing only linear project types; and
5. **no development watersheds** – containing no projects.

Figure 6.2. Distribution of watershed types.



6.3 Results

6.3.1 Overall trends

The rates of follower projects per year derived from the watershed analysis, when calculated over the entirety of the dataset (1852 to 2015), proved to be markedly different than those obtained using the travel time analysis, as shown in Figure 6.3. This was largely due to differences in the results in the first two temporal categories (1852 to 1899, and 1900 to 1949), which are presented in Figures 6.4 and 6.5.[16] The rates in these categories did not decline markedly after year 5, but remained relatively stable (in the 1852 to 1899 category, the rate actually increased).

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[16] Again, the rates shown in this sequence of figures show the number of follower projects linked to precursor projects built over the entirety of each period. The x-axes refer to the number of years that elapsed after *each* precursor project was built, and not to a 30-year period. For this reason, the rates indicated at the right-hand side of the 1852-1899 graph (Figure 6.3) do not match up with those on the left-hand side of the 1900-1949 graph (Figure 6.4), and so on.

Figure 6.3. Potential follower projects occurring within watershed spatial limits, 1852 to 2015.

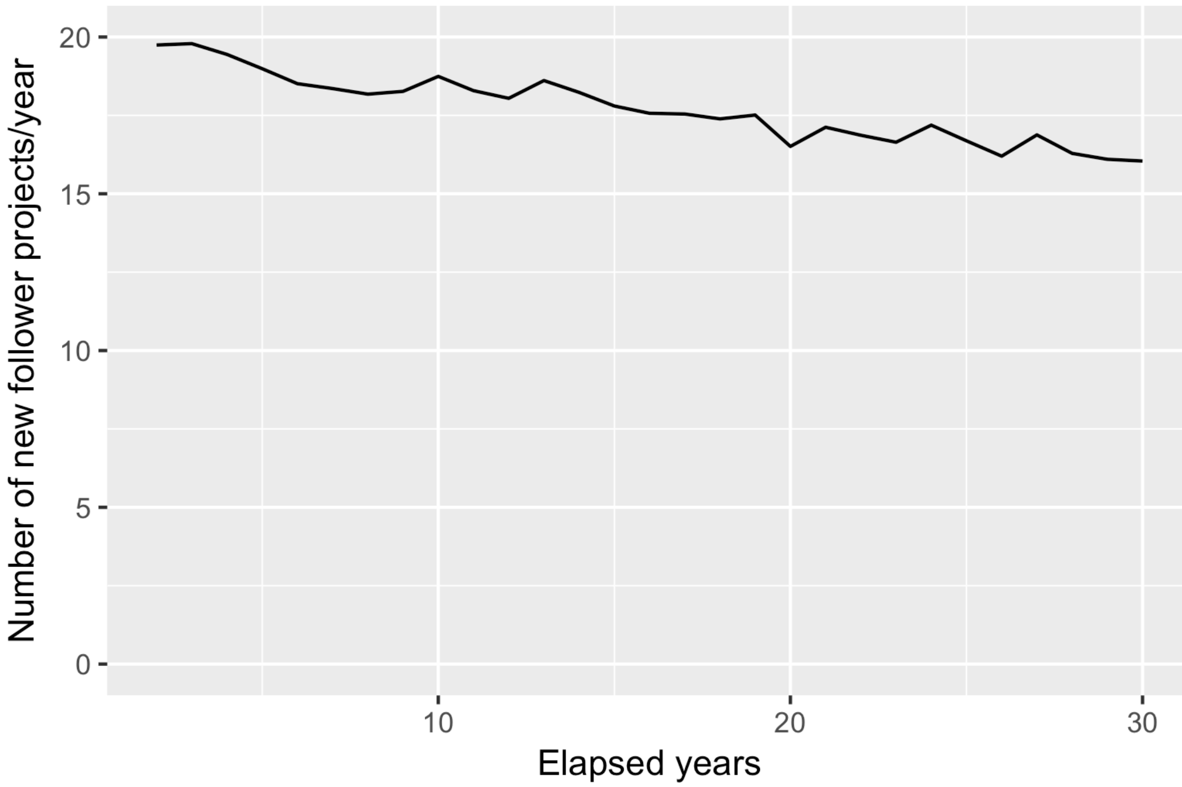


Figure 6.4. Potential follower projects occurring within watershed spatial limits, 1852 to 1899.

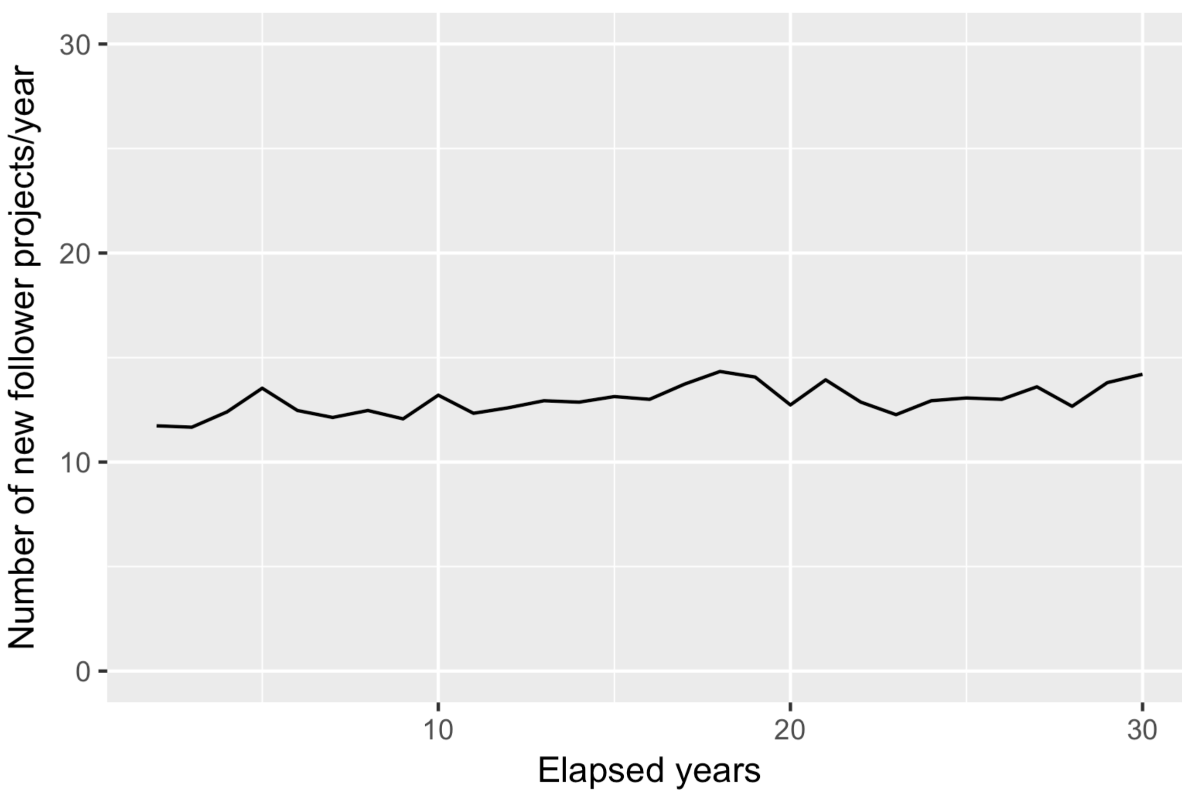
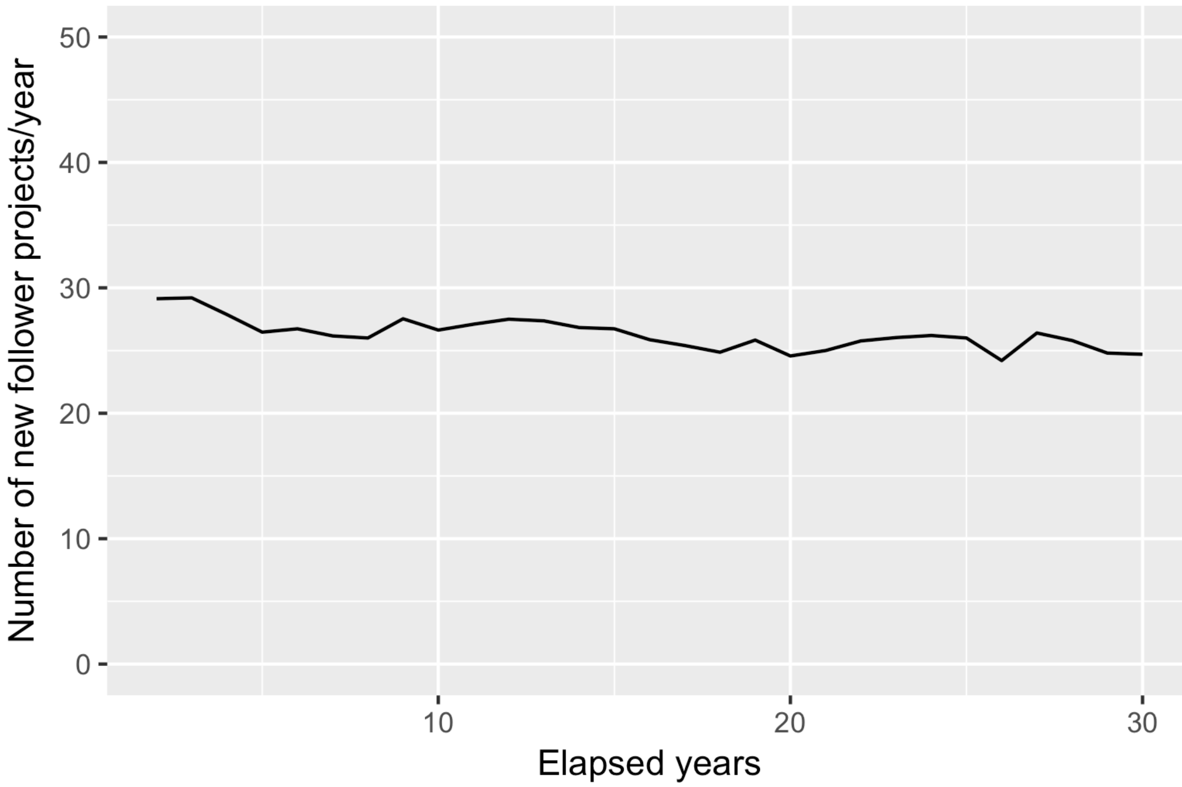
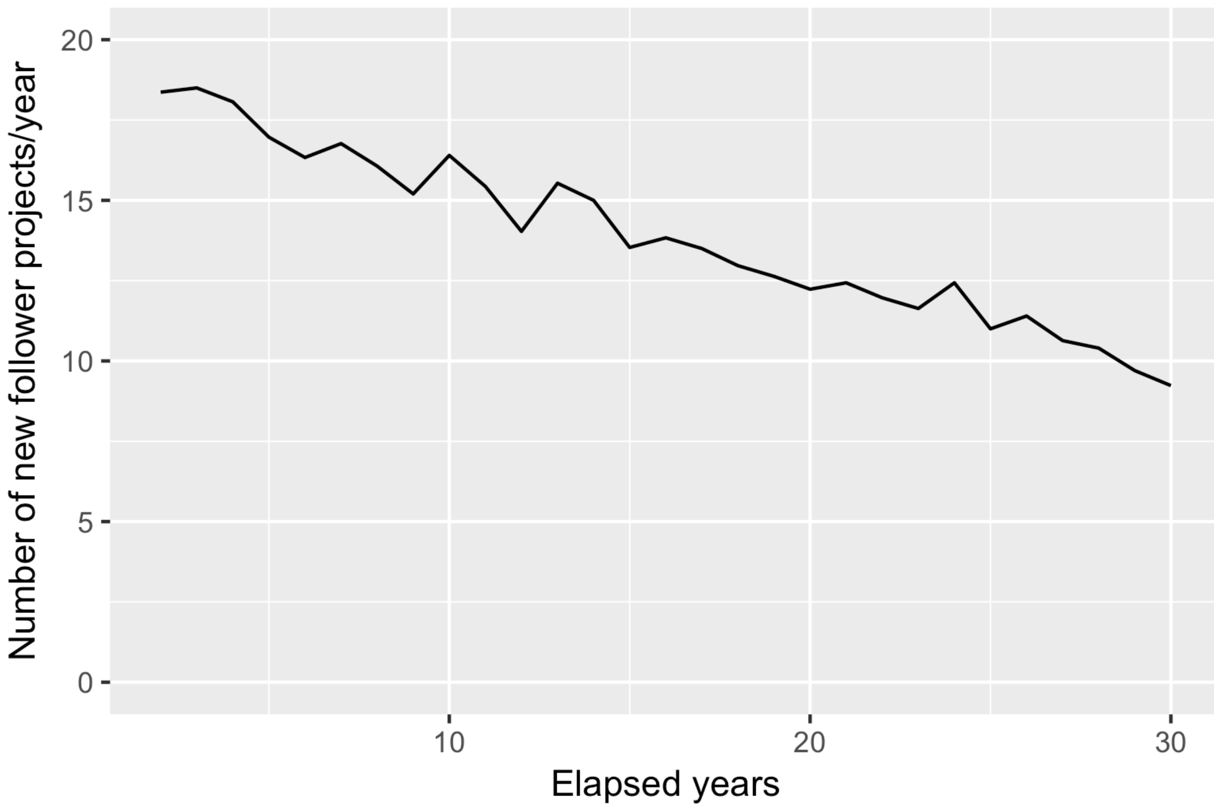


Figure 6.5. Potential follower projects occurring within watershed spatial limits, 1900 to 1949.



However, the rates in the final temporal category (1950 to 2015) were relatively consistent with the travel time results, as shown in Figure 6.6. The gradual drop-off over time observed in the same period in the travel time analysis was also mirrored, with the highest rates occurring between years 1 and 4, and the rate declining to about half of that initial peak near the end of the 30 years.

Figure 6.6. Potential follower projects occurring within watershed spatial limits, 1950 to 2015.



While watershed boundaries would not be useful analogues for travel time proximity in BC's early history, they are today. The similarities between the results of the travel time and watershed analyses for the period between 1950 and 2015 are explored further in the following section.

6.3.2 Similarities between travel time and watershed analyses (1950 to 2015)

There were several notable similarities between the results of the travel time and watershed analyses. As shown in Figure 6.7, the number of potential links between precursor and follower development types were relatively consistent. Out of the eight development types:

- in three cases (coal mines, powerlines, and major roads), the results of the watershed analysis mapped almost exactly onto the results of the 90-minute travel time analysis;

- in four cases (gas plants, hydro projects, and metal mines, and mineral mines), the results of the watershed analysis fell somewhere between the 60- and 90-minute travel time analyses;
- in one case (railroads), the results of the watershed analysis fell somewhat above the 90-minute travel time analysis.

When the mean number of follower projects (at the 30-year temporal limit) calculated in the two analyses were compared, these results again proved consistent (Figure 6.8a to 6.8c):

- for five follower project development types (coal mines, hydro plants, major roads, powerlines, and railroads), results were identical or had overlapping 95% confidence intervals regardless of the precursor development type. Of these, variation between results was most marked for follower powerlines, which had a relatively wide 95% confidence interval;
- for two follower project development types (metal mines and mineral mines), results were identical or had overlapping 95% confidence intervals for all but one development type pairing (precursor metal mines and coal mines, respectively);
- for one follower project development type (gas plants), results were inconsistent for three development type pairings: the travel time analysis produced a significantly higher mean for precursor coal mines and gas plants, while the watershed analysis produced a significantly higher mean for precursor mineral mines.

Figure 6.7. Comparison of rate/year of potential precursor-follower links derived from travel time and watershed analyses, 1950 to 2015.

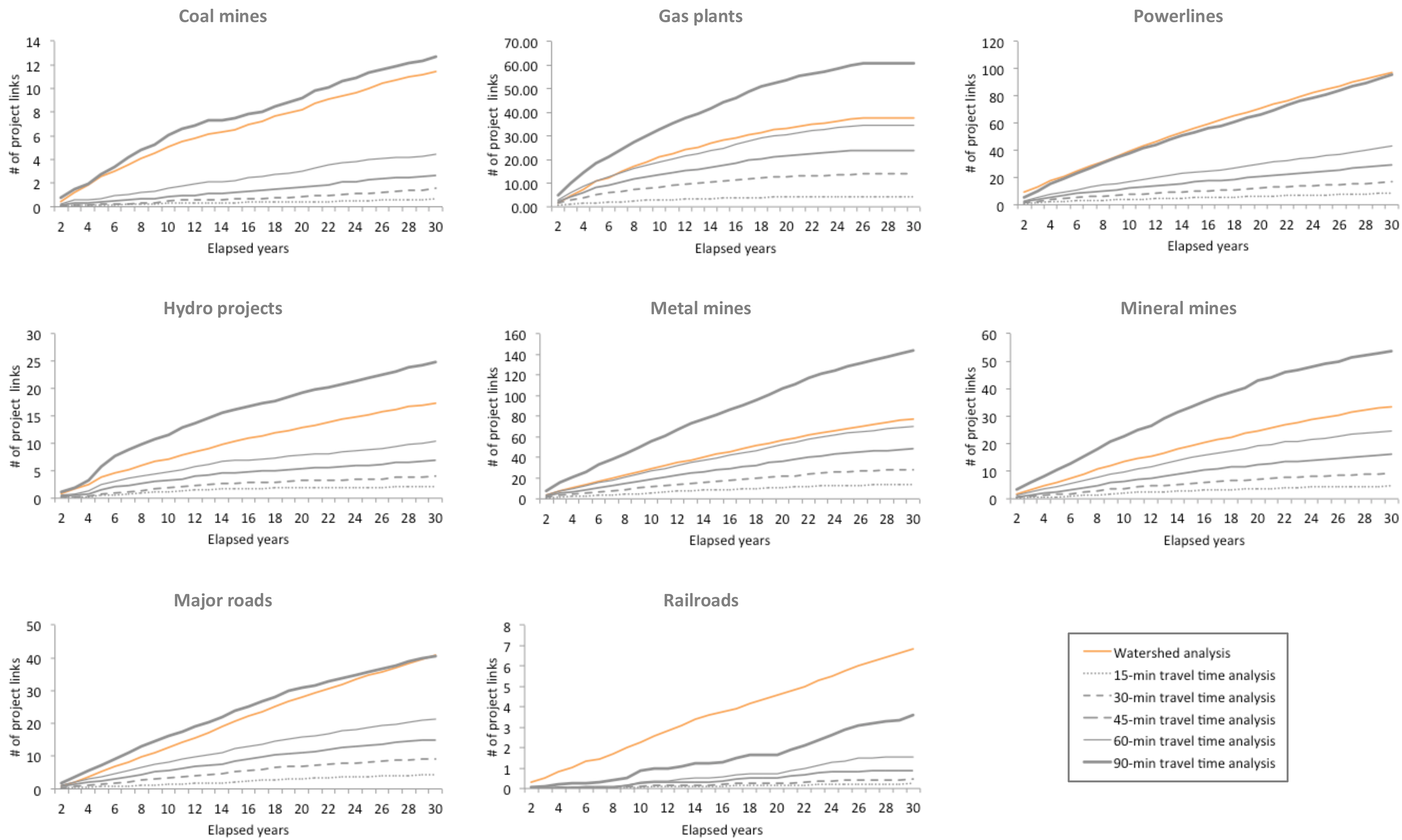
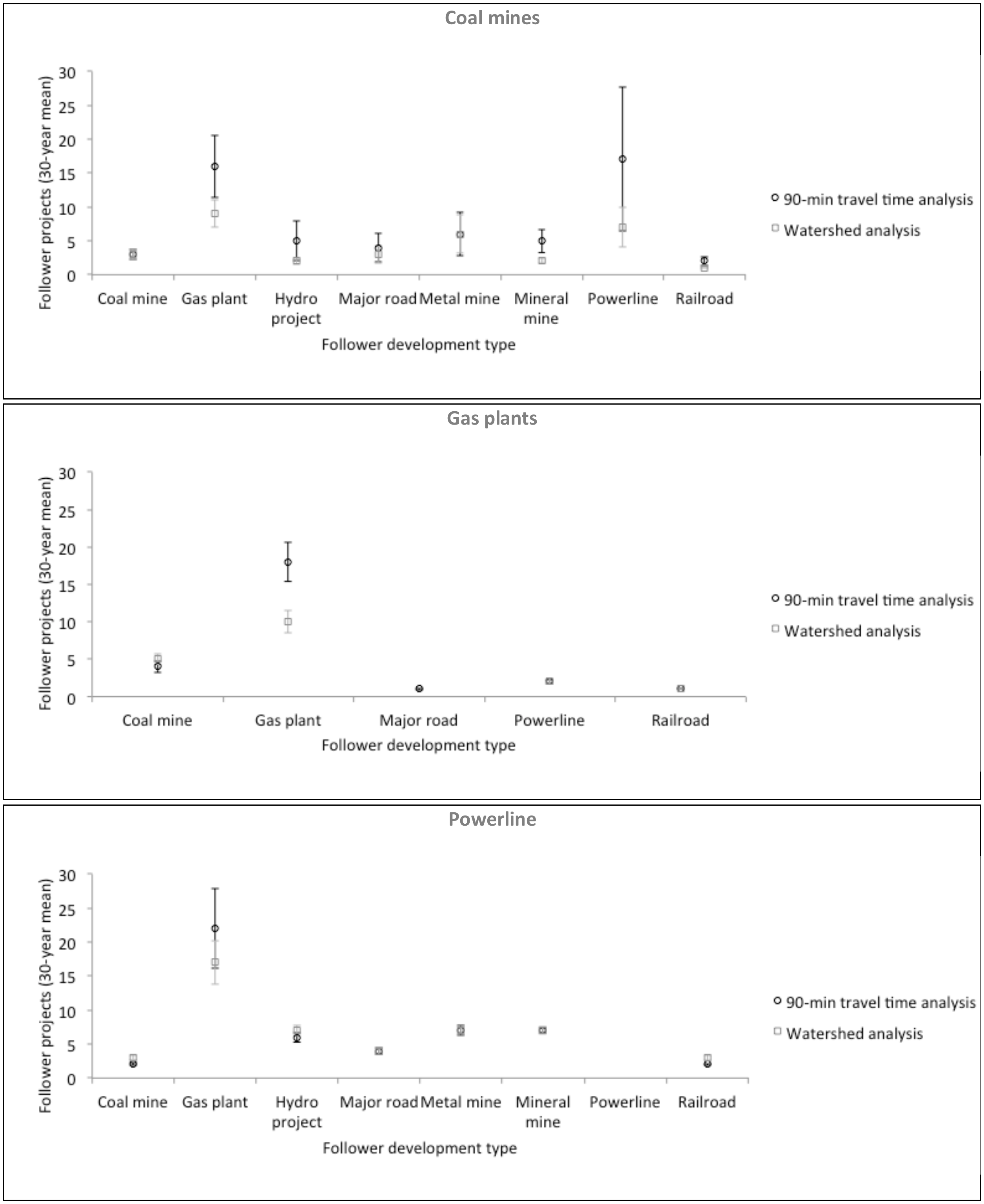
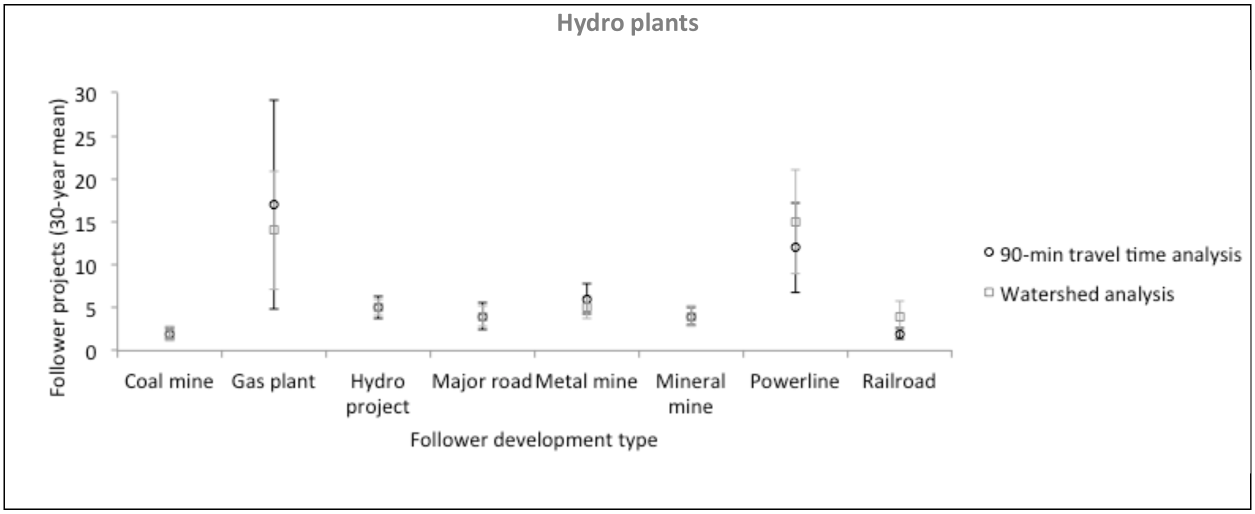


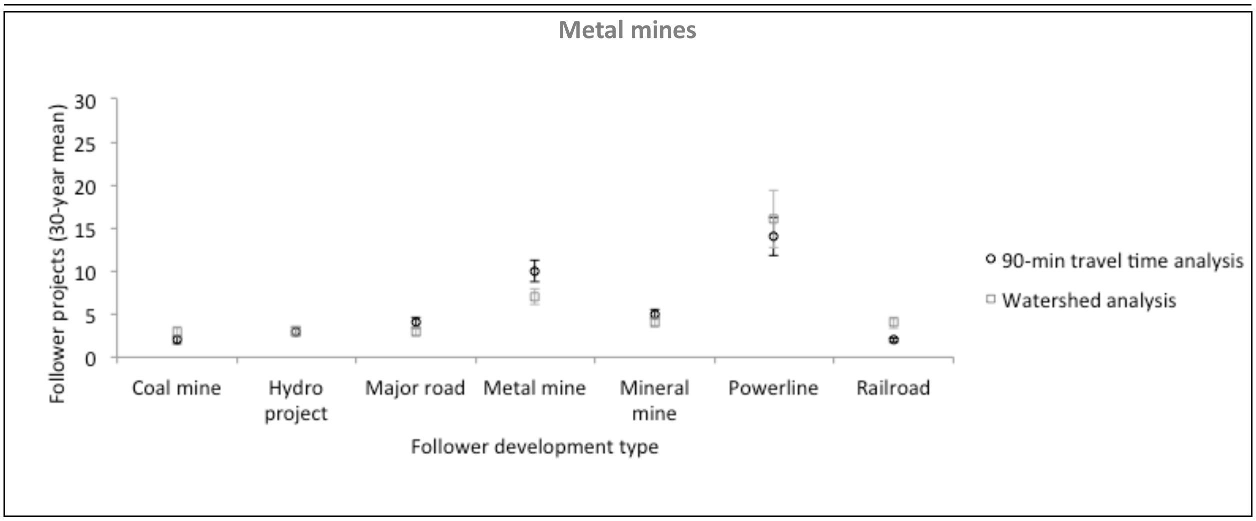
Figure 6.8a. Comparison of 30-year means from 90-minute travel time and watershed analyses.

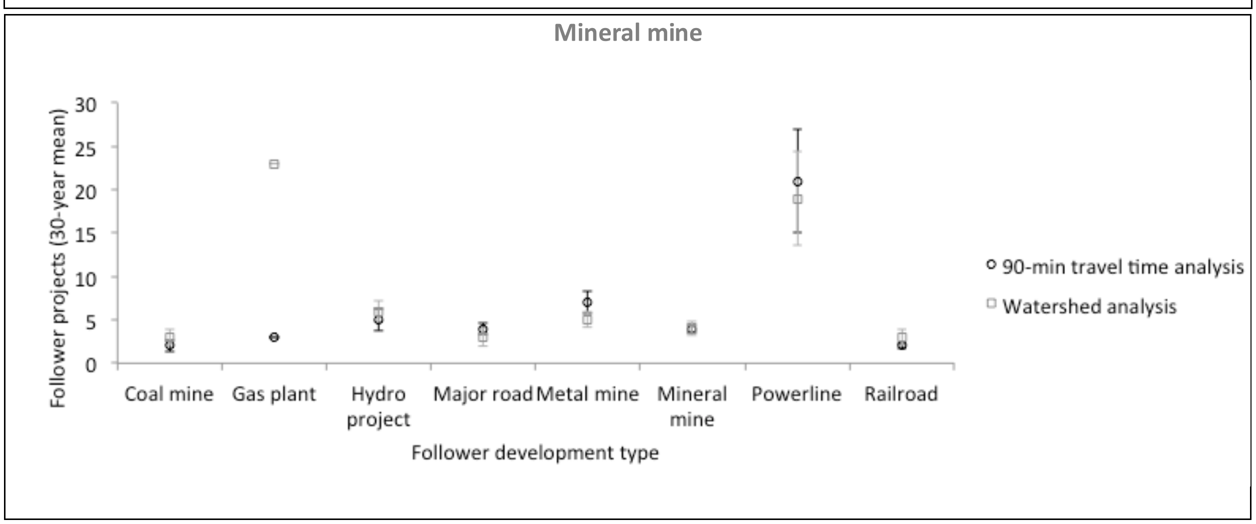


Note: Error bars represent 95% confidence interval.

Figure 6.8b. Comparison of 30-year means from 90-minute travel time and watershed analyses.

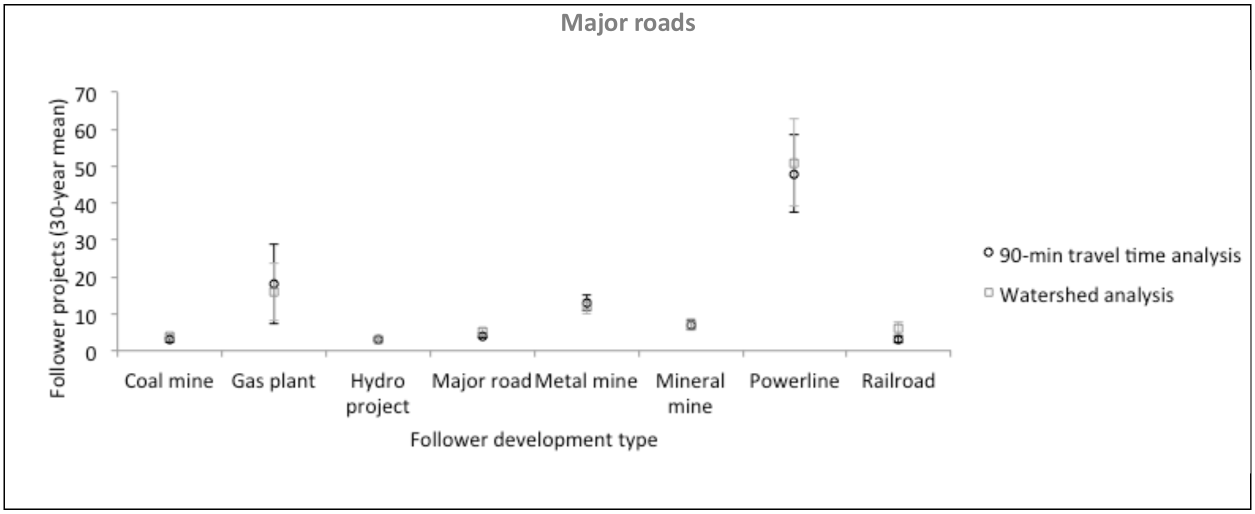


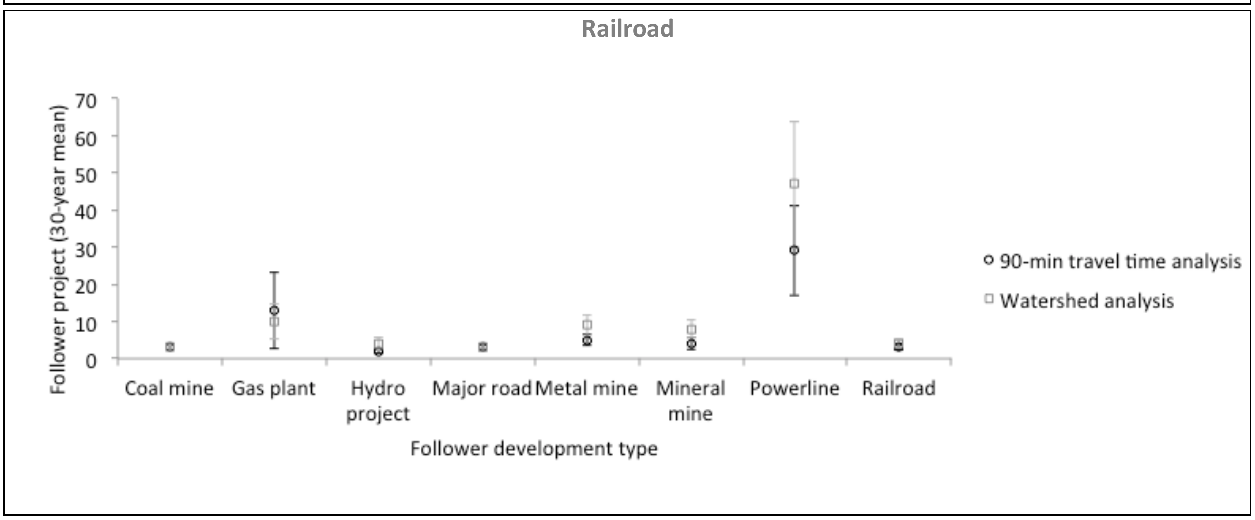




Note: Error bars represent 95% confidence interval.

Figure 6.8c. Comparison of 30-year means from 90-minute travel time and watershed analyses.





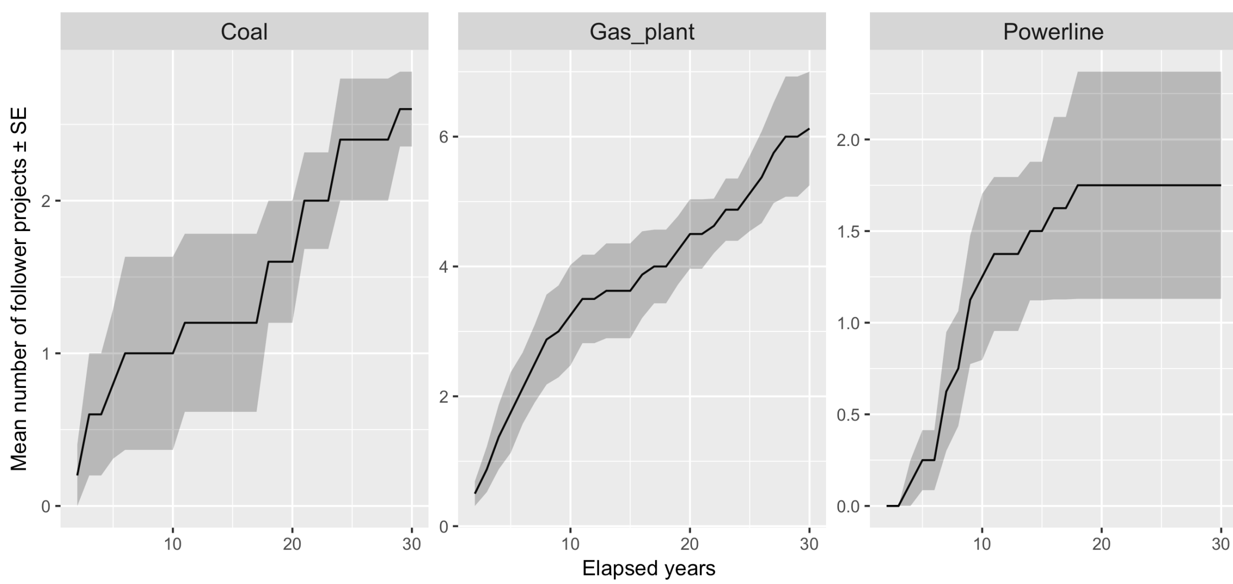
Note: Error bars represent 95% confidence interval.

The inconsistency for follower gas plants is likely related to the previously noted explosion of oil and gas exploration in northeastern BC—also the location of the province's major coalfields—which has resulted in high road density. As greater distances can be travelled in the same amount of time, the spatial boundaries for the travel time analysis are also relatively larger, and therefore contain more projects. Mineral mines are more evenly dispersed throughout BC. However, the province's largest major watershed system (the Fraser River watershed system), which extends into the gas and coalfields at its northeastern extent, also contains some of BC's richest mineral resources and by far the highest number of mineral mines (15% of the provincial total). This may explain why the watershed analysis showed a higher mean number of gas plants associated with precursor mineral mines.

6.3.3 Trends by project type

A set of STS graphs generated from the results of the watershed analysis is presented in Figures 6.9a to 6.17d. Graphs with fewer than eight panels reflect the fact that one or more combinations of precursor and follower project types did not occur within any watersheds of the type depicted.

Figure 6.9a. Precursor coal mines and mean numbers of follower projects (by development type) within major fossil watershed system boundaries, 1950 to 2015.



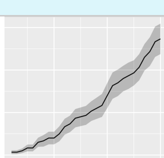
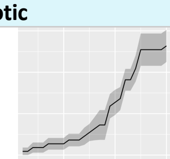
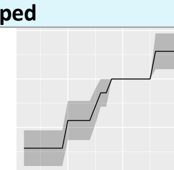
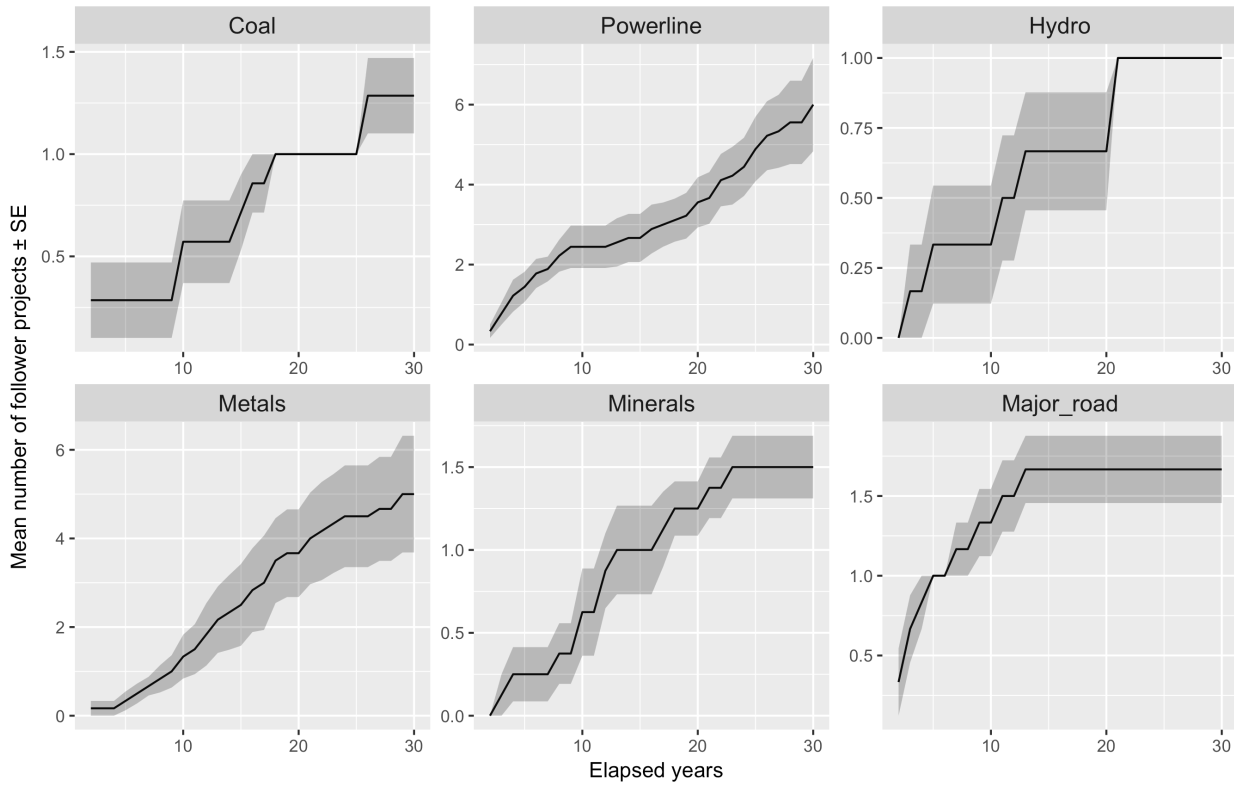
KEY (see Section 5.3.2 for a more detailed guide to interpreting this graph.)		
Trajectories at different *time intervals* describe follower project development rates:		
Linear	**Asymptotic**	**Stepped**
A relatively constant rate of project development that has remained fairly steady through time. 	A saturation effect where rapid development quickly approaches or reaches an upper limit. 	Characterized by few follower projects, each followed by a period of hiatus. 

Figure 6.9b. Precursor coal mines and mean numbers of follower projects (by development type) within major mixed watershed system boundaries, 1950 to 2015.



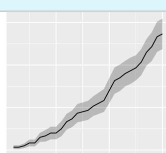
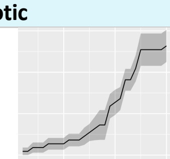
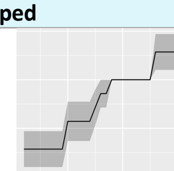
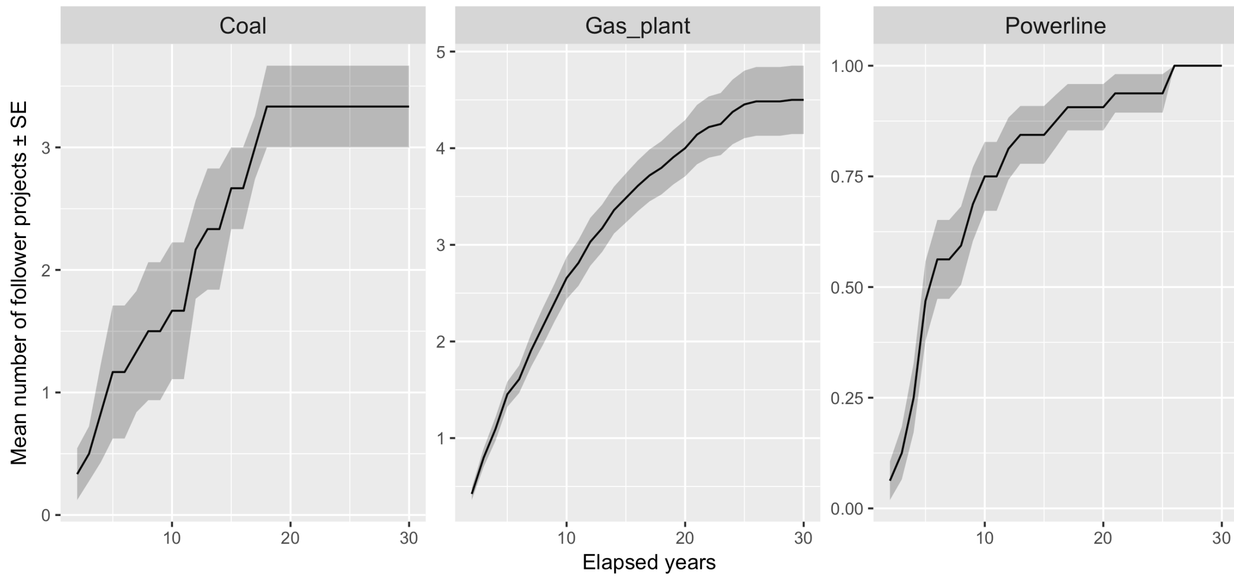
KEY (see Section 5.3.2 for a more detailed guide to interpreting this graph.)		
Trajectories at different *time intervals* describe follower project development rates:		
Linear	**Asymptotic**	**Stepped**
A relatively constant rate of project development that has remained fairly steady through time. 	A saturation effect where rapid development quickly approaches or reaches an upper limit. 	Characterized by few follower projects, each followed by a period of hiatus. 

Figure 6.10a. Precursor gas plants and mean numbers of follower projects (by development type) within major fossil watershed system boundaries, 1950 to 2015.



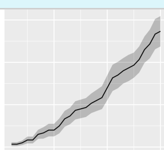
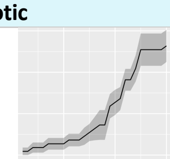
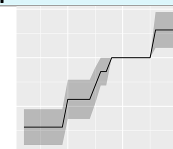
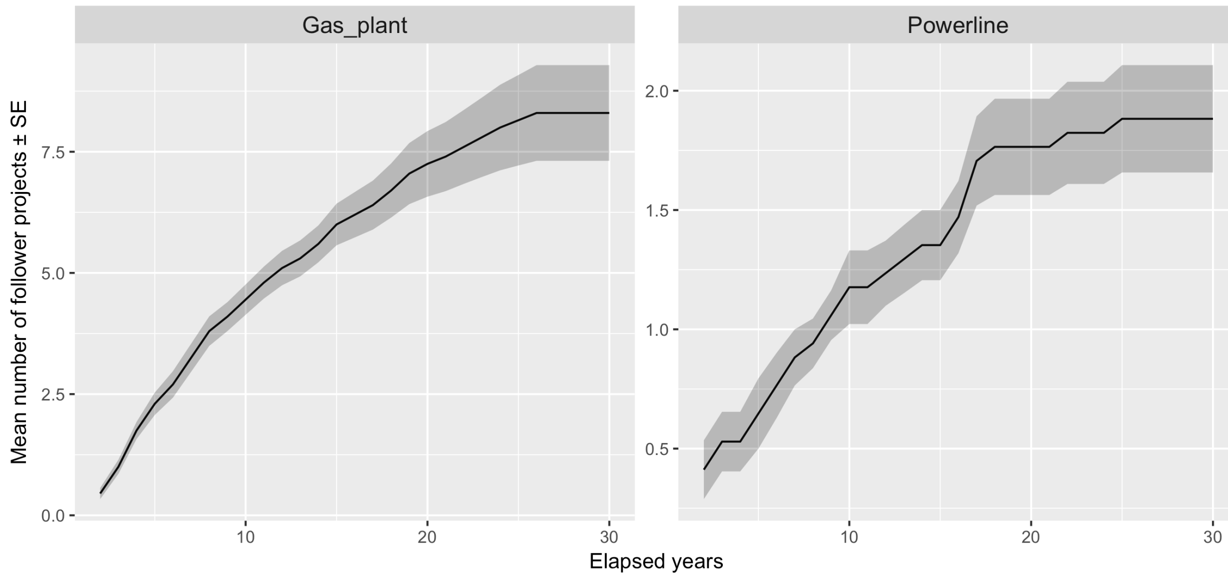
KEY (see Section 5.3.2 for a more detailed guide to interpreting this graph.)		
Trajectories at different *time intervals* describe follower project development rates:		
Linear	**Asymptotic**	**Stepped**
A relatively constant rate of project development that has remained fairly steady through time. 	A saturation effect where rapid development quickly approaches or reaches an upper limit. 	Characterized by few follower projects, each followed by a period of hiatus. 

Figure 6.10b. Precursor gas plants and mean numbers of follower projects (by development type) within major mixed watershed system boundaries, 1950 to 2015.



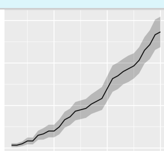
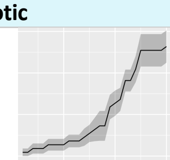
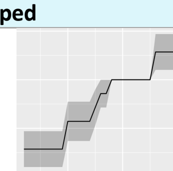
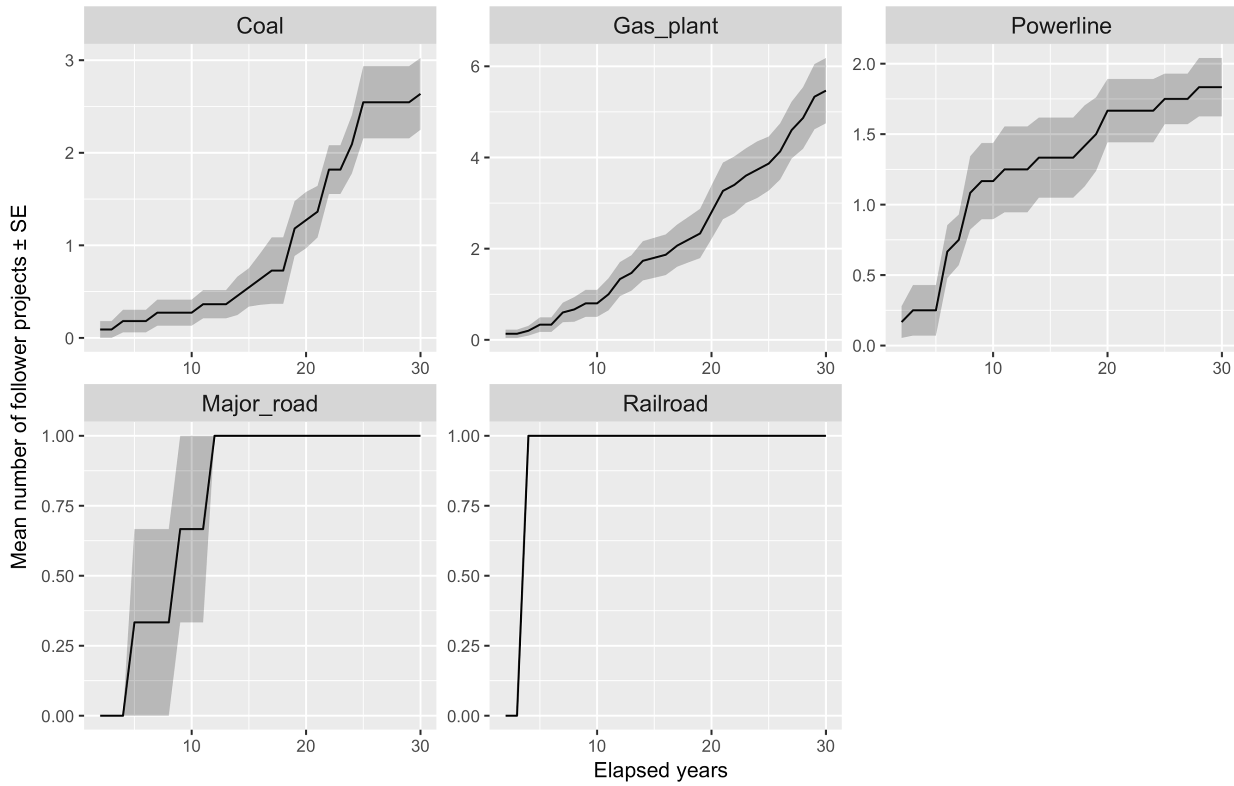
KEY (see Section 5.3.2 for a more detailed guide to interpreting this graph.)		
Trajectories at different *time intervals* describe follower project development rates:		
Linear	**Asymptotic**	**Stepped**
A relatively constant rate of project development that has remained fairly steady through time. 	A saturation effect where rapid development quickly approaches or reaches an upper limit. 	Characterized by few follower projects, each followed by a period of hiatus. 

Figure 6.11a. Precursor powerlines and mean numbers of follower projects (by development type) within major fossil watershed system boundaries, 1950 to 2015.



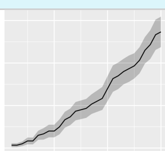
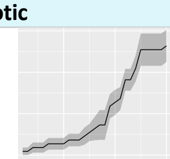
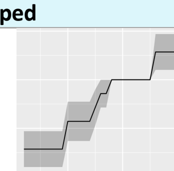
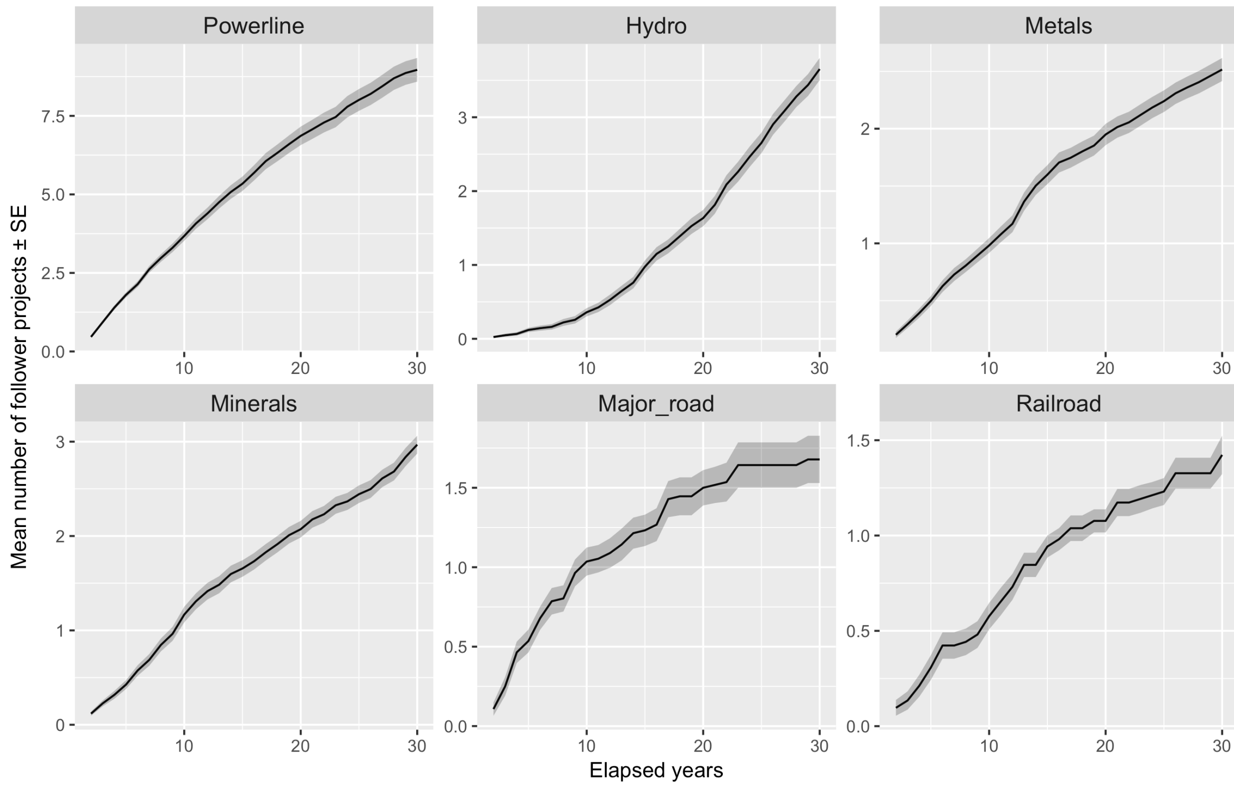
KEY (see Section 5.3.2 for a more detailed guide to interpreting this graph.)		
Trajectories at different *time intervals* describe follower project development rates:		
Linear	**Asymptotic**	**Stepped**
A relatively constant rate of project development that has remained fairly steady through time. 	A saturation effect where rapid development quickly approaches or reaches an upper limit. 	Characterized by few follower projects, each followed by a period of hiatus. 

Figure 6.11b. Precursor powerlines and mean numbers of follower projects (by development type) within major mineral watershed system boundaries, 1950 to 2015.



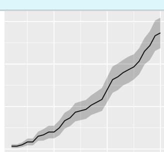
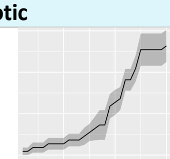
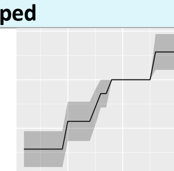
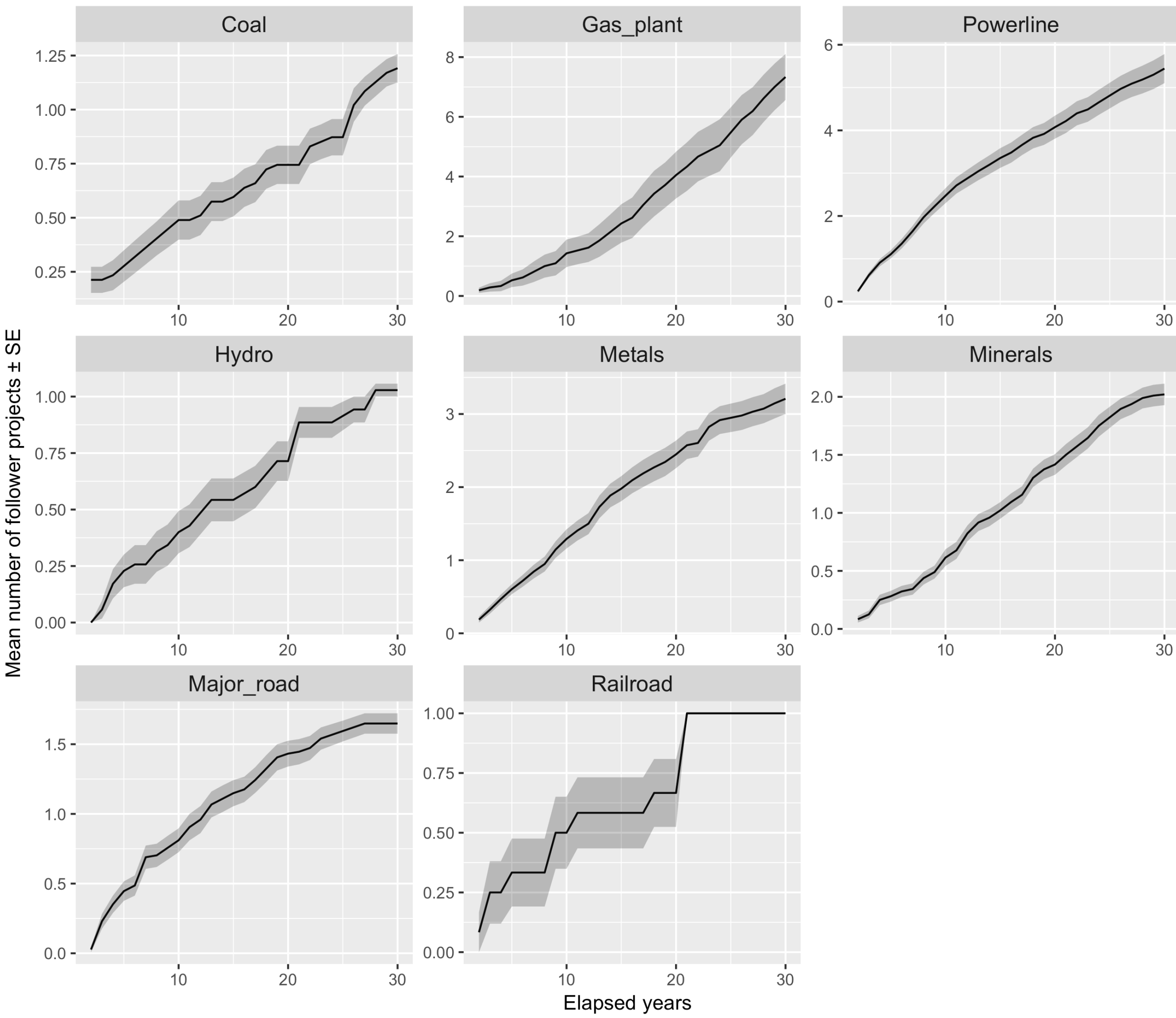
KEY (see Section 5.3.2 for a more detailed guide to interpreting this graph.)		
Trajectories at different *time intervals* describe follower project development rates:		
Linear	**Asymptotic**	**Stepped**
A relatively constant rate of project development that has remained fairly steady through time. 	A saturation effect where rapid development quickly approaches or reaches an upper limit. 	Characterized by few follower projects, each followed by a period of hiatus. 

Figure 6.11c. Precursor powerlines and mean numbers of follower projects (by development type) within major mixed watershed system boundaries, 1950 to 2015.



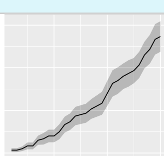
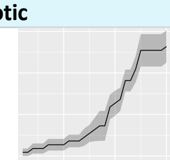
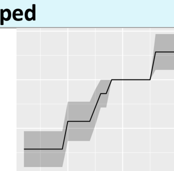
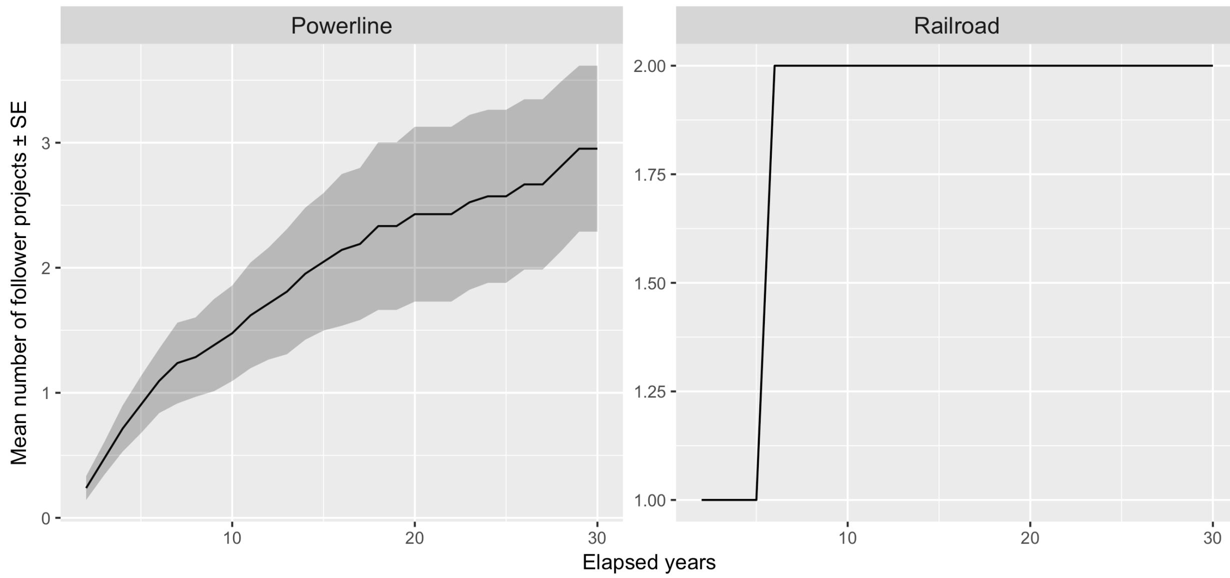
KEY (see Section 5.3.2 for a more detailed guide to interpreting this graph.)		
Trajectories at different *time intervals* describe follower project development rates:		
Linear	**Asymptotic**	**Stepped**
A relatively constant rate of project development that has remained fairly steady through time. 	A saturation effect where rapid development quickly approaches or reaches an upper limit. 	Characterized by few follower projects, each followed by a period of hiatus. 

Figure 6.11d. Precursor powerlines and mean numbers of follower projects (by development type) within major connective watershed system boundaries, 1950 to 2015.



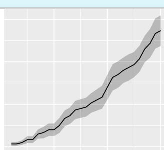
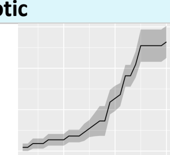
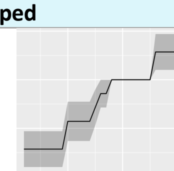
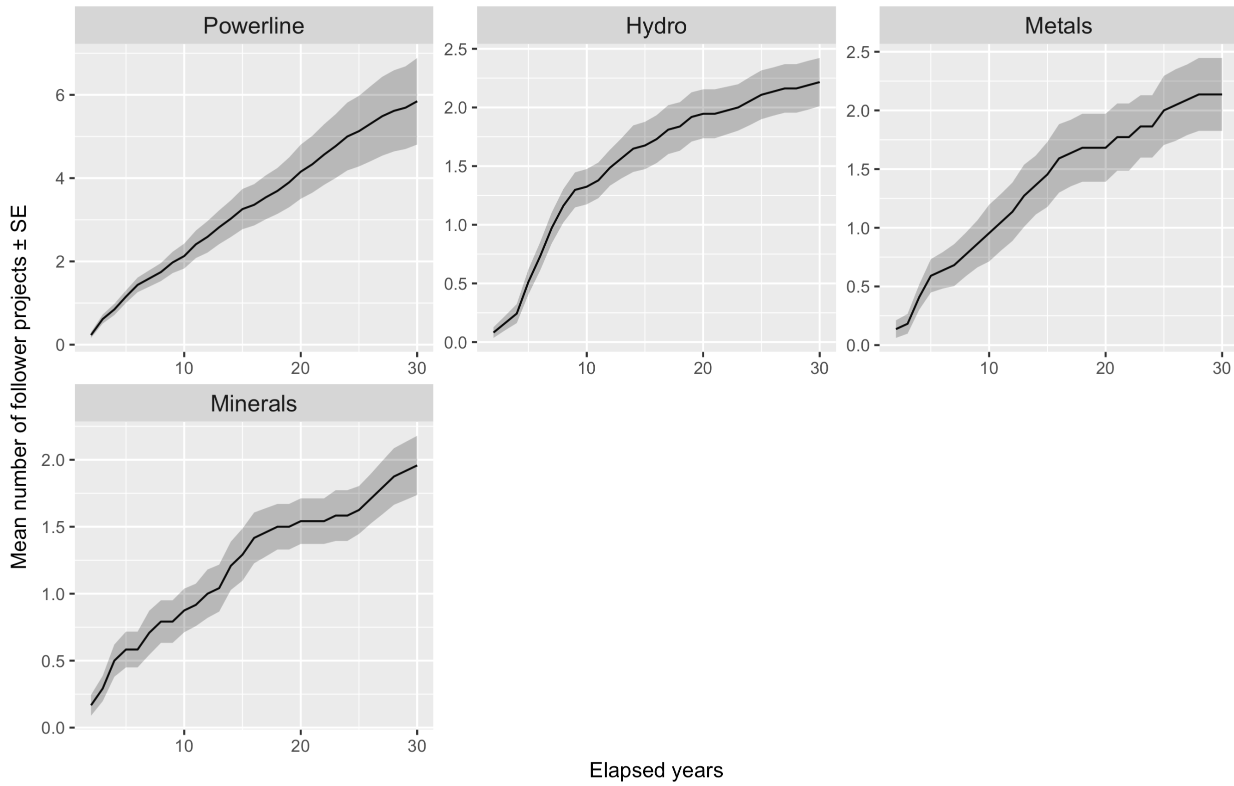
KEY (see Section 5.3.2 for a more detailed guide to interpreting this graph.)		
Trajectories at different *time intervals* describe follower project development rates:		
Linear	**Asymptotic**	**Stepped**
A relatively constant rate of project development that has remained fairly steady through time. 	A saturation effect where rapid development quickly approaches or reaches an upper limit. 	Characterized by few follower projects, each followed by a period of hiatus. 

Figure 6.12a. Precursor hydro projects and mean numbers of follower projects (by development type) within major mineral watershed system boundaries, 1950 to 2015.



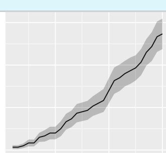
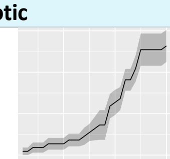
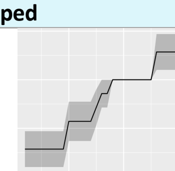
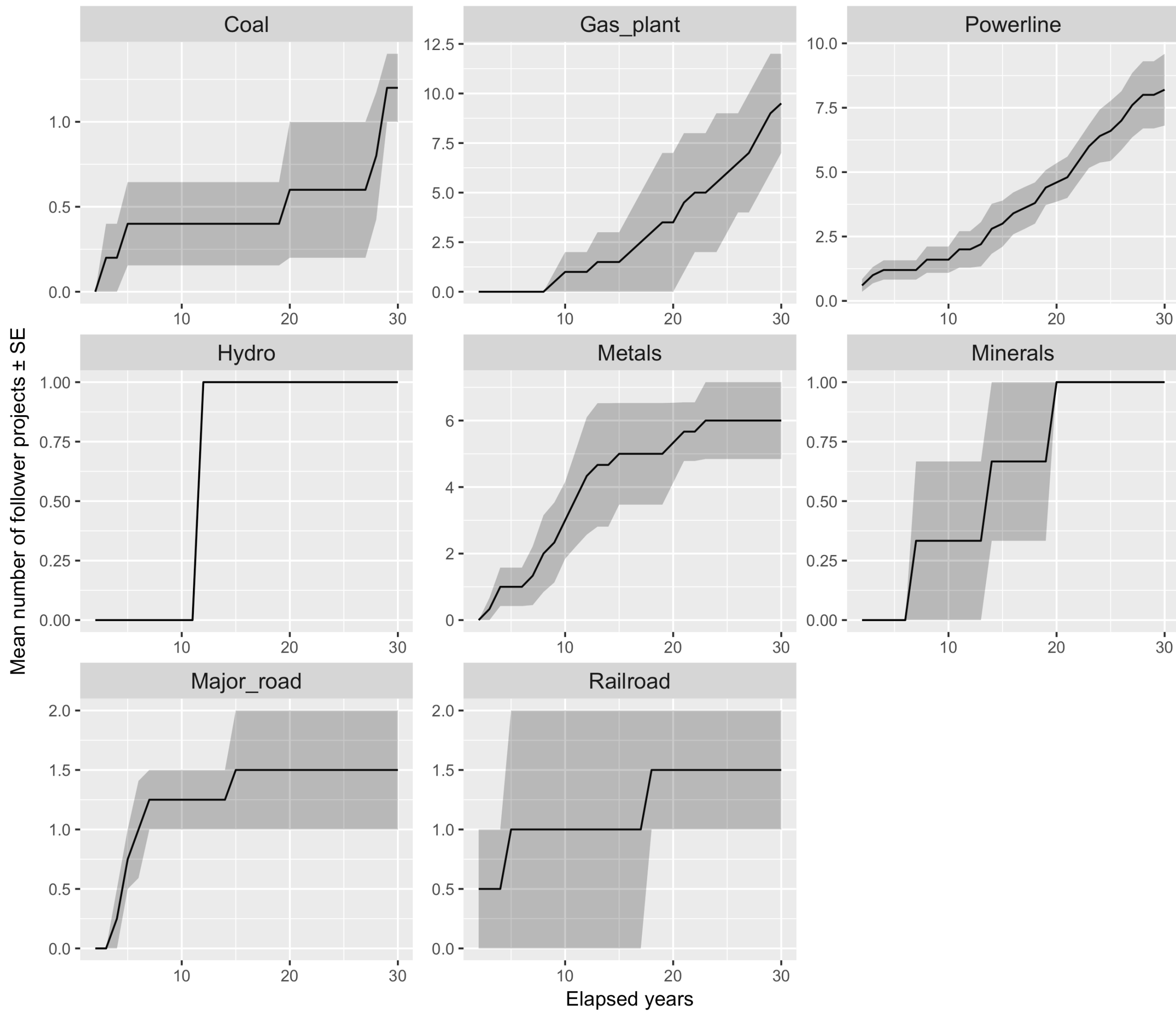
KEY (see Section 5.3.2 for a more detailed guide to interpreting this graph.)					
Trajectories at different *time intervals* describe follower project development rates:					
Linear		**Asymptotic**		**Stepped**	
A relatively constant rate of project development that has remained fairly steady through time.		A saturation effect where rapid development quickly approaches or reaches an upper limit.		Characterized by few follower projects, each followed by a period of hiatus.	

Figure 6.12b. Precursor hydro projects and mean numbers of follower projects (by development type) within major mixed watershed system boundaries, 1950 to 2015.



KEY (see Section 5.3.2 for a more detailed guide to interpreting this graph.)

Trajectories at different *time intervals* describe follower project development rates:

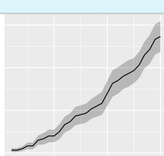
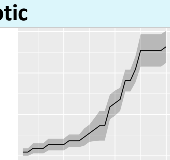
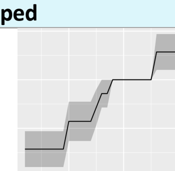
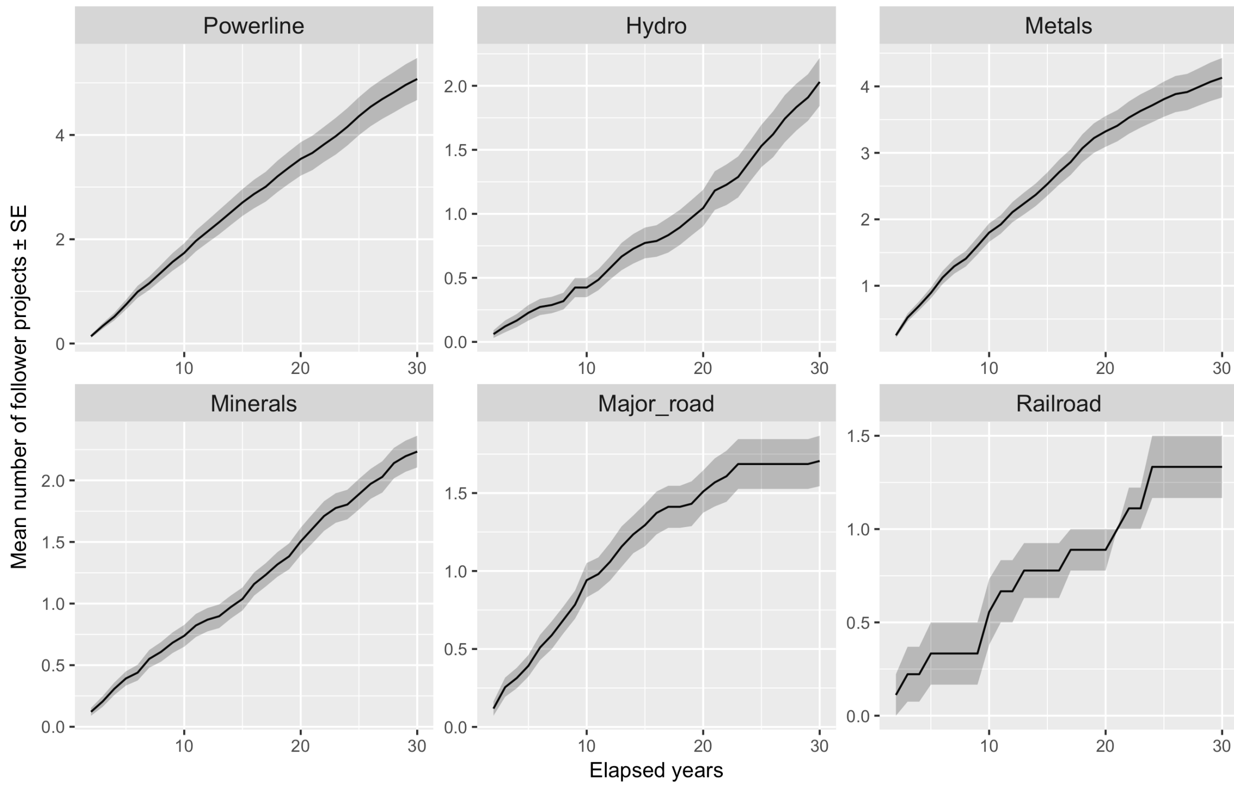
Linear	Asymptotic	Stepped
A relatively constant rate of project development that has remained fairly steady through time. 	A saturation effect where rapid development quickly approaches or reaches an upper limit. 	Characterized by few follower projects, each followed by a period of hiatus. 

Figure 6.13a. Precursor metal mine projects and mean numbers of follower projects (by development type) within major mineral watershed system boundaries, 1950 to 2015.



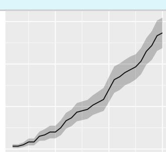
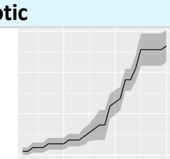
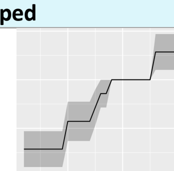
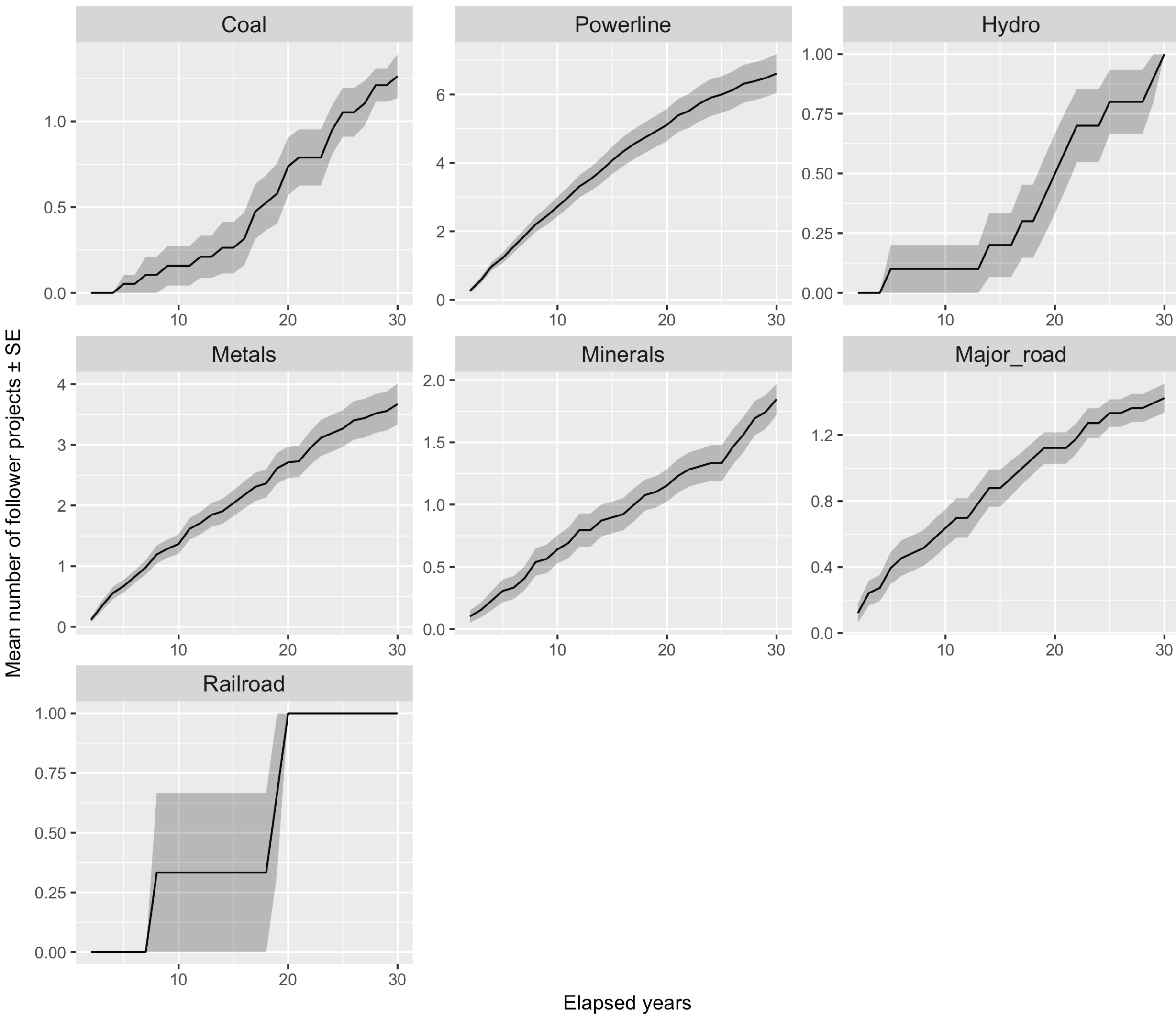
KEY (see Section 5.3.2 for a more detailed guide to interpreting this graph.)		
Trajectories at different *time intervals* describe follower project development rates:		
Linear	**Asymptotic**	**Stepped**
A relatively constant rate of project development that has remained fairly steady through time. 	A saturation effect where rapid development quickly approaches or reaches an upper limit. 	Characterized by few follower projects, each followed by a period of hiatus. 

Figure 6.13b. Precursor metal mine projects and mean numbers of follower projects (by development type) within major mixed watershed system boundaries, 1950 to 2015.



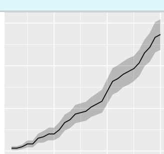
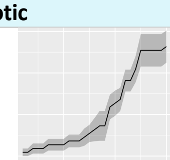
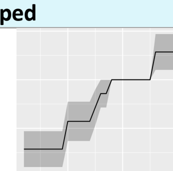
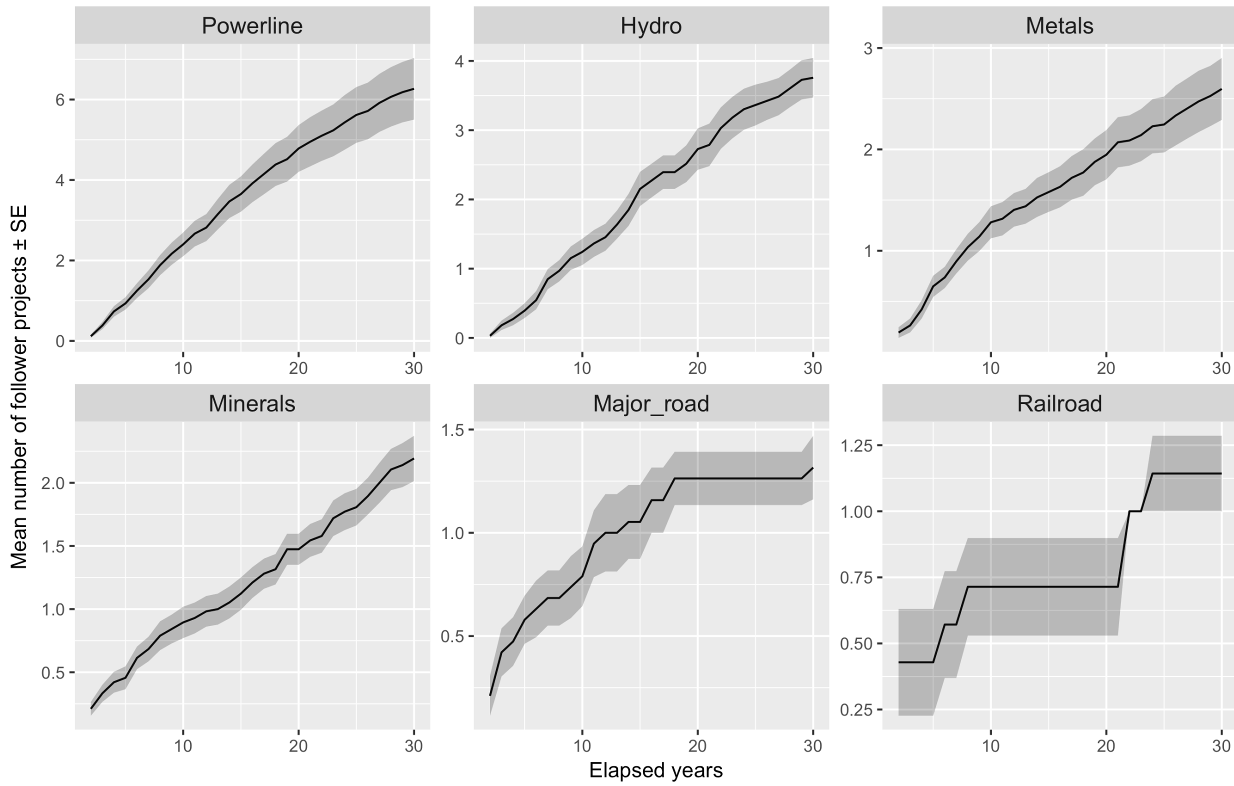
KEY (see Section 5.3.2 for a more detailed guide to interpreting this graph.)		
Trajectories at different *time intervals* describe follower project development rates:		
Linear	**Asymptotic**	**Stepped**
A relatively constant rate of project development that has remained fairly steady through time. 	A saturation effect where rapid development quickly approaches or reaches an upper limit. 	Characterized by few follower projects, each followed by a period of hiatus. 

Figure 6.14a. Precursor mineral mine projects and mean numbers of follower projects (by development type) within major mineral watershed system boundaries, 1950 to 2015.



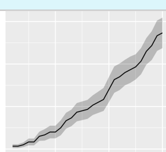
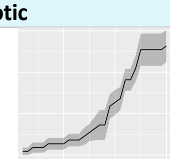
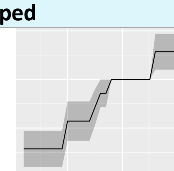
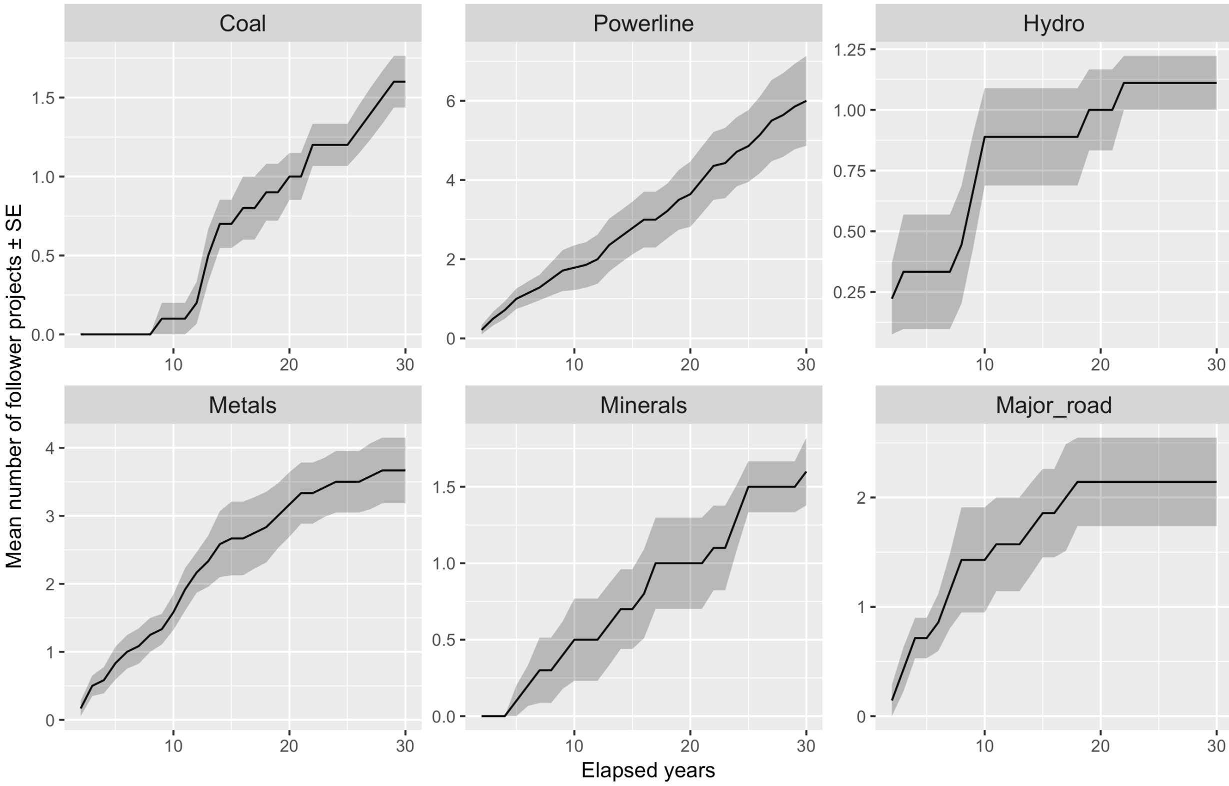
KEY (see Section 5.3.2 for a more detailed guide to interpreting this graph.)		
Trajectories at different *time intervals* describe follower project development rates:		
Linear	**Asymptotic**	**Stepped**
A relatively constant rate of project development that has remained fairly steady through time. 	A saturation effect where rapid development quickly approaches or reaches an upper limit. 	Characterized by few follower projects, each followed by a period of hiatus. 

Figure 6.14b. Precursor mineral mine projects and mean numbers of follower projects (by development type) within mixed watershed system boundaries, 1950 to 2015.



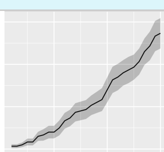
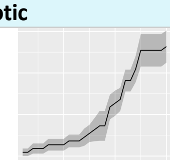
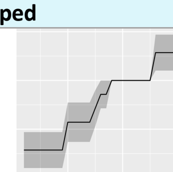
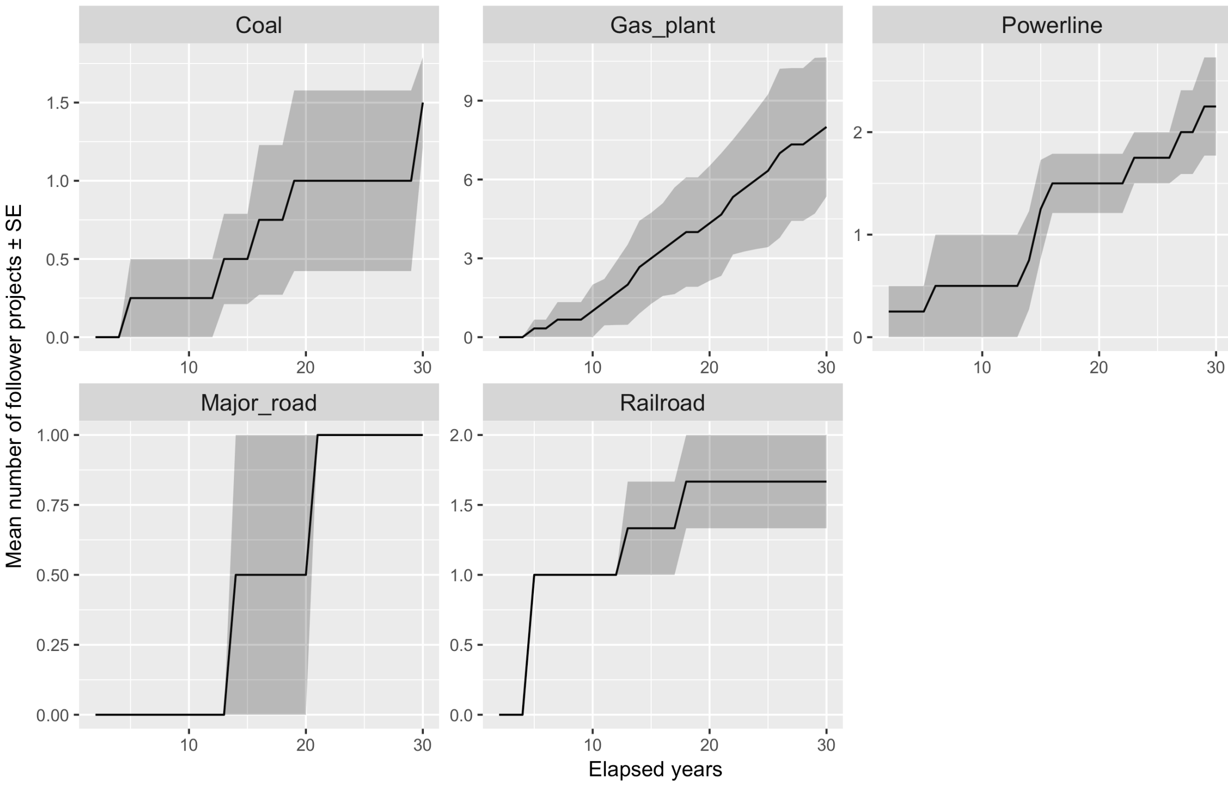
KEY (see Section 5.3.2 for a more detailed guide to interpreting this graph.)		
Trajectories at different *time intervals* describe follower project development rates:		
Linear	**Asymptotic**	**Stepped**
A relatively constant rate of project development that has remained fairly steady through time. 	A saturation effect where rapid development quickly approaches or reaches an upper limit. 	Characterized by few follower projects, each followed by a period of hiatus. 

Figure 6.15a. Precursor major road projects and mean numbers of follower projects (by development type) within major fossil watershed system boundaries, 1950 to 2015.



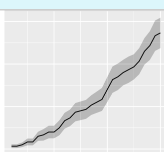
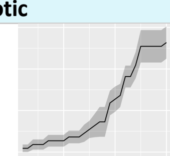
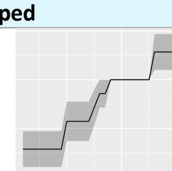
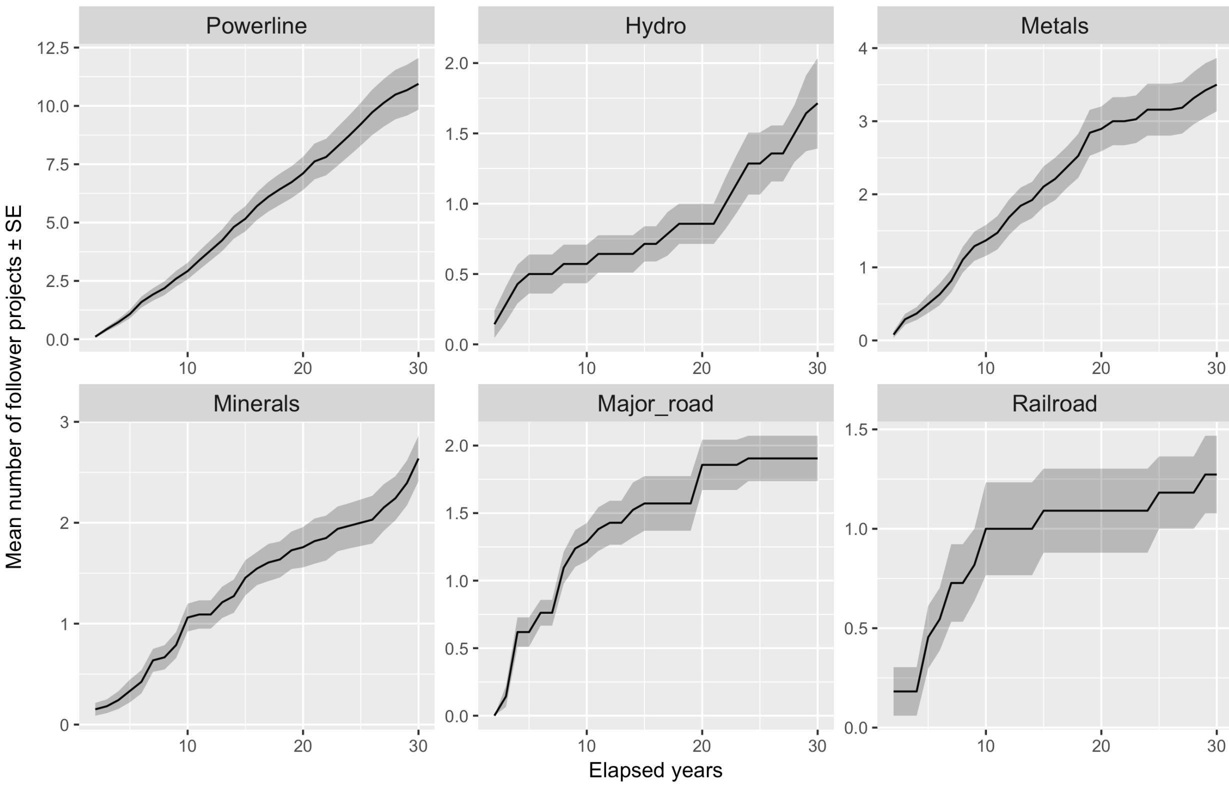
KEY (see Section 5.3.2 for a more detailed guide to interpreting this graph.)		
Trajectories at different *time intervals* describe follower project development rates:		
Linear	**Asymptotic**	**Stepped**
A relatively constant rate of project development that has remained fairly steady through time. 	A saturation effect where rapid development quickly approaches or reaches an upper limit. 	Characterized by few follower projects, each followed by a period of hiatus. 

Figure 6.15b. Precursor major road projects and mean numbers of follower projects (by development type) within mineral watershed boundaries, 1950 to 2015.



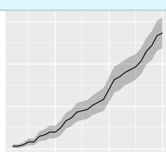
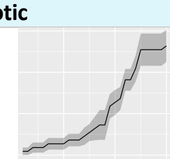
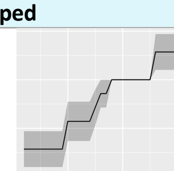
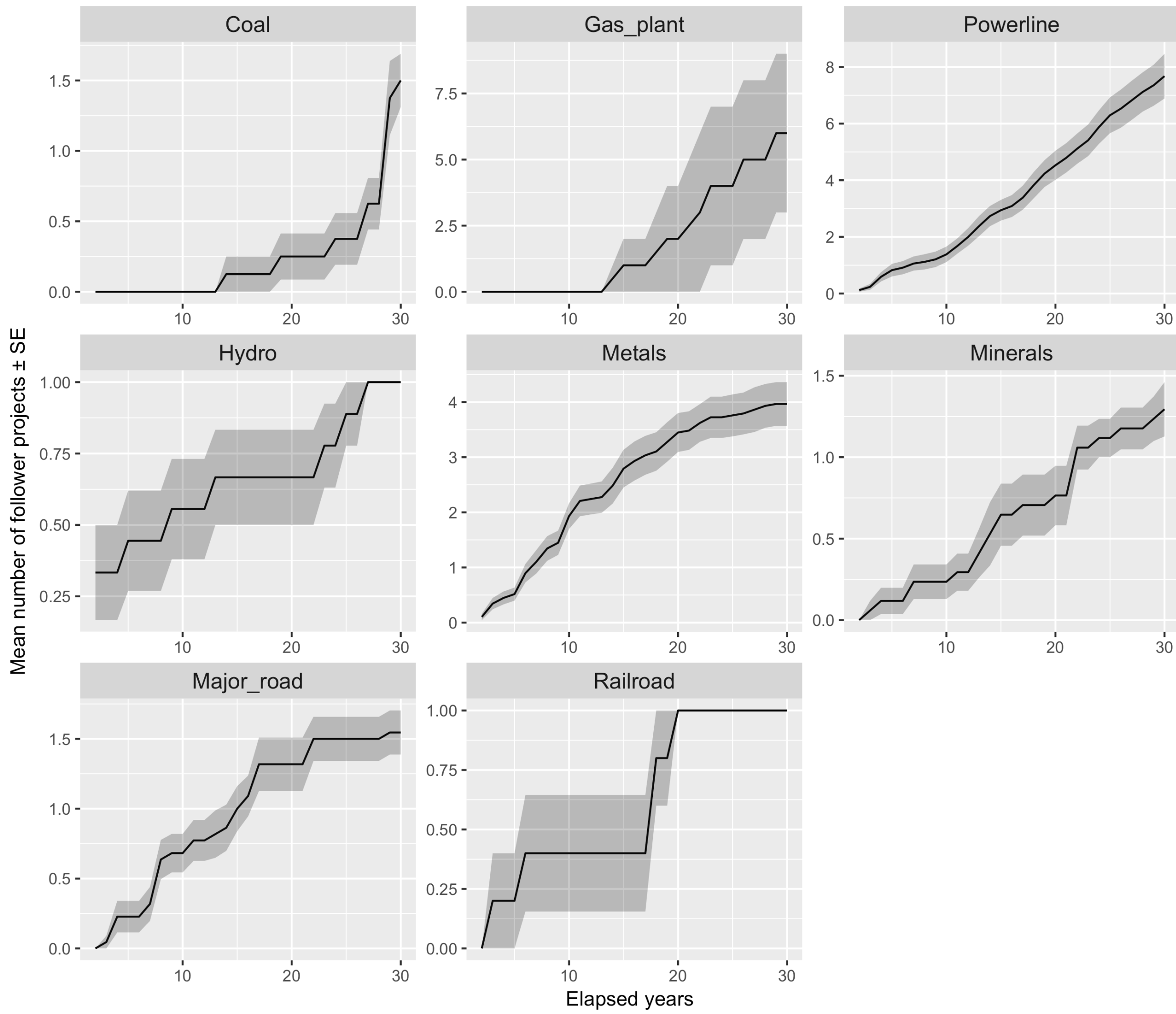
KEY (see Section 5.3.2 for a more detailed guide to interpreting this graph.)		
Trajectories at different *time intervals* describe follower project development rates:		
Linear	**Asymptotic**	**Stepped**
A relatively constant rate of project development that has remained fairly steady through time. 	A saturation effect where rapid development quickly approaches or reaches an upper limit. 	Characterized by few follower projects, each followed by a period of hiatus. 

Figure 6.15c. Precursor major road projects and mean numbers of follower projects (by development type) within mixed watershed boundaries, 1950 to 2015.



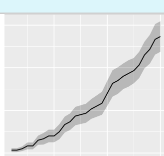
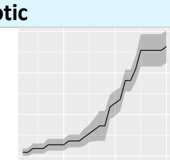
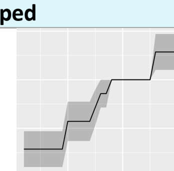
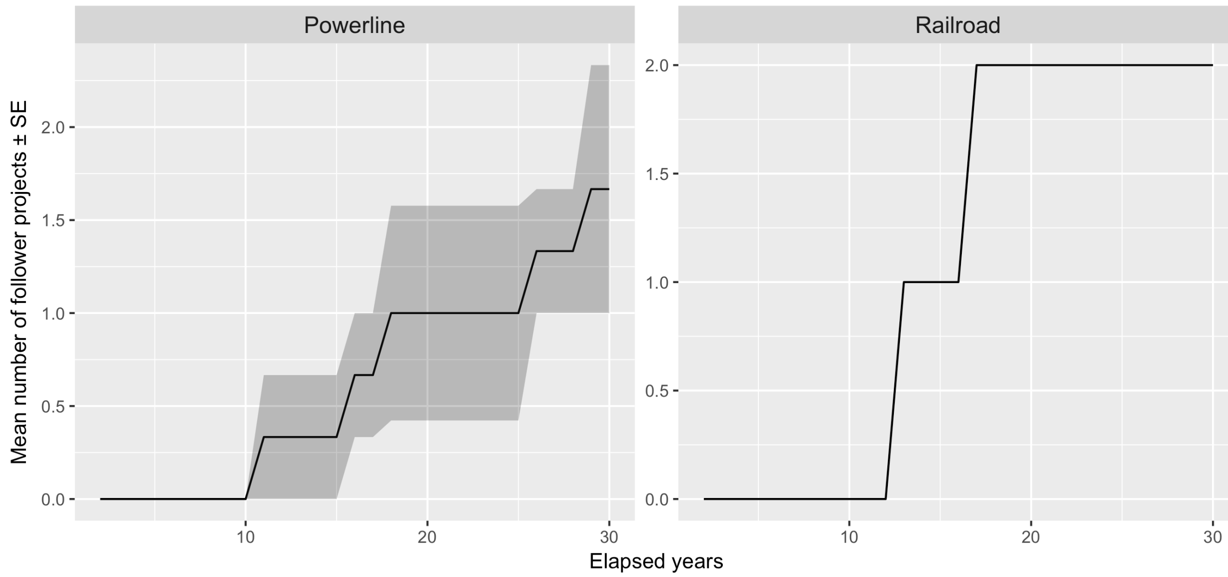
KEY (see Section 5.3.2 for a more detailed guide to interpreting this graph.)		
Trajectories at different *time intervals* describe follower project development rates:		
Linear	**Asymptotic**	**Stepped**
A relatively constant rate of project development that has remained fairly steady through time. 	A saturation effect where rapid development quickly approaches or reaches an upper limit. 	Characterized by few follower projects, each followed by a period of hiatus. 

Figure 6.15d. Precursor major road projects and mean numbers of follower projects (by development type) within connective watershed boundaries, 1950 to 2015.



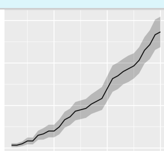
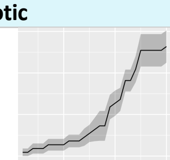
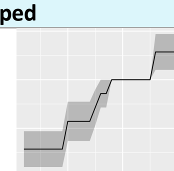
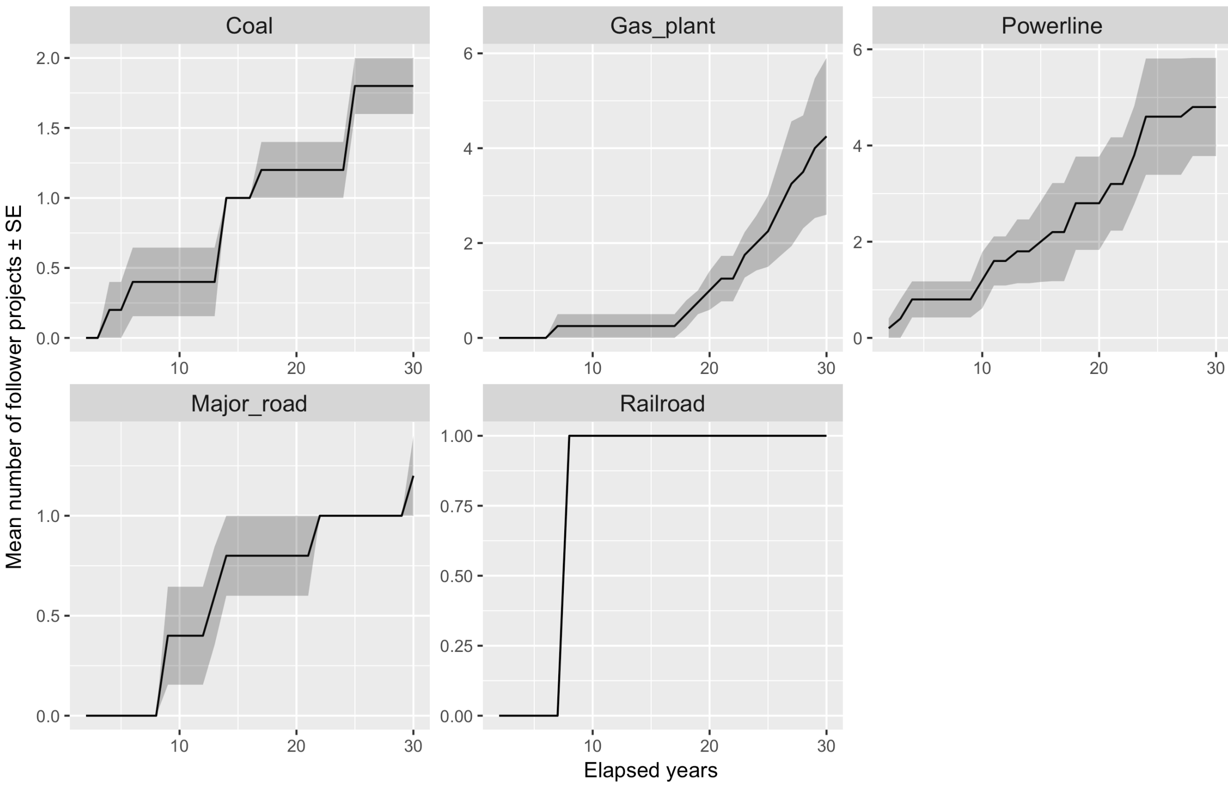
KEY (see Section 5.3.2 for a more detailed guide to interpreting this graph.)		
Trajectories at different *time intervals* describe follower project development rates:		
Linear	**Asymptotic**	**Stepped**
A relatively constant rate of project development that has remained fairly steady through time. 	A saturation effect where rapid development quickly approaches or reaches an upper limit. 	Characterized by few follower projects, each followed by a period of hiatus. 

Figure 6.16a. Precursor railroad projects and mean numbers of follower projects (by development type) within fossil watershed boundaries, 1950 to 2015.



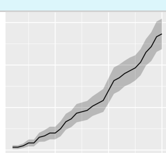
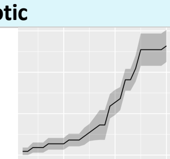
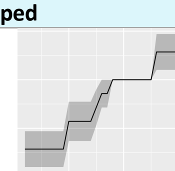
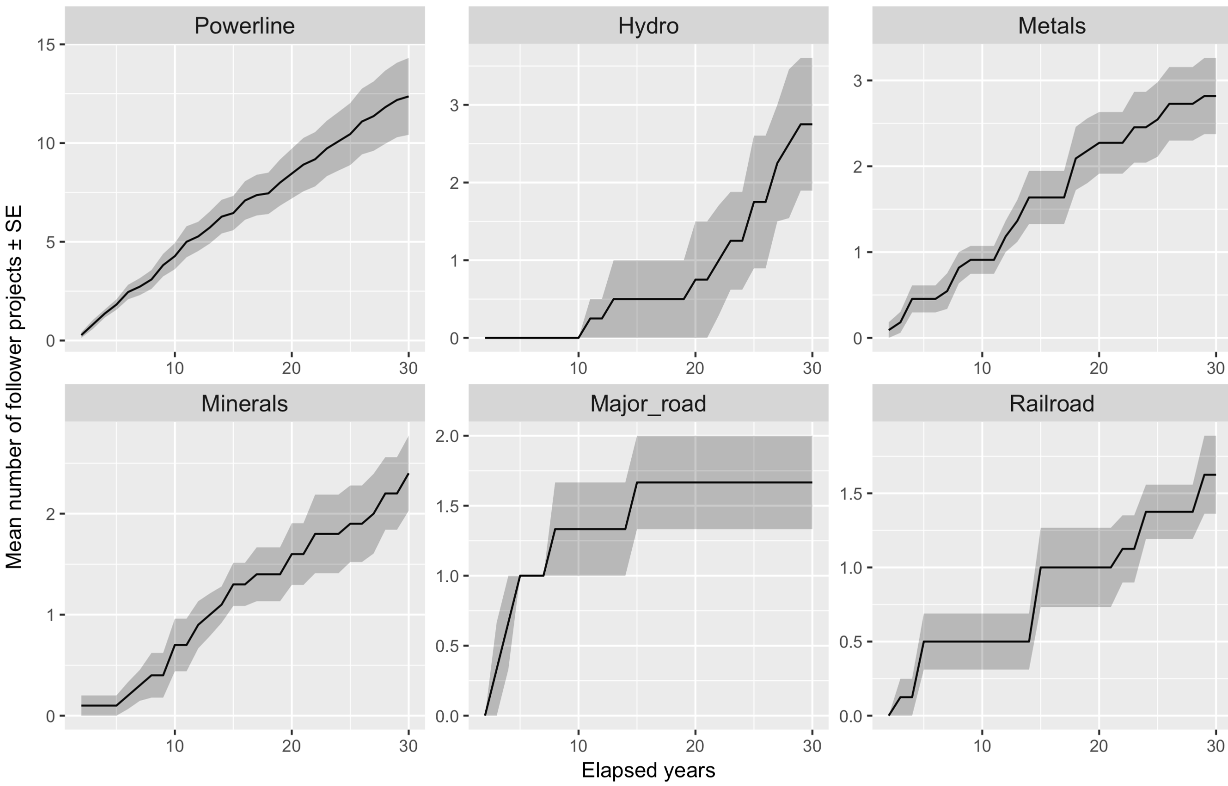
KEY (see Section 5.3.2 for a more detailed guide to interpreting this graph.)		
Trajectories at different *time intervals* describe follower project development rates:		
Linear	**Asymptotic**	**Stepped**
A relatively constant rate of project development that has remained fairly steady through time. 	A saturation effect where rapid development quickly approaches or reaches an upper limit. 	Characterized by few follower projects, each followed by a period of hiatus. 

Figure 6.17b. Precursor railroad projects and mean numbers of follower projects (by development type) within mineral watershed boundaries, 1950 to 2015.



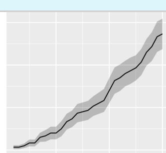
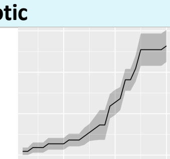
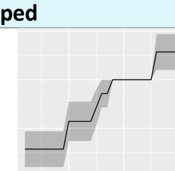
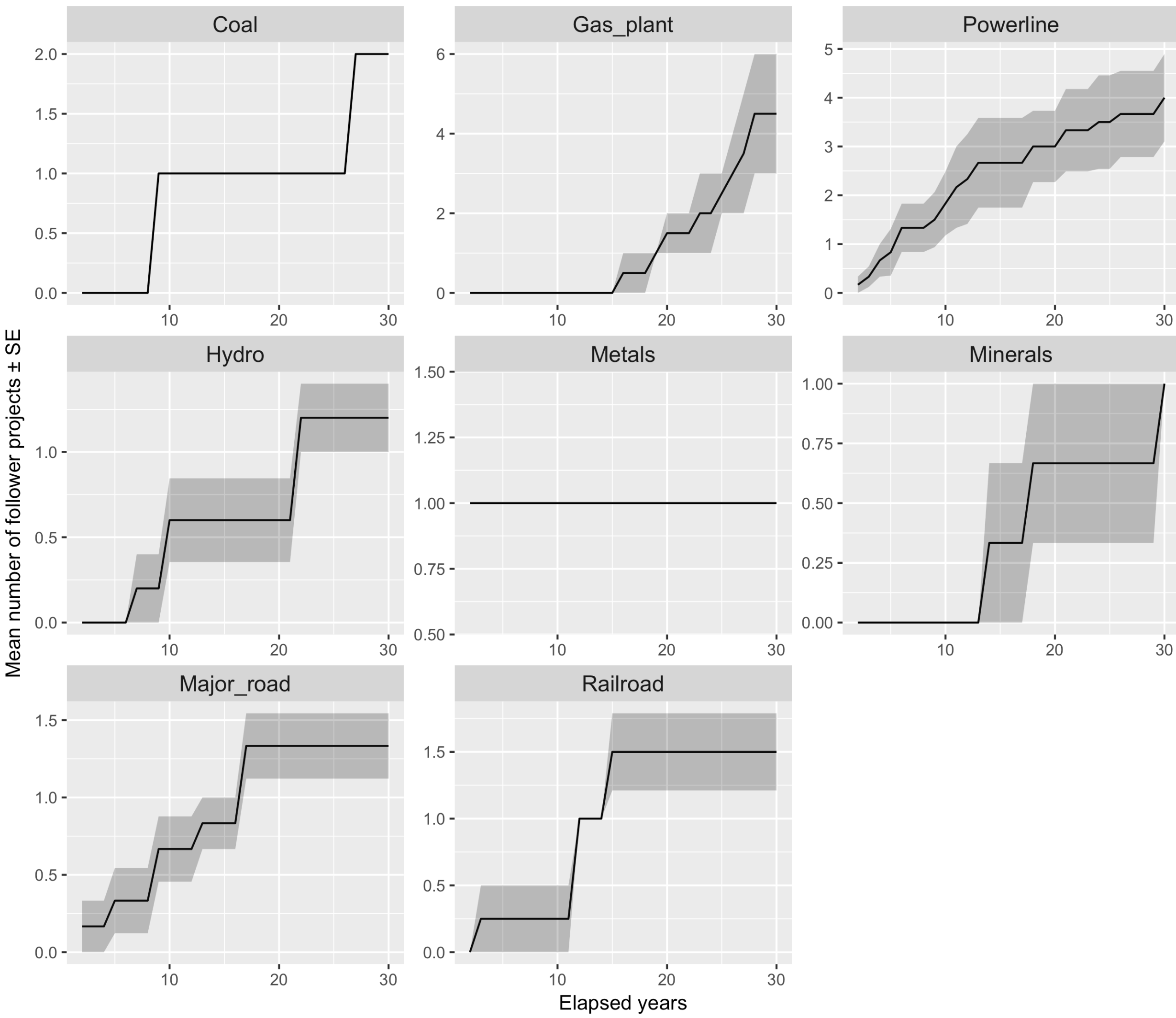
KEY (see Section 5.3.2 for a more detailed guide to interpreting this graph.)		
Trajectories at different *time intervals* describe follower project development rates:		
Linear	**Asymptotic**	**Stepped**
A relatively constant rate of project development that has remained fairly steady through time. 	A saturation effect where rapid development quickly approaches or reaches an upper limit. 	Characterized by few follower projects, each followed by a period of hiatus. 

Figure 6.17c. Precursor railroad projects and mean numbers of follower projects (by development type) within mixed watershed boundaries, 1950 to 2015.



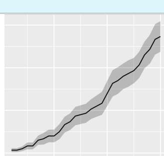
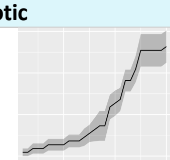
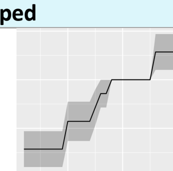
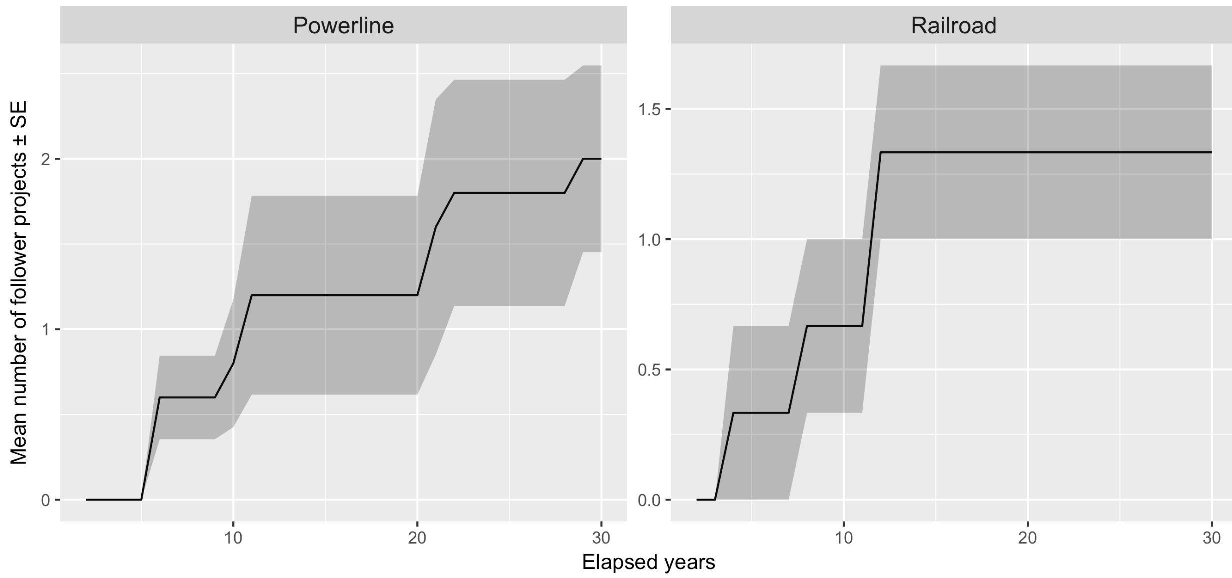
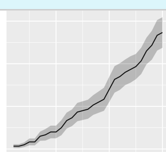
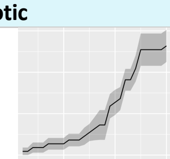
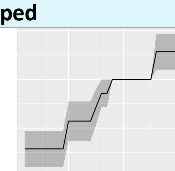
KEY (see Section 5.3.2 for a more detailed guide to interpreting this graph.)		
Trajectories at different *time intervals* describe follower project development rates:		
Linear	**Asymptotic**	**Stepped**
A relatively constant rate of project development that has remained fairly steady through time. 	A saturation effect where rapid development quickly approaches or reaches an upper limit. 	Characterized by few follower projects, each followed by a period of hiatus. 

Figure 6.17d. Precursor railroad projects and mean numbers of follower projects (by development type) within major connective watershed system boundaries, 1950 to 2015.



KEY (see Section 5.3.2 for a more detailed guide to interpreting this graph.)		
Trajectories at different *time intervals* describe follower project development rates:		
Linear	**Asymptotic**	**Stepped**
A relatively constant rate of project development that has remained fairly steady through time. 	A saturation effect where rapid development quickly approaches or reaches an upper limit. 	Characterized by few follower projects, each followed by a period of hiatus. 

Tables 6.1 to 6.5 present the rates at which follower projects succeeded precursor projects within each watershed type. The matrices in these tables have identical rows and columns listing precursor and follower project types, respectively. For the sake of brevity, data in these tables has been aggregated into five periods after the precursor projects were built: Years 1 to 2, Years 3 to 5, Years 6 to 10, Years 11 to 15, and Years 16 to 30.

Table 6.1. Rate per year of precursor and follower projects, by watershed type, Years 1 to 2.

Watershed type	Precursor project type	Rate/year of follower project types							
		Coal mine	Gas plant	Powerline	Hydro project	Metal mine	Mineral mine	Major road	Railroad
Fossil	Coal	**0.20**	0.50	-	-	-	-	-	-
	Gas plant	0.33	**0.42**	0.06	-	-	-	-	-
	Powerline	0.09	0.13	**0.17**	-	-	-	-	-
	Hydro	0.09	0.13	0.17	-	-	-	-	-
	Metals	-	-	-	-	-	-	-	-
	Minerals	-	-	-	-	-	-	-	-
	Major road	-	-	0.25	-	-	-	-	-
	Railroad	-	-	0.20	-	-	-	-	-
Mineral	Coal	-	-	-	-	-	-	-	-
	Gas plant	-	-	-	-	-	-	-	-
	Powerline	-	-	**0.23**	0.08	0.14	0.17	0.29	0.50
	Hydro	-	-	0.46	**0.02**	0.20	0.12	0.11	0.10
	Metals	-	-	0.14	0.06	**0.25**	0.12	0.12	0.11
	Minerals	-	-	0.12	0.03	0.19	**0.21**	0.21	0.43
	Major road	-	-	0.11	0.14	0.08	0.15	**-**	0.18
	Railroad	-	-	0.27	-	0.09	0.10	-	**-**
Mixed	Coal	**0.29**	-	0.33	-	0.17	-	0.33	-
	Gas plant	-	**0.45**	0.41	-	-	-	-	-
	Powerline	0.21	0.19	**0.24**	-	0.19	0.08	0.03	0.08
	Hydro	-	-	0.60	**-**	-	-	-	0.50
	Metals	-	-	0.26	-	**0.12**	0.10	0.12	-
	Minerals	-	1.00	0.21	0.22	0.17	**-**	0.14	-
	Major road	-	-	0.12	0.33	0.10	-	**-**	-
	Railroad	-	-	0.17	-	1.00	-	0.17	**-**
Connective	Coal	-	-	-	-	-	-	-	-
	Gas plant	-	-	-	-	-	-	-	-
	Hydro	-	-	0.24	-	-	-	-	1.00
	Powerline	-	-	-	-	-	-	-	-
	Metals	-	-	-	-	-	-	-	-
	Minerals	-	-	-	-	-	-	-	-
	Major road	-	-	-	-	-	-	-	-
	Railroad	-	-	-	-	-	-	-	-

Table 6.2. Rate per year of precursor and follower projects, by watershed type, Years 3 to 5.

Watershed type	Precursor project type	Rate/year of follower project types							
		Coal mine	Gas plant	Powerline	Hydro project	Metal mine	Mineral mine	Major road	Railroad
Fossil	Coal	**0.20**	0.42	0.08	-	-	-	0.33	-
	Gas plant	0.28	**0.34**	0.14	-	-	-	-	-
	Powerline	0.03	0.07	**0.03**	-	-	-	0.11	0.33
	Hydro	-	-	-	-	-	-	-	-
	Metals	-	-	-	-	-	-	-	-
	Minerals	-	-	-	-	-	-	-	-
	Major road	0.08	0.11	-	-	-	-	-	0.33
	Railroad	0.07	-	0.20	-	-	-	-	-
Mineral	Coal	-	-	-	-	-	-	-	-
	Gas plant	-	-	-	-	-	-	-	-
	Powerline	-	-	**0.52**	0.01	0.12	0.09	0.08	0.06
	Hydro	-	-	0.23	**0.16**	0.13	0.16	0.20	0.13
	Metals	-	-	0.20	0.06	**0.21**	0.09	0.09	0.07
	Minerals	-	-	0.27	0.12	0.15	**0.08**	0.12	-
	Major road	-	-	0.32	0.12	0.14	0.06	**0.21**	0.09
	Railroad	-	-	0.52	-	0.12	-	0.33	**0.17**
Mixed	Coal	**-**	-	0.37	0.11	0.06	0.08	0.22	-
	Gas plant	-	**0.62**	0.08	-	-	-	-	-
	Powerline	0.02	0.11	**0.29**	0.08	0.14	0.07	0.14	0.08
	Hydro	0.13	-	0.20	**-**	0.33	-	0.25	0.17
	Metals	0.02	-	0.32	0.03	**0.19**	0.07	0.09	-
	Minerals	-	0.33	0.26	0.04	0.22	**0.03**	0.19	-
	Major road	-	-	0.24	0.04	0.14	0.04	**0.08**	0.07
	Railroad	-	-	0.22	-	-	-	0.06	**0.08**
Connective	Coal	-	-	-	-	-	-	-	-
	Gas plant	-	-	-	-	-	-	-	-
	Hydro	-	-	0.22	-	-	-	-	-
	Powerline	-	-	**-**	-	-	-	-	-
	Metals	-	-	-	-	-	-	-	-
	Minerals	-	-	-	-	-	-	-	-
	Major road	-	-	-	-	-	-	-	-
	Railroad	-	-	-	-	-	-	-	**0.11**

Table 6.3. Rate per year of precursor and follower projects, by watershed type, Years 6 to 10.

Watershed type	Precursor project type	Rate/year of follower project types							
		Coal mine	Gas plant	Powerline	Hydro project	Metal mine	Mineral mine	Major road	Railroad
Fossil	Coal	**0.04**	0.30	0.20	-	-	-	-	-
	Gas plant	0.10	**0.24**	0.06	-	-	-	-	-
	Powerline	0.02	0.09	**0.18**	-	-	-	0.07	-
	Hydro	-	-	-	-	-	-	-	-
	Metals	-	-	-	-	-	-	-	-
	Minerals	-	-	-	-	-	-	-	-
	Major road	-	0.13	0.05	-	-	-	-	-
	Railroad	0.04	0.05	0.08	-	-	-	0.08	**0.20**
Mineral	Coal	-	-	-	-	-	-	-	-
	Gas plant	-	-	-	-	-	-	-	-
	Powerline	-	-	**0.38**	0.05	0.10	0.15	0.10	0.05
	Hydro	-	-	0.19	**0.16**	0.07	0.06	0.14	-
	Metals	-	-	0.20	0.04	**0.18**	0.07	0.11	0.04
	Minerals	-	-	0.29	0.17	0.13	**0.09**	0.04	0.06
	Major road	-	-	0.37	0.01	0.17	0.15	**0.13**	0.11
	Railroad	-	-	0.49	-	0.09	0.12	0.07	**-**
Mixed	Coal	**0.06**	-	0.20	-	0.20	0.08	0.07	-
	Gas plant	-	**0.43**	0.11	-	-	-	-	-
	Powerline	0.04	0.18	**0.27**	0.03	0.14	0.07	0.07	0.03
	Hydro	-	0.20	0.08	**-**	0.40	0.07	0.10	-
	Metals	0.02	-	0.30	-	**0.14**	0.07	0.05	0.07
	Minerals	0.02	0.60	0.16	0.11	0.15	**0.08**	0.14	-
	Major road	-	-	0.11	0.02	0.28	0.02	**0.09**	0.04
	Railroad	0.20	-	0.20	0.12	-	-	0.07	**-**
Connective	Coal	-	-	-	-	-	-	-	-
	Gas plant	-	-	-	-	-	-	-	-
	Hydro	-	-	0.11	-	-	-	-	0.20
	Powerline	-	-	**-**	-	-	-	-	-
	Metals	-	-	-	-	-	-	-	-
	Minerals	-	-	-	-	-	-	-	-
	Major road	-	-	-	-	-	-	-	-
	Railroad	-	-	0.16	-	-	-	-	**0.07**

Table 6.4. Rate per year of precursor and follower projects, by watershed type, Years 11 to 15.

Watershed type	Precursor project type	Rate/year of follower project types							
		Coal mine	**Gas plant**	**Powerline**	**Hydro project**	**Metal mine**	**Mineral mine**	**Major road**	**Railroad**
Fossil	Coal	**0.04**	0.08	0.05	-	-	-	-	-
	Gas plant	0.20	**0.17**	0.02	-	-	-	-	-
	Powerline	0.05	0.20	**0.03**	-	-	-	0.07	-
	Hydro	-	-	-	-	-	-	-	-
	Metals	-	-	-	-	-	-	-	-
	Minerals	-	-	-	-	-	-	-	-
	Major road	0.05	0.40	0.15	-	-	-	**0.10**	0.07
	Railroad	0.12	-	0.16	-	-	-	0.08	**-**
Mineral	Coal	-	-	-	-	-	-	-	-
	Gas plant	-	-	-	-	-	-	-	-
	Powerline	-	-	**0.33**	0.12	0.12	0.10	0.04	0.07
	Hydro	-	-	0.23	**0.07**	0.10	0.08	0.11	-
	Metals	-	-	0.19	0.07	**0.15**	0.06	0.07	0.04
	Minerals	-	-	0.25	0.18	0.06	**0.05**	0.05	-
	Major road	-	-	0.45	0.03	0.15	0.08	**0.06**	0.02
	Railroad	-	-	0.44	0.10	0.15	0.12	0.07	**0.10**
Mixed	Coal	**0.03**	-	0.04	0.07	0.23	0.08	0.07	**-**
	Gas plant	-	**0.31**	0.04	-	-	-	-	-
	Powerline	0.02	0.20	**0.18**	0.03	0.14	0.08	0.07	0.02
	Hydro	-	0.10	0.28	**0.20**	0.40	0.07	0.05	-
	Metals	0.02	-	0.27	0.02	**0.13**	0.05	0.05	-
	Minerals	0.12	0.40	0.20	-	0.22	**0.04**	0.09	-
	Major road	0.03	0.20	0.31	0.02	0.17	0.08	**0.06**	-
	Railroad	-	-	0.17	-	-	0.07	0.03	**0.25**
Connective	Coal	-	-	-	-	-	-	-	-
	Gas plant	-	-	-	-	-	-	-	-
	Hydro	-	-	0.11	-	-	-	-	-
	Powerline	-	-	-	-	-	-	-	-
	Metals	-	-	-	-	-	-	-	-
	Minerals	-	-	-	-	-	-	-	-
	Major road	-	-	0.07	-	-	-	-	0.20
	Railroad	-	-	0.08	-	-	-	-	**0.13**

Table 6.5. Rate per year of precursor and follower projects, by watershed type, Years 16 to 30.

Watershed type	Precursor project type	Rate/year of follower project types							
		Coal mine	Gas plant	Powerline	Hydro project	Metal mine	Mineral mine	Major road	Railroad
Fossil	Coal	**0.09**	0.17	0.02	-	-	-	-	-
	Gas plant	0.04	**0.07**	0.01	-	-	-	-	-
	Powerline	0.14	0.24	**0.03**	-	-	-	-	-
	Hydro	-	-	-	-	-	-	-	-
	Metals	-	-	-	-	-	-	-	-
	Minerals	-	-	-	-	-	-	-	-
	Major road	0.07	0.33	0.07	-	-	-	**0.03**	0.02
	Railroad	0.05	0.27	0.19	-	-	-	0.03	**-**
Mineral	Coal	-	-	-	-	-	-	-	-
	Gas plant	-	-	-	-	-	-	-	-
	Powerline	-	-	**0.24**	0.18	0.06	0.09	0.03	0.03
	Hydro	-	-	0.17	**0.04**	0.05	0.04	0.03	0.03
	Metals	-	-	0.16	0.08	**0.11**	0.08	0.03	0.04
	Minerals	-	-	0.17	0.11	0.07	**0.07**	0.02	0.03
	Major road	-	-	0.39	0.07	0.09	0.08	**0.02**	0.01
	Railroad	-	-	0.39	0.15	0.08	0.07	-	**0.04**
Mixed	Coal	**0.04**	-	0.22	0.02	0.17	0.03	-	-
	Gas plant	-	**0.15**	0.04	-	-	-	-	-
	Powerline	0.04	0.33	**0.14**	0.03	0.08	0.07	0.03	0.03
	Hydro	0.05	0.53	0.35	**-**	0.07	0.02	-	0.03
	Metals	0.07	-	0.17	0.05	**0.11**	0.06	0.04	0.04
	Minerals	0.06	0.53	0.21	0.01	0.07	**0.06**	0.02	-
	Major road	0.09	0.33	0.32	0.02	0.08	0.04	**0.04**	0.04
	Railroad	0.07	0.30	0.09	0.04	-	0.04	0.03	**-**
Connective	Coal	-	-	-	-	-	-	-	-
	Gas plant	-	-	-	-	-	-	-	-
	Hydro	-	-	0.06	-	-	-	-	-
	Powerline	-	-	**-**	-	-	-	-	-
	Metals	-	-	-	-	-	-	-	-
	Minerals	-	-	-	-	-	-	-	-
	Major road	-	-	0.09	-	-	-	-	0.07
	Railroad	-	-	0.05	-	-	-	-	-

6.4 Discussion

On powerlines. Within the STS graphs and the tables presented in the preceding section, follower powerline projects consistently occur at high rates, paired with a variety of precursor projects. The pattern in the STS graphs for follower powerlines is dependably linear, indicating that powerline building is happening at a steady pace. New powerlines are often built along corridors originated by other linear features (the inverse is not nearly as common), and usually have connectivity with the greater transmission grid. Powerlines are also necessary to transport energy either to or from most of the project types.

On linear features in general. As precursor projects, all three linear features—powerlines, major roads, and railroads—are all linked with high rates of follower projects, particularly in mineral and mixed watersheds, which have the greatest potential for resource extraction in general. Most patterns displayed are linear, although some (e.g., precursor powerlines with follower powerlines in a mixed watershed) are verging toward asymptotic, suggesting that powerlines in those watersheds may be reaching a density at which they will soon plateau.

On non-linear features. Coal and gas plants seem to rapidly propagate projects of their own or each other's types within fossil watersheds, especially within the first decade. This trend is consistent with what was seen in the travel time analysis. Linear patterns are observable for both project types. Several coal mines and many gas plants were built within the last 30 years, so the error ribbon is relatively wide for both of these precursor project types.

As I have shown, the travel time and watershed analyses produced results that were similar in two ways. First, the watershed analysis results demonstrated the same trends in the annual rate of project proliferation over the decades as the travel time analysis. Second, the mean number of follower projects was consistent between the two analyses for most development type pairings.

The travel time and watershed analyses fulfilled the first criterion for causality discussed in at the previous chapter—time precedence—by showing that when we build projects of certain types, projects of other types tend to follow. The classification of watersheds by resource potential serves to establish a causal mechanism, the second criterion for causality. In the following chapter, I will demonstrate how the patterns identified in the preceding analysis can improve upon the accuracy of the future development scenarios used in cumulative effects assessments.

Chapter 7: Ground-truthing the method

7.1 Introduction

Earlier in this manuscript, I argued that current approaches to consideration of induced development in CEA were fundamentally myopic. The focus of this chapter is to explore (or assess) the specific consequence of this myopia in British Columbia, and the extent to which the method described and refined in the preceding two chapters improves upon current practice. In the following sections, I investigate how predictions of future development made in Environmental Impact Statements (EISs) compare with the development that actually occurred over the ensuing years. I then contrast both with the projections generated using the watershed analysis approach introduced in the previous chapter.

7.2 Data and methods

As noted in Chapter 2, environmental impact assessment was formally established as a regulatory process in BC over two decades ago (*Environmental Assessment Act* 1994). Since that time, the BC EAO has certified 140 projects. Of these projects, 63 matched the development type categories used in the previous part of this analysis: coal mines, gas plants, hydro plants, major roads, metal mines, mineral mines, powerlines, and railroads (the other projects in E-PIC include tourist resorts, landfill projects, wind farms, and other development types).

For several of the oldest certifications, E-PIC did not have a digital version of the EIS on file, and the paper copies held by the Vancouver Public Library were consulted instead. Of the 63 projects, 44 were actually built subsequent to certification. In the 12 earliest EISs, cumulative effects assessments tended to be more perfunctory, and consideration of future project scenarios was done on a purely conceptual basis, if at all. The remaining 32 projects belonged to the following development types: coal mines (5), gas plants (3), powerlines (3), hydro plants (18), and metal mines (3).

For these 32 projects, I compared *ex ante* predictions of future development (i.e., those projects considered reasonably foreseeable in the CEA sections of the EISs) to *ex post* data on development (i.e., those projects that were actually built in subsequent years). I then contrasted the *ex ante* predictions with the results of the watershed analysis discussed in Chapter 6 to gauge the accuracy of a projection produced using the watershed approach versus the approach used in the CEAs. (The watershed analysis was first re-run with data from the 32 relevant projects excised.)

These comparisons are acknowledged to be limited in two ways. First, as previously mentioned, there are no *ex ante* data for major roads, mineral mines, and railroads, and a small sample size for the other five development types. Second, the oldest projects were permitted less than 20 years ago, precluding insight on developments up to the 30-year horizon.

7.3 Results

The results of this analysis are presented in Figures 7.1 to 7.5 in a similar format to the STS graphs in the preceding chapter, with the vertical axes defining the average follower project count. Follower projects within the same major watershed system are plotted in red (development predicted in the EIS), blue (development projected by the watershed analysis), and green (the actual observed number of development projects) within the time in years marked along the x-axis, beginning at the time the precursor project began operation.

For the sake of consistency, the horizontal axes in these graphs have the same temporal breaks as the STS graphs, representing intervals of between 2 and 30 years. However, as noted previously, the projects in this sample were all built within the last 20 years, so their follower projects cannot yet be counted for the entire 30-year period. Thus, in the graphs for coal mines, metal mines, and powerlines, the plotted lines only extend to the 10 year mark, as all the precursor projects involved were built within the last 10 years. For the remaining two graphs—gas plants and hydro plants—the plotted lines extend to the 30-year mark, because at least some of the precursor projects were built between 16 and 20 years ago. However, as this time interval is far from over, the number of follower projects may still increase. The dashed line used to plot the last time interval in each facet is intended to suggest the possibility that the number of projects may rise. The limited selection of project type and watershed type combinations reflect the small sample size used in this analysis.

Figure 7.1. Future development within fossil watersheds predicted in EISs (red) compared with watershed analysis projection (blue) and actual observed development (green) for precursor coal mines.

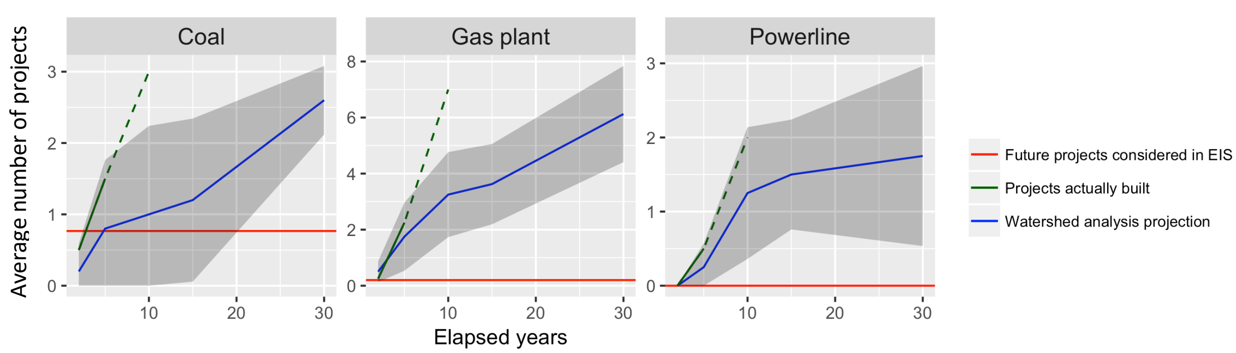


Figure 7.2. Future development within fossil watersheds predicted in EISs (red) compared with watershed analysis projection (blue) and actual observed development (green) for precursor gas plants.

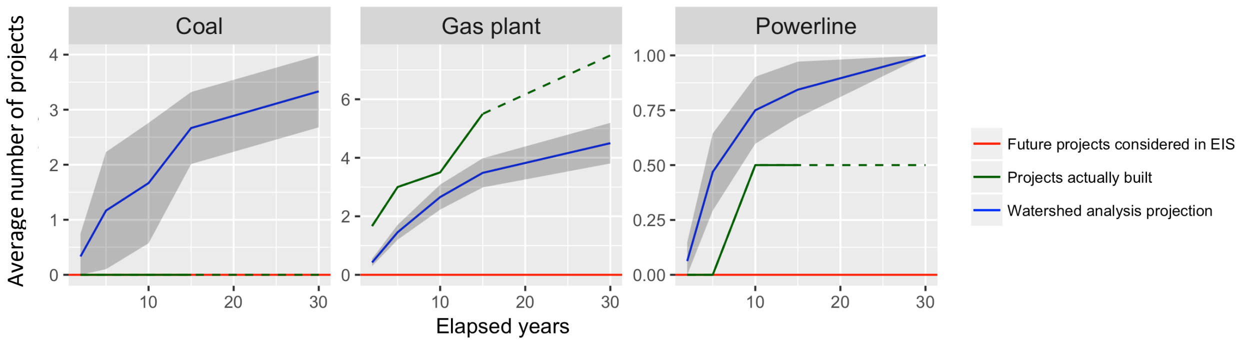


Figure 7.3. Future development within mineral watersheds predicted in EISs (red) compared with watershed analysis projection (blue) and actual observed development (green) for precursor powerlines.

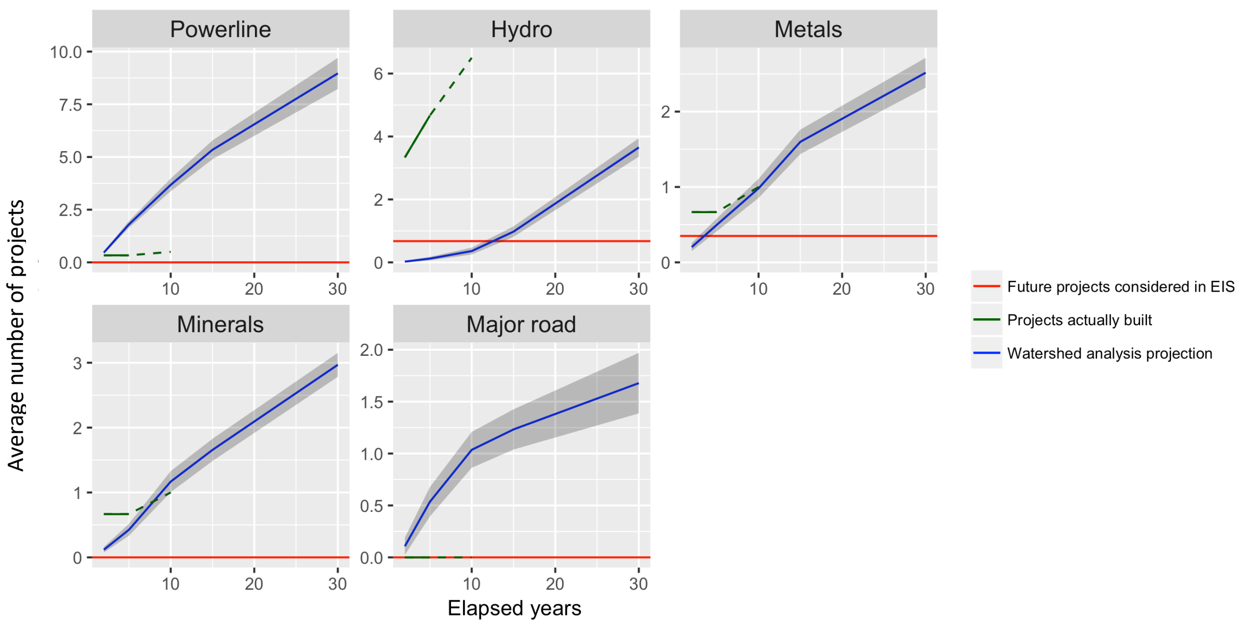


Figure 7.4. Future development within mineral watersheds predicted in EISs (red) compared with watershed analysis projection (blue) and actual observed development (green) for precursor hydro plants.

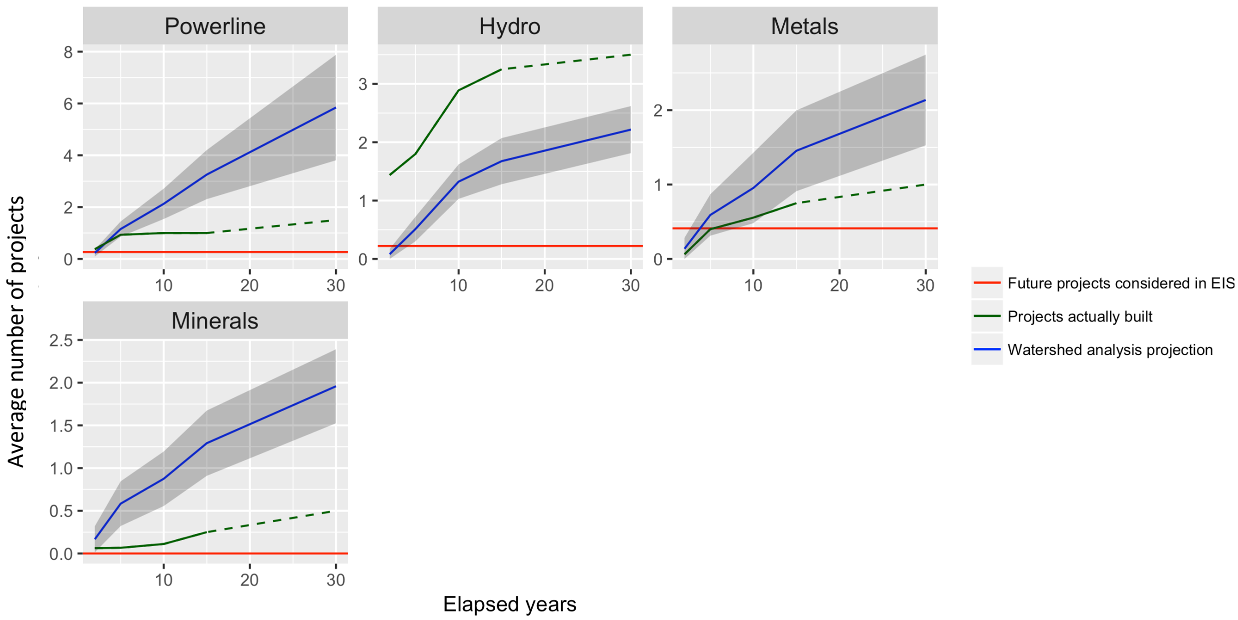
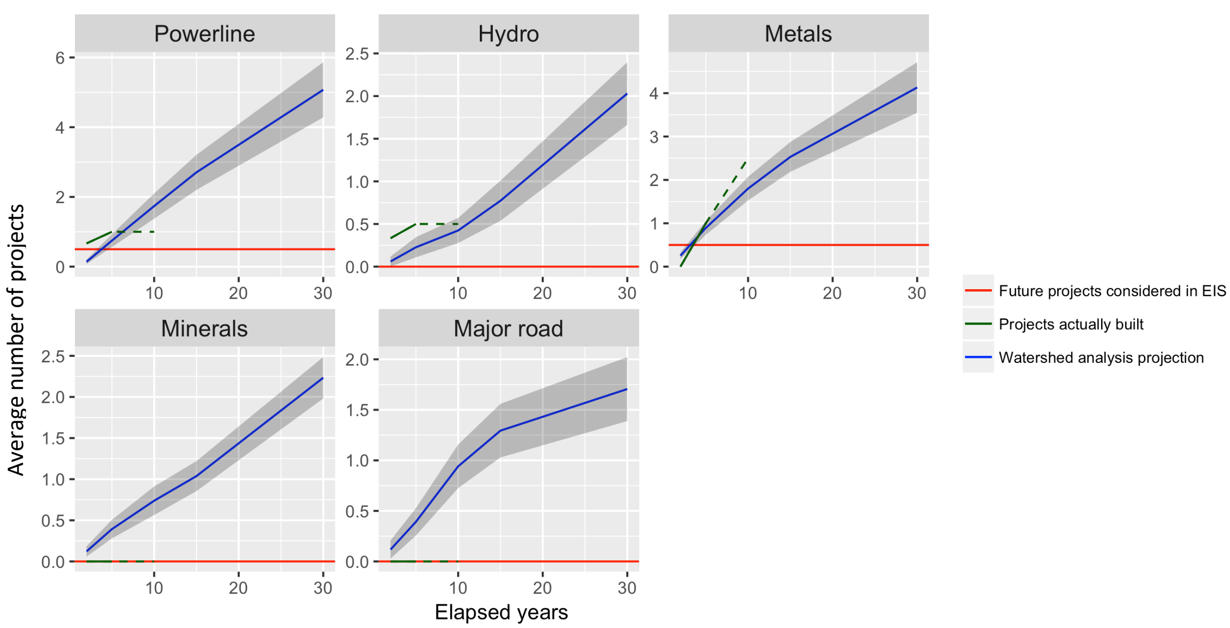


Figure 7.5. Future development within mineral watersheds predicted in EISs (red) compared with differentiated watershed analysis projection (blue) and actual observed development (green) for precursor metal mines.



The 32 projects analysed belong to 20 different combinations of precursor/follower project pairings and watershed types. Of these 20 combinations, the mean number of projects actually built:

- was the same as what was predicted in the EIS—zero projects—in 4 cases (20%);
- was higher than what was predicted in the EIS in 16 cases (80%).

In every precursor/follower project type pairing, the mean number of future projects actually built was the same or higher than predictions in the EISs by the 5-year mark. This shortfall was sometimes small (e.g., precursor powerlines and follower powerlines within mineral watersheds), and sometimes more significant (e.g., precursor gas plants and follower gas plants; precursor powerlines and follower hydro projects within mineral watersheds).

By comparison, out of the same 20 combinations of precursor/follower project pairings and watershed types, the number of projects actually built:

- was zero (as the EIS had predicted) and fell below what the watershed analysis projected in 4 cases (20%);
- fell somewhere between the EIS prediction and the watershed analysis projection in 4 cases (20%);
- intersected with the watershed analysis projection in 9 cases (45%); or
- exceeded the watershed analysis projection in 3 cases (15%).

The sample size for each combination of precursor project and watershed type are vanishingly small for all but hydro projects in mixed watersheds. For this reason, it is with caution that I report on the trends by project type revealed by this analysis according to the characterization scheme introduced in the preceding chapters. I do so for illustrative purposes, in order to demonstrate what might be done with a greater number of data points.

Precursor coal mines in fossil watersheds. The five precursor coal mines in the sample were all built less than ten years ago. In that time, the observed trend for follower coal mines, gas plants, and powerlines has been linear. This is consistent with the 30-year watershed analysis projection for coal mines and gas plants. The trend for powerlines has historically been asymptotic, suggesting that the number of powerlines in these watersheds may begin to level off in the next two decades.

Precursor gas plants in fossil watersheds. There are 16 years of data relating to the oldest of the three gas plants in the sample. No follower coal mines have occurred thus far, which is not the trend which has been observed historically. The trend for follower gas plants appears to be linear, and for powerlines, potentially asymptotic, consistent with the watershed analysis projection.

Precursor powerlines in mineral watersheds. As with coal mines, all three powerlines in the sample are less than a decade old. No follower major roads have been built in these watersheds so far, and indeed, very few have been built anywhere in the province in recent years. The trend in follower powerlines seems flat thus far, not linear as the watershed analysis projection suggests. However, for the other three follower project types—hydro, metal mines, and mineral mines—it appears that the linear pattern observed in the watershed analysis projection may be manifesting, though at a much higher rate than anticipated for hydro projects.

Precursor hydro projects in mineral watersheds. There are a greater number of hydro projects in the sample than any other project type (18), and the oldest is nearly 20 years old. It is perhaps significant, then, that the trends for this particular combination conform relatively closely to the watershed analysis projection in terms of their characterization. The trends for follower powerlines, metal mines, and mineral mines are all linear, though with a slower upward trend than in the projection. Follower hydro projects are occurring more rapidly than projected, but with a very similar asymptotic curve.

Precursor metal mines in mineral watersheds. As with coal mines and hydro projects, there are fewer than 10 years of data for the three metal mines in the sample. No follower mineral mines or major roads have been built thus far. However, the linear trends for powerlines, hydro projects, and metal mines appear to be relatively consistent with the watershed analysis projection.

7.4 Discussion

Although the sample size is admittedly small, the results of this demonstration would seem to confirm two points. Firstly, as argued in the first chapter of this manuscript, current cumulative effects assessment practice *has* consistently underestimated the future development included in EISs in at least 80% of cases, and potentially in even more, depending on how development unfolds over the next decade or more. Moreover, this underestimation manifests almost immediately: not in some murky point in the far future, but within the first five years after the project is permitted and built.

The implications of this are unsettling. CEA should consider a range of alternative future scenarios and the direct and indirect impacts that land use change will have on the environment. While considering the effects of past and existing projects is also important, the heart of CEA is its focus on future possibilities. The past provides valuable context and an opportunity for learning, but it is inherently unchangeable. The future is where we need to concentrate our planning efforts, and instead we seem to be doing our best to ignore it.

Secondly, the projection derived from the watershed analysis has been shown to provide a more realistic picture of the potential for future development than the approach that was taken in the BC EISs. I argue that this method, despite its limitations, better aligns with the precautionary principle than current assessment practice, which trivializes it. In the next chapter, I outline how this method could be operationalized outside of British Columbia, including how the results could be incorporated into CEAs.

Chapter 8: A reflection on building and trialling methods for cumulative effects assessment

8.1 Introduction

The methodology described in this manuscript is an attempt to illuminate empirically what might to some appear obvious: that human activity more often than not begets more human activity. By understanding how development has historically germinated and spread in a particular context, we can stake out the possibility space within which future development might be expected to occur. This chapter outlines, in more general terms, how the key elements of this approach might be applied to the practice of CEA outside the British Columbian example explored in earlier chapters. It concludes by anticipating and countering some likely objections to the proposed method, and ends with a few final reflections.

8.2 Method essentials

8.2.1 Data collection

The state of the environment in any region can be thought of as a product of the cumulative effects of human activities over time, coupled with the effects of any natural disturbances. To identify context-specific trends, information on past and existing development (the dependent variables) must first be obtained from reliable sources such as government repositories or official reports filed by development proponents (as part of either their permitting efforts or responsibilities as publicly traded companies). These data should be assembled into a series of layers and relational tables within a geodatabase, and should include, at a minimum:

- the geographic locations of developments in consistent formats (i.e., points, lines, polygons, or rasters);
- some consistent indication of the temporal dimensions of developments (e.g., construction start and end dates, operation start and end dates);
- other metadata on the nature of developments (i.e., area cleared, volume of earth displaced, production capacity, resources extracted, etc.).

Developments should be classified by type and sub-type, as necessary, according to common requirements and drivers. Run-of-river hydroelectric projects, for example, may vary considerably in scale, but are all positioned in order to generate power from the natural flow of water under the influence of gravity, and produce energy in a form that must be carried to market via transmission infrastructure.

Additional spatial data on one or more independent variables that provide a credible causal mechanism for development should also be assembled. In the analysis described in Chapter 6, this variable was the presence of exploitable resources. Other possibilities include both intrinsic components (for example, a nearby water source, assuming that ready access to water is critical to the development type), and extrinsic components (for example, major transportation arteries to bring labour and equipment to site and transport resources to market).[17]

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[17] For example, remote renewable energy resources can be used to produce hydrogen or combined with direct air capture to produce synthetic carbon-neutral hydrocarbons, necessitating roads to take away their product instead of powerlines.

Analysts may also wish to consider temporal (non-spatial) independent variables. Economic cycles in commodity demand, for instance, may be incorporated into the analysis as a leading variable. It may be useful to track political regime change and attendant changes to policies that either restrict or promote development (such as environmental impact assessment requirements, or infrastructure subsidies and royalty credits) over time. If technological innovation has had a direct or indirect bearing on the feasibility of development, this may also be important to explore.

In selecting the scope for data collection efforts, it is important to recognize certain trade-offs. It is unlikely that data that meets the necessary requirements will be available from one source at the same resolution or quality for all development types. The more comprehensive the final dataset, therefore, the greater the effort needed to ensure its contents are consistent. Similarly, collecting longer time series may provide a richer understanding of the emergence of certain historical patterns, but will likely introduce additional strictures in terms of data quality and completeness. In addition, due to technological innovations, extrapolations from early patterns may not have relevance to projections made in the present day. It will thus be necessary to exercise judgment on whether particular data are too imperfect or incomplete to include or too important to exclude.

8.2.2 Analysis of historical development patterns

The basic premise of the analysis is to look for patterns in how projects have historically followed other projects at certain spatial and temporal intervals. Spatial intervals could be formulated in a number of different ways. In Chapters 5 and 6, I considered two different types of spatial intervals based on (1) proximity to other projects in terms of minutes of travel time and (2) presence of other projects within the same watershed system. Another possibility not explored in this manuscript would be simple proximity (e.g., Euclidean distance), with perhaps penalties and/or multipliers assigned for crossing steep topographies or waterbodies.

The temporal intervals chosen in this manuscript range from short-term (2 years) to medium-term (30 years). Although many of the projects in this analysis were designed to operate for longer than three decades, this represents a six-fold increase in terms of the time horizon for future projects typically seen in CEAs. The maximum temporal boundary chosen should be appropriate to the length of the time series data collected as described in the previous section; if only a few decades of relatively consistent historical data are available for analysis, the accuracy of any long-term projections will be highly suspect.

To facilitate comparisons between project types and simplify the overall analysis, I elected to “bin” the travel time distances into discrete ranges (e.g., 15 to 30 minutes’ travel distance). Analysts with a greater appetite for complexity might instead wish to use a continuous scale, which may reveal nuances in trends between intervals.

The next step is to calculate the probability (i.e., the historical frequency) of initial *precursor projects* preceding later *follower projects* at the spatial and temporal intervals selected. In other words (after Dowlatabadi et al. 2004):

$$\rho\langle x|y\rangle_{s,t,\Delta t} = \frac{x \cap y_{s,\Delta t}}{x_t}$$

Where:

$\rho\langle x\|y\rangle_{s,t,\Delta t}$	is the probability of a project of type *y* initiated at time *t* occurring within spatial interval *s* of a project of type *x*, within the temporal interval Δ*t*.
$x \cap y_{s,\Delta t}$	is the number of projects of type *y* occurring within a distance of *s* from projects of type *x* and within a period of Δ*t* after *x*'s occurrence.
x_t	is the number of projects of type *x* at time *t*.

These basic frequentist probabilities can then be calibrated using one or more of the independent variables collected, thus reducing the possibility that strongly correlated precursor/follower project pairings are not linked by some causal mechanism. If extrapolations based on these refined probabilities produce projections that relatively closely accord with real-world development (particularly relative to what is typically found in cumulative effects assessments), then the analysis may be sufficient at this stage.

Depending on the richness of the database, additional independent variables may be introduced to enhance the realism of the projections. It may also help to narrow the spatial or temporal scope of the analysis to be more specific to the time and region of interest, again assuming there is sufficient data within that more limited scope. Where there are few projects of a particular type historically, or where their occurrence has changed significantly (perhaps due to a recent technological innovation), there will be higher degrees of uncertainty. Confidence intervals calculated on these calibrated probabilities can then be used to delineate the space within which development is likeliest to proceed, based on our historical experience. Different confidence intervals could be selected depending on how conservative a projection is desired.

Multiple scenarios of future development can then be derived based on these projections. Duinker and Grieg (2007), among others, advise against using three scenarios, as the middle scenarios will be often be interpreted by users as the "most likely." Cornish (2004) recommends a suite of five options: (1) a surprise-free continuation of current trends (the "business as usual" scenario); (2) a pessimistic scenario; (3) a disastrous, worst-case scenario; (4) an optimistic scenario; and (5) a transformational or miraculous scenario.

8.2.3 Implementation

None of the resulting scenarios will be infallible glimpses into the future, and analysts should resist the temptation to regard them as predictions. Rather, the scenarios can be broadly thought of as explorations of what *could* happen rather than what *will* happen: divergent future possibilities grounded in an empirical study of the past. Considering the possibilities contained in these projections can help to clarify mitigation and management targets, guide thresholds, and refine the planning needed to achieve acceptable outcomes.

In project-level CEAs, multiple scenarios derived from this method could be worked through in addition to the single limited scenario based on current practice. In regional CEAs (still in their nascence in British Columbia), managers and stakeholders could ensure that planning and policy decisions meet the needs of most, if not all, future scenarios and understand where potential risks may lie. As the exact location and timing of the projected developments would be unknown, analysis based on these scenarios would, by necessity, be order of magnitude estimates of the likely impact of development on environmental components. Even without precise details, the impacts of these future developments could be thought about in broad terms; for example:

- The addition of a new major road could be taken into account when assessing the potential for habitat fragmentation and evaluating future road densities against thresholds or targets.
- The consequence of adding multiple major metal mines over a five-year period could be evaluated in terms of the increased demands on local emergency services.
- The effect of higher traffic volumes on major transportation arteries due to the addition of the same metal mines could be taken into account as part of mitigation planning for wildlife and human health.

More thorough analysis could be accomplished by making inferences from examples of roughly analogous projects in similar settings, or by using a simple method for scoring the environmental consequence of different project types (see Arkema et al. 2014 for one example of how this could be accomplished). There is already precedent for including multiple scenarios of future development in project-level and regional CEAs (see Hegmann 1995 in the Yukon Territory; Noble 2008 in Saskatchewan; Seabridge Gold Inc. 2013 in British Columbia).

8.3 Conclusions

> There is a story of a drunkard searching under a street lamp for his house key, which he had dropped some distance away. Asked why he didn't look where he had dropped it, he replied, "It's lighter here!" (Kaplan 1964, 11)

The temptation to look for a thing where it is easiest to find—as opposed to where it is likeliest to be—is strong. And indeed, the most brightly lit space is not a bad place to *start* looking. However, current practice in cumulative effects assessment searches only under the street lamp and stops where the lamp light ends, beyond which things get dark and difficult to discern but where we are most likely to find our missing keys.

In discussing my proposed solution to this problem with both academic and professional colleagues—and, to be honest, in arguing with myself about it over the last four and a half years—certain potential objections tended to emerge. These could be summarized as follows: (1) the method has the potential to be *over*-cautious, producing projections of future development that may consistently outstrip what actually occurs; (2) the method is too speculative or leaves too much uncertain; (3) more detail on the exact nature of future developments is required to actually conduct a meaningful CEA; (4) this method is too challenging to be implemented at the project level; and (5) the method depends on an assumption that the past will resemble the future and thus does not address the possibility of major disruptive changes. In this final section, I attempt to pre-empt some of these potential challenges, and provide some concluding thoughts.

8.3.1 Being cautious about precaution

As noted in Chapter 1, the precautionary principle has been recognized in policy, both in Canada and elsewhere, as important for any actions taken under deep uncertainty. Looking outside the world of impact assessment, we can see many instances of standards that employ the precautionary principle—of regulatory regimes that prohibit or limit activities where there is credible threat of serious consequences, even when cause-effect relationships are not well understood. For example, in the case of certain chemicals, when the precise threshold for dangerous human health effects is unknown, regulators may set an exposure standard factor hundreds of times lower than the lowest exposure at which health effects have been observed to occur (Worksafe BC 2015). Similarly, building codes often include safety factors—again, often applying a multiplier to widen the margin of safety—that ensure structures are built more strongly than needed to support anticipated loads, both because comprehensive testing of all aspects of building design is impractical, and because structures may need to withstand unanticipated uses and emergency situations (Young and Plunkett 2002).

We build in these margins of safety because what matters from a management perspective, at least in these other areas of governance, is the worst-case scenario. In environmental impact assessment, practices at present seem to be biased in the other direction. If we are serious in our goal of environmental protection, we should be willing to accept over-prediction much more readily than under-prediction.

8.3.2 Being circumspect about speculation

The International Finance Corporation (IFC 2013, 39) notes: "If experience has shown that projects of the same type as the one being assessed cause further associated development to occur, then such developments are reasonably predictable" in its handbook on conducting CEA in emerging markets. For IFC member countries Canada and the United States, why is this view easier to recommend in developing nations than to adopt domestically? Just as BC Hydro resisted including "more speculative future projects" in the NTL Project case, proponents and government agencies on both sides of the border have expressed their concerns over engaging in speculation over probable futures (e.g., Mid States Coalition for Progress v. Surface Transportation Board 2003, 50).

This objection would be reasonable if environmental impact assessment and CEA were not *inherently predictive exercises*. As argued in the US Court of Appeals District of Columbia, the basic tenet of environmental impact assessment is:

> …to predict the environmental effects of proposed action before the action is taken and those effects fully known. Reasonable forecasting and speculation is thus implicit […], and we must reject any attempt by agencies to shirk their responsibilities by labeling any and all discussion of future environmental effects as "crystal ball inquiry." (Scientists' Institute for Public Information, Inc. v. Atomic Energy Commission 1973)

In June of 2001, President George W. Bush critiqued the Kyoto Protocol's emission targets, saying, "No one can say with any certainty what constitutes a dangerous level of warming, and therefore what level must be avoided" (Marshall 2014). This argument—that without certainty, we should not or cannot act—is sometimes made to defend assessments that do not include induced developments.

As discussed earlier, according to the precautionary principle, uncertainty does not excuse inaction. In addition, reason would seem to demand, at a minimum, consideration of all available evidence including the evidence of historical precedent, not just the evidence that is nearest at hand. While we have no crystal ball, we do have the benefit of experience; if there is a way to leverage that experience to meaningfully assess the environmental impacts of induced development, we have a responsibility to use it.

8.3.3 Being particular about particulars

The case has been made that without a minimum level of detail about a future project, it is impossible to evaluate its potential to contribute to cumulative effects. This argument sounds quite sensible: how can you factor a development into any analysis when you know virtually nothing about it? If I wanted to be facetious, I would urge readers to peek at how much actual detail assessors have on the future projects they *do* include in CEAs to see the copious piles of bricks that can be made from the wispiest pieces of straw.

A better response would be that certain types of meaningful analysis are absolutely possible even in the absence of copious amounts of detail; I have given several examples of what could be achieved in Section 8.2.3. CEAs that consider future development in any formulation cannot hope to achieve great accuracy, even by the standards of current best practice, which—as noted earlier—is inherently plagued with deep uncertainties. That is not the end of the world: broad, order-of-magnitude conclusions are all that utility requires. In the absence of other information, we can prepare a range of scenarios of future development that roughly follow the pace of historical trends, both conservative and optimistic, and be reasonably confident that the most probable future lies somewhere within those scenarios. By doing so, we can narrow the range of *what might be*, and thus better equip authorities and stakeholders to evaluate project proposals and make appropriate management decisions.

8.3.4 Being practical about practice

I have devoted much (perhaps too much) of this thesis regaling you with the limitations in available data and the many challenges associated with developing this method. Keeping that in mind, I understand if some readers are doubtful about whether it is reasonable to expect project proponents or other analysts to adopt this approach as part of project-level CEA.

In short, I almost agree, mostly because I am of the mind (with Noble 2010 and others) that CEA itself may not belong at the project level at all, but as part of strategic planning by governments at the regional scale. However, the project level is the site at which CEA is currently legally entrenched, in Canada and internationally, whereas there are few formal processes for regional planning and environmental management. Thus, I argue it would be advantageous to adopt an approach that can be integrated into both levels of CEA. For the time being, this would mean that project-level CEA would need to engage in broader regional analyses. Once regional assessment and management processes are better established, the method proposed in this thesis may be of more use to regional planners interested in exploring alternative scenarios of the future to develop regional objectives, thresholds, and inputs to project-level processes.

8.3.5 What if everything changes?

Sometimes an established pattern (like the preceding section headings) is not the best predictor of what comes next (the heading of this section). Of course, the future does not always reflect the past. The main assumption of the approach proposed in these pages is that the system that produced historical trends will continue to generate the same results in the future: in other words, that we can expect business as usual. But what if a significant change occurs to the system?

Some types of changes might be addressed through calibrations to the approach. Technological innovation (such as robotic mining or off-grid energy) may disrupt the patterns we have historically observed in mining and energy projects. However, it may be possible to find analogous characteristics between new project types and old ones—perhaps based on common dependencies such as proximity to water or to population centres—and use these analogues to bridge the gap until sufficient data on occurrences of the new project type have been accumulated. In project-level environmental impact assessment, the obligation could be placed on the developer of a new project type to establish how its project diverges from the patterns observed in the past.

One of the limitations of this approach is that it cannot address more disruptive changes. The relatively minor regulatory and policy changes profiled in Chapter 2's British Columbia example have arguably had an influence on the province's development trends. A larger political disruption—for example, a complete transformation of state-Indigenous relations—would undoubtedly throw extrapolations grounded in the previous political regime into doubt.

Similarly, an extreme ecological disruption, due for instance to factors relating to climate change, would render moot scenarios based on earlier ecological conditions.

While this is an important caveat, I argue that it does not detract from the merits of this approach. The goal of cumulative effects assessment is to enable us to make informed management choices today based on our best estimation of what the future might hold. Developing these estimations necessarily involves making defensible assumptions in the face of two different types of uncertainties, which I will attempt to distinguish between using the following analogy.

Imagine that you are a graduate student attending a nine o'clock class. By carefully tracking the length of your commute over the previous weeks, you know that this commute takes an average of 20 minutes. There are a number of factors that can affect the time involved by a few minutes: the sidewalk being icy or the bus being full can make it longer, dry conditions and empty bus stops can speed things up. One morning, you have an important presentation to make in class, so you decide to leave your home at eight o'clock in order to ensure your punctual arrival. As you cross an intersection, a driver rounds the corner looking the other way and crashes into you, breaking your leg. When your presentation is slated to begin, you are in a hospital emergency room.

The first type of uncertainty involved the mundane variations inherent in a business-as-usual scenario, affecting whether your commute took 18 minutes or 28. The second type of uncertainty involved an uncommon and thus unexpected event: a serious injury which upended everything. If you had even contemplated the question, you would probably have concluded that being hit by a car that morning was *possible*, but no one would fault you for failing to account for that eventuality in your morning preparations. On the other hand, if you had arrived late because the bus was full, as it had been on multiple past mornings, you could be correctly criticized for planning incompetently.

The possibility of unexpected, disruptive change exists. However, the potential for these types of disruptions to occur does not free conscientious decision-makers from the responsibility of planning for events that are expected and routine.

8.4 Coda: Return to the NTL Project

As this thesis began with the example of the Northwest Transmission Line Project, it is perhaps fitting to revisit that project at its conclusion. I began this research in 2013, one year before construction of the NTL Project was completed, and the data used in my analysis extends only to 2015, one year after.

Since the commissioning of the NTL Project in mid-2014, three new hydroelectric projects have been built, delivering a total of 277 megawatts of energy from the Iskut River to the provincial grid via the new powerline. Two of these projects had high enough capacities to warrant an environmental assessment, while the third was below the regulatory threshold. All three have contracts to produce power for BC Hydro into the 2070s (Alta Gas 2018). Another nine hydro projects have been proposed and are currently in various stages of planning and permitting; of these, only two will trigger an environmental assessment (BC MJTST 2018). Six new metal mines are proposed (the one mine built at the time of writing is expected to operate until at least

2043), additional exploration and expansion is ongoing at two existing mines (BC MJTST 2018), and a previously closed mine is contemplating re-opening (Skeena Resources 2018).

These changes have all occurred in a period of less than four years.

8.5 Next steps and last thoughts

Current cumulative effects assessment practice is essentially geared toward avoiding a false positive: because we are not certain what projects will happen in the future, we assume that very few will. The approach I have developed in this thesis is more concerned with avoiding a false negative: I would rather we over-estimate the number of future projects that may contribute to cumulative effects than under-estimate it.

The precautionary principle is recognized in policy, both in Canada and elsewhere, as important for any decision made under conditions of uncertainty. This principle guides decision-makers to err on the side of risk avoidance whenever there are threats of serious or irreversible damage. I would argue that this principle supports the need to adopt approaches to cumulative effects assessment that are biased toward environmental protection rather than toward development proponents.

In terms of application, cumulative effects assessments at present are typically carried out at the individual project level, and I have elected to target my approach to assessments at the project level for this very reason. The method could be implemented at this level to increase the current scope of consideration of future projects in those assessments to better match what could plausibly occur. In addition, while cumulative effects assessments at the regional strategic level are still relatively rare, there is broad agreement that this is the level where cumulative effects should be addressed. At this level, my method could alert decision-makers to the possible future of development in their region, could form the first part of a system for appropriately apportioning responsibility for mitigation and offsetting between developers—perhaps in a manner similar to the Acid Rain Program established by the United States Environmental Protection Agency in the mid-1990s (Barreca et al. 2017)—and for establishing thresholds for development based on factors such as ecological carrying capacity.

We have all seen new types of development—particularly infrastructure—catalyse development many times before. The potential for new projects to spur this type of growth is often explicitly invoked as a project benefit. It seems negligent not to prepare for the future that everyone confidently expects, especially when that expectation is driven by repeated past experiences. It is the very essence of "reasonably foreseeable."

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Mineral Act. S.B.C. 1891, c. 25.

Mineral Tenure Act. R.S.B.C. 1996, c. 292.

Mining District Act. 1863. Colony of British Columbia. May 27, 1863.

Ordinance to Amend and Consolidate the Gold Mining Laws. 1865. Colony of British Columbia. March 29, 1865.

Placer Mining Act, S.B.C. 1891, c. 26.

Reviewable Projects Regulation. 1995. B.C. Reg. 276.

Reviewable Projects Regulation. 2002. B.C. Reg. 370.

Rules and Regulations for the working of Gold Mines. 1859. Colony of British Columbia. September 7, 1859.

Utilities Commission Act. S.B.C. 1980, c. 60.

Water Act. S.B.C. 1909, c. 48.

Water Sustainability Act. S.B.C. 2016, c. 15.

Wildlife Act. R.S.B.C. 1996, c. 488.

Canada

The British North America Act, S.C. 1867, c. 3.

The Constitution Act. 1867, c. 3.

Canadian Environmental Assessment Act. S.C. 1992, c. 37.

Canadian Environmental Assessment Act. S.C. 2012, c.19.

Department of the Environment Act. S.C. 1971, c. 18.

United States

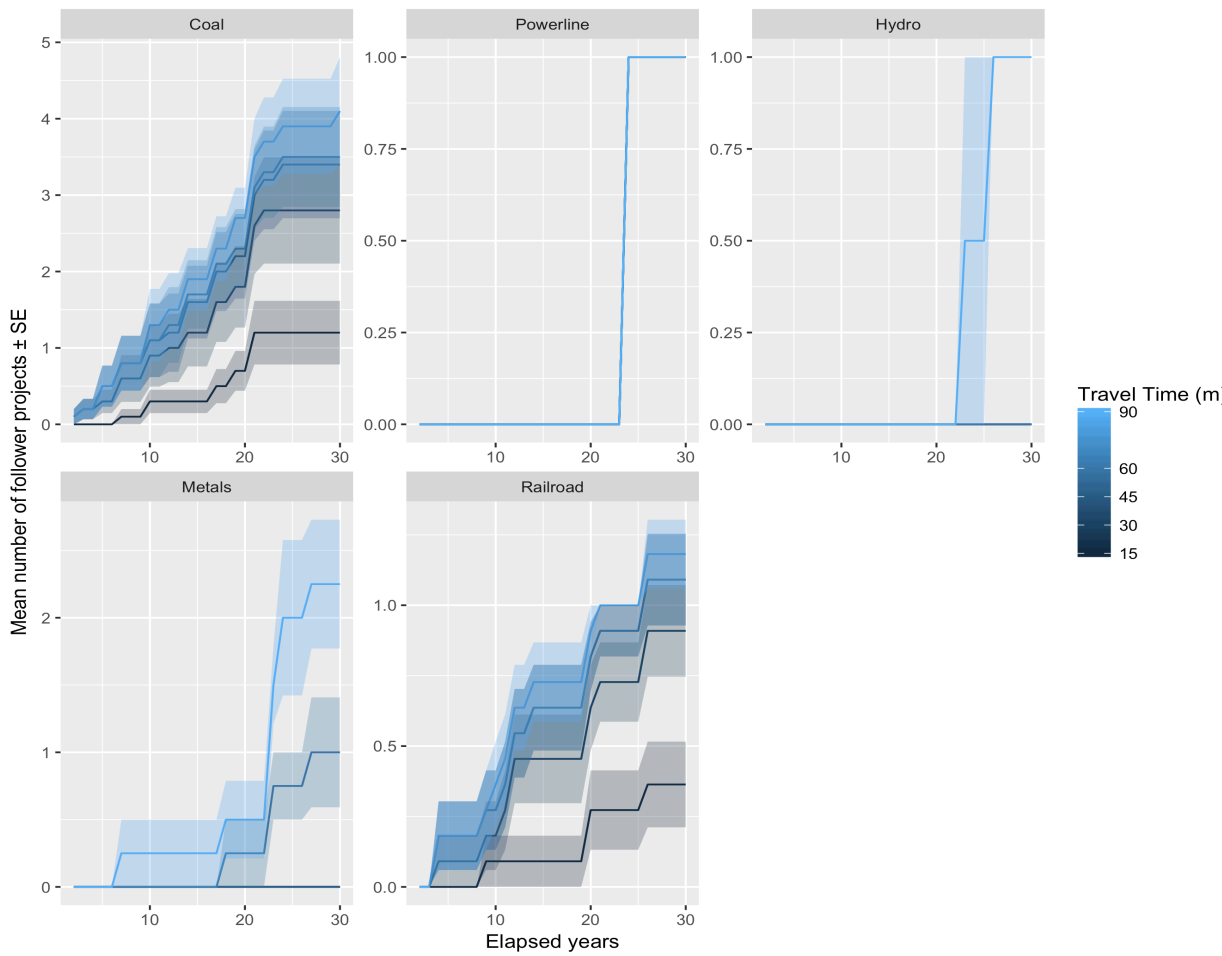
Executive Order 12866. Regulatory Planning and Review. 1993. 58 FR 51735.

Executive Order 13563. Improving Regulation and Regulatory Review. 2011. 76 FR 3821.

National Environmental Policy Act. 1969. 42 U.S.C. § 4321 et seq.

Appendix A Space-time spillover graphs of travel time analysis results, 1852 to 1899

Figure A.1. Space-time spillover graph of travel time analysis results for precursor coal mines, 1852-1899.



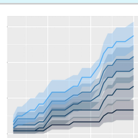
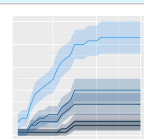
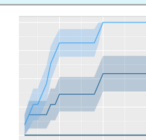
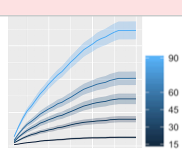
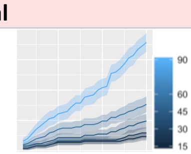
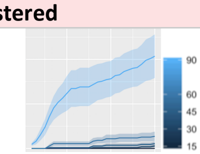
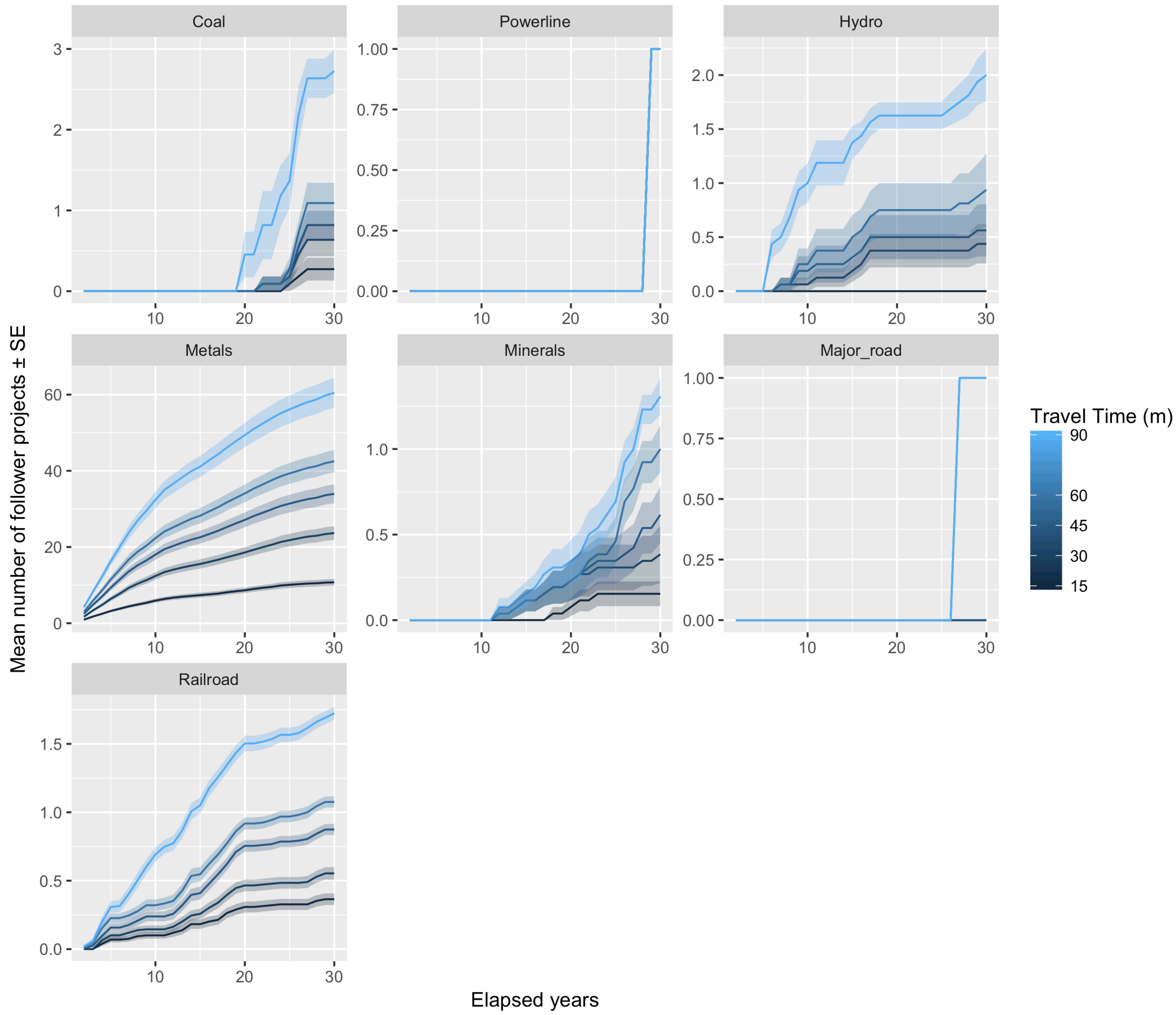
KEY (see text above for a more detailed guide to interpreting this graph.)		
Trajectories at different *time intervals* describe follower project development rates:		
Linear	**Asymptotic**	**Stepped**
A relatively constant rate of project development that has remained fairly steady through time. 	A saturation effect where rapid development quickly approaches or reaches an upper limit. 	Characterized by few follower projects, each followed by a period of hiatus. 
Fanning out of trajectories at different *distances* describes the spatial distribution of development:		
Radial	**Areal**	**Clustered**
Project development opportunities are along a limited number of linear pathways radiating away from the initial project. 	Project development is distributed across the landscape. 	Where projects effectively create focal points of activity. 

Figure A.2. Space-time spillover graph of travel time analysis results for precursor metal mines, 1852 to 1899.



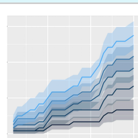
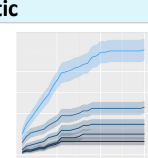
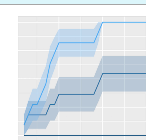
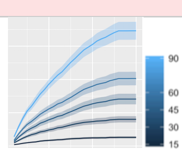
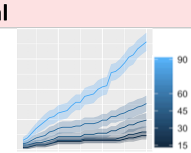
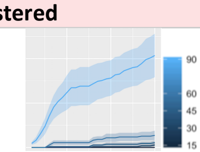
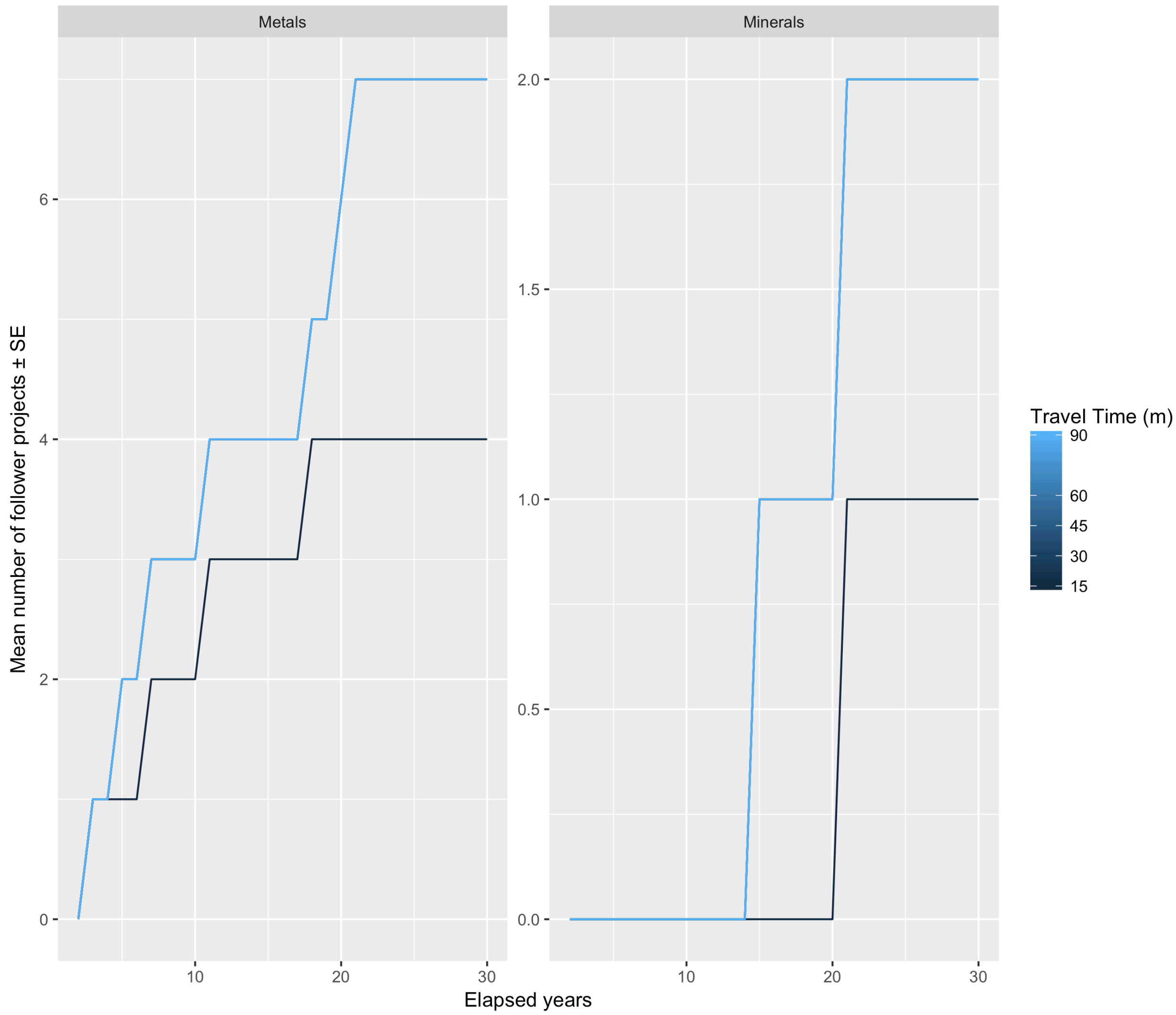
KEY (see text above for a more detailed guide to interpreting this graph.)		
Trajectories at different *time intervals* describe follower project development rates:		
Linear	**Asymptotic**	**Stepped**
A relatively constant rate of project development that has remained fairly steady through time. 	A saturation effect where rapid development quickly approaches or reaches an upper limit. 	Characterized by few follower projects, each followed by a period of hiatus. 
Fanning out of trajectories at different *distances* describes the spatial distribution of development:		
Radial	**Areal**	**Clustered**
Project development opportunities are along a limited number of linear pathways radiating away from the initial project. 	Project development is distributed across the landscape. 	Where projects effectively create focal points of activity. 

Figure A.3. Space-time spillover graph of travel time analysis results for precursor mineral mines, 1852 to 1899.



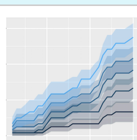
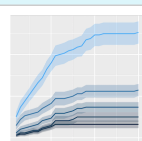
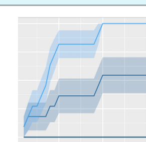
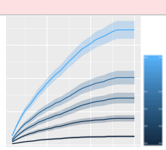
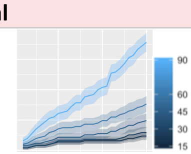
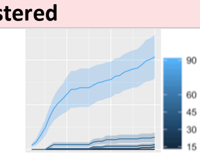
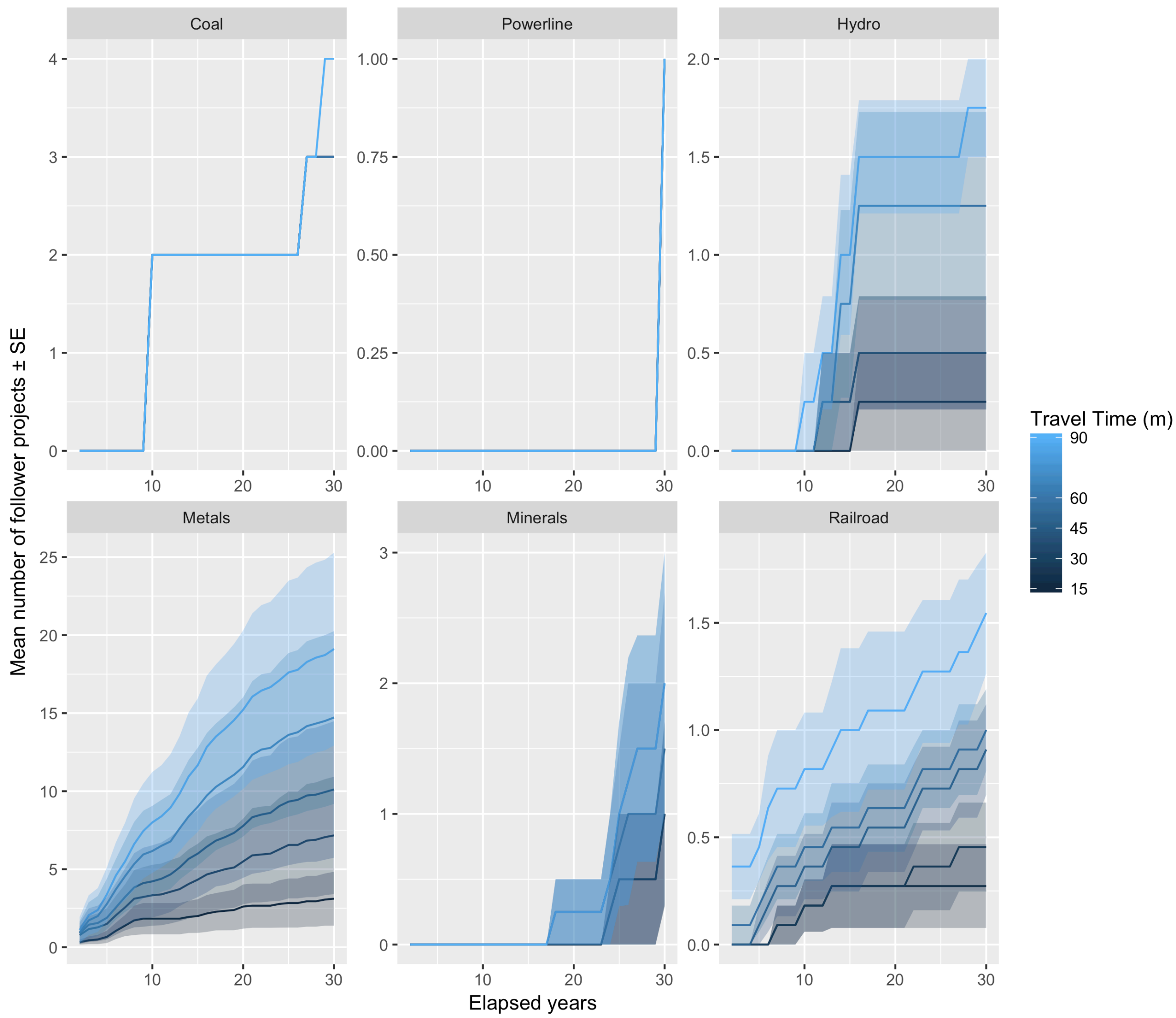
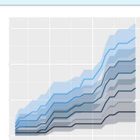
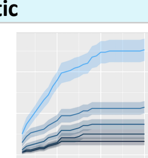
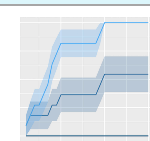
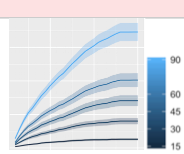
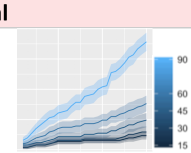
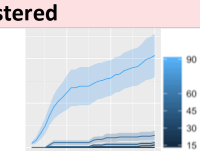
KEY (see text above for a more detailed guide to interpreting this graph.)		
Trajectories at different *time intervals* describe follower project development rates:		
Linear	**Asymptotic**	**Stepped**
A relatively constant rate of project development that has remained fairly steady through time. 	A saturation effect where rapid development quickly approaches or reaches an upper limit. 	Characterized by few follower projects, each followed by a period of hiatus. 
Fanning out of trajectories at different *distances* describes the spatial distribution of development:		
Radial	**Areal**	**Clustered**
Project development opportunities are along a limited number of linear pathways radiating away from the initial project. 	Project development is distributed across the landscape. 	Where projects effectively create focal points of activity. 

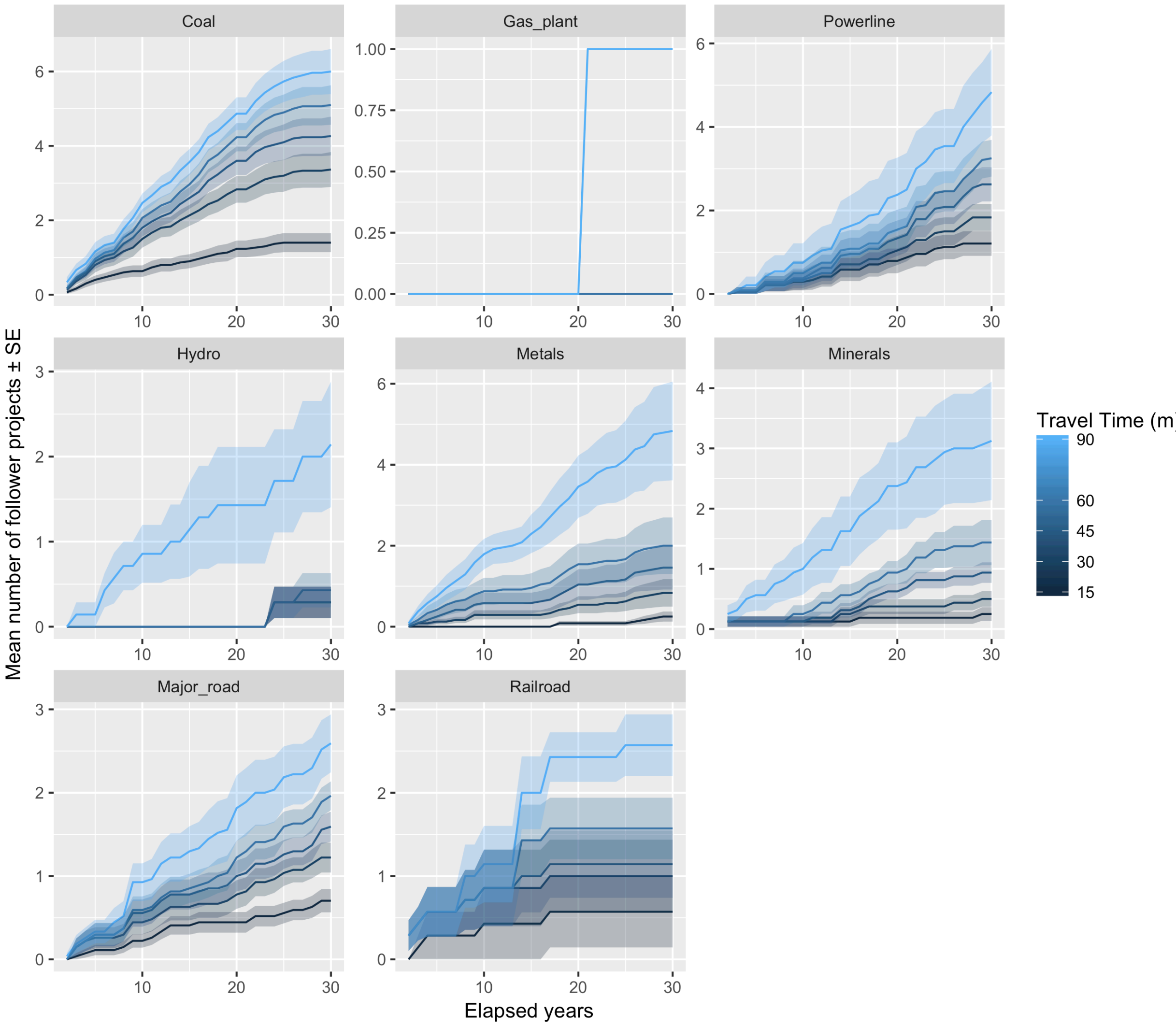
Figure A.4. Space-time spillover graph of travel time analysis results for precursor railroads, 1899 to 1852.



KEY (see text above for a more detailed guide to interpreting this graph.)		
Trajectories at different *time intervals* describe follower project development rates:		
Linear	**Asymptotic**	**Stepped**
A relatively constant rate of project development that has remained fairly steady through time. 	A saturation effect where rapid development quickly approaches or reaches an upper limit. 	Characterized by few follower projects, each followed by a period of hiatus. 
Fanning out of trajectories at different *distances* describes the spatial distribution of development:		
Radial	**Areal**	**Clustered**
Project development opportunities are along a limited number of linear pathways radiating away from the initial project. 	Project development is distributed across the landscape. 	Where projects effectively create focal points of activity. 

Appendix B Space-time spillover graphs of travel time analysis results, 1900 to 1949

Figure B.1. Space-time spillover graph of travel time analysis results for precursor coal mines, 1900 to 1949.



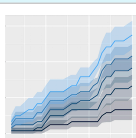
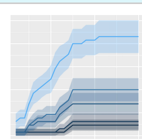
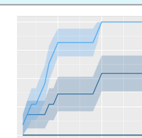
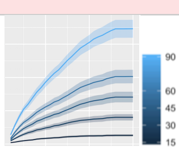
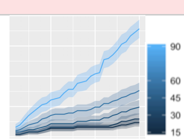
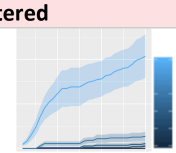
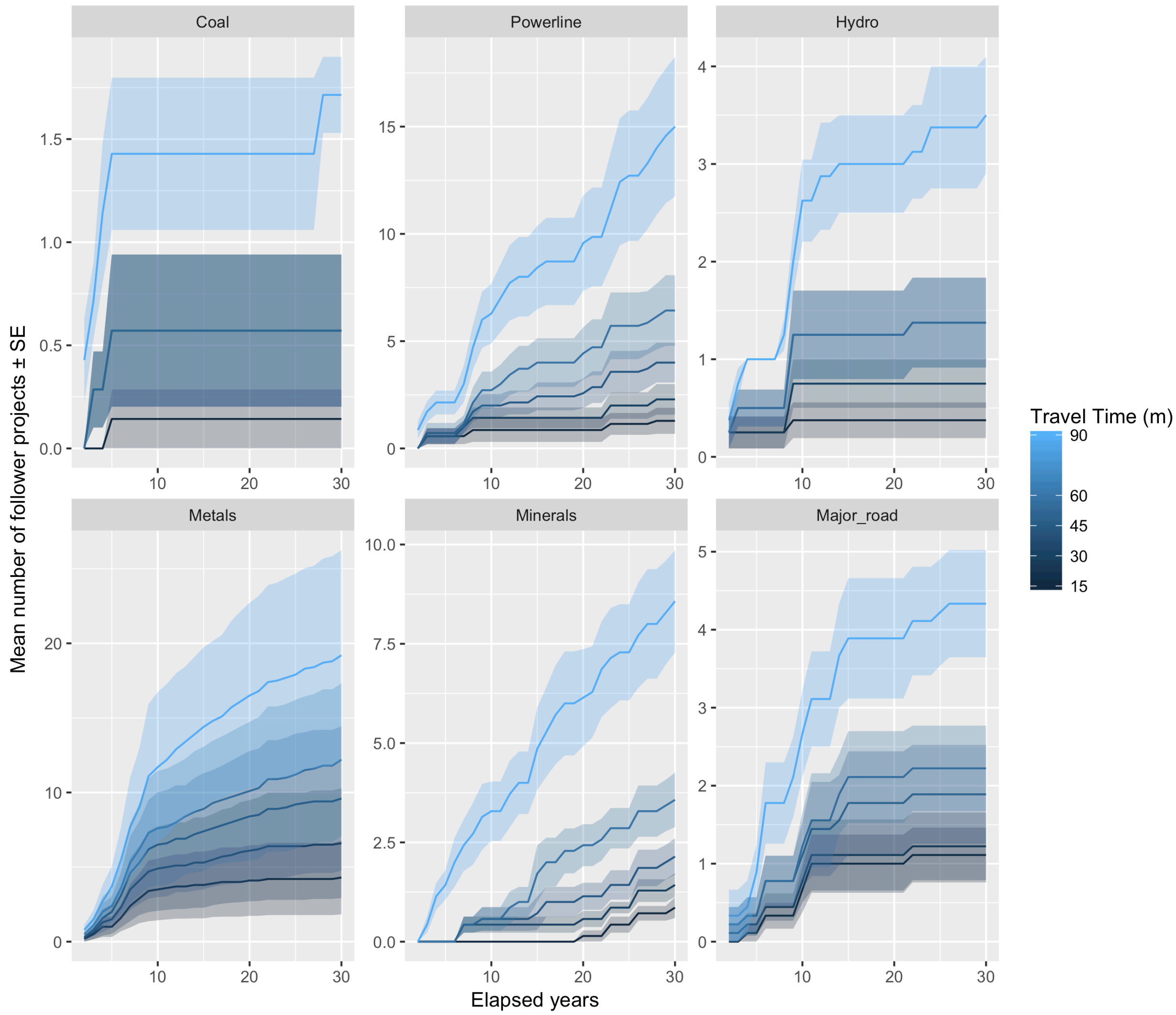
KEY (see text above for a more detailed guide to interpreting this graph.)		
Trajectories at different *time intervals* describe follower project development rates:		
Linear	**Asymptotic**	**Stepped**
A relatively constant rate of project development that has remained fairly steady through time. 	A saturation effect where rapid development quickly approaches or reaches an upper limit. 	Characterized by few follower projects, each followed by a period of hiatus. 
Fanning out of trajectories at different *distances* describes the spatial distribution of development:		
Radial	**Areal**	**Clustered**
Project development opportunities are along a limited number of linear pathways radiating away from the initial project. 	Project development is distributed across the landscape. 	Where projects effectively create focal points of activity. 

Figure B.2. Space-time spillover graph of travel time analysis results for precursor powerlines, 1900 to 1949.



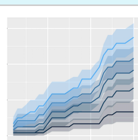
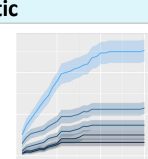
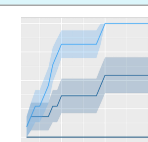
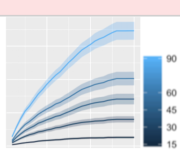
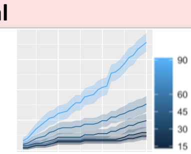
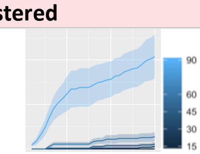
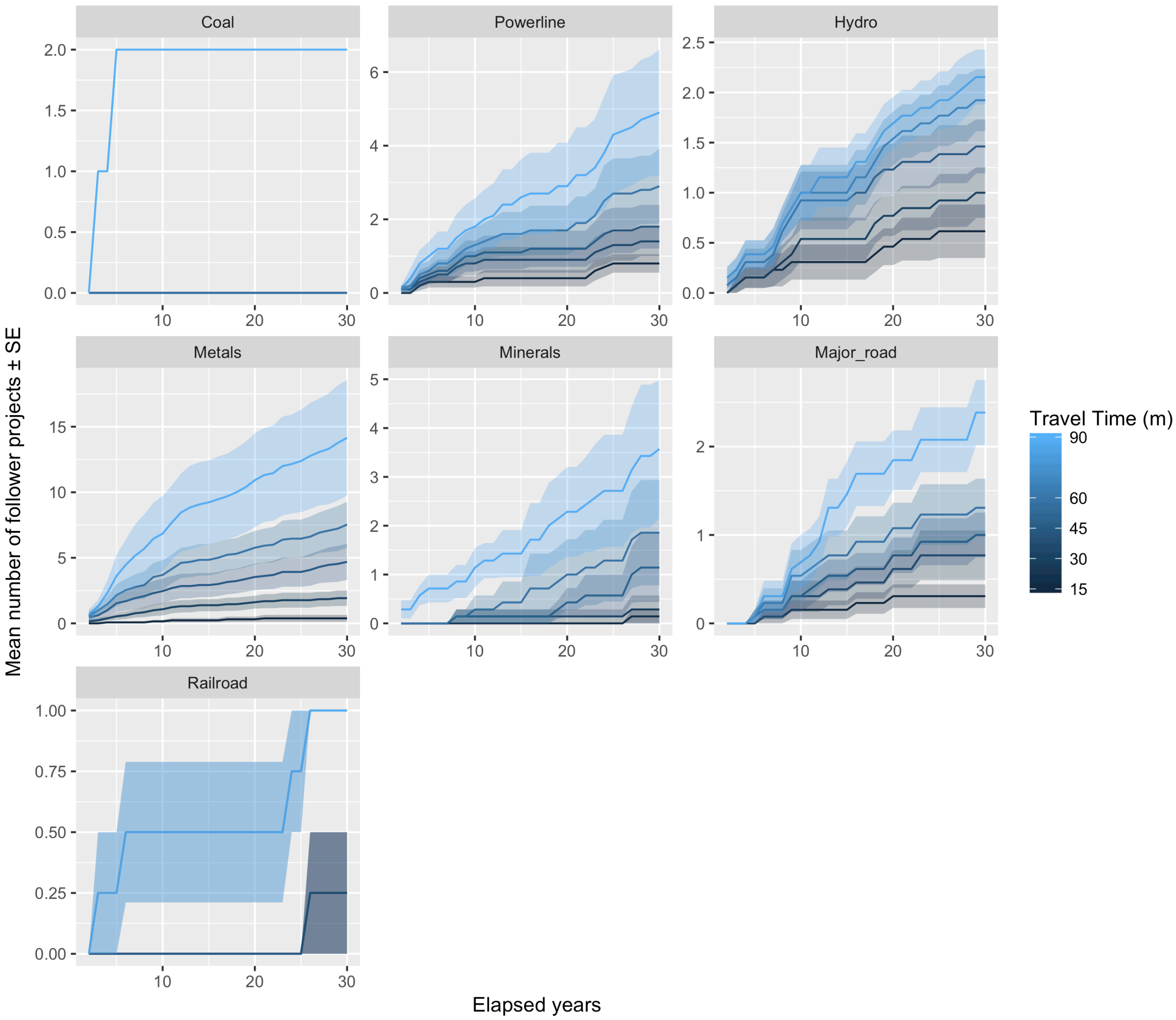
KEY (see text above for a more detailed guide to interpreting this graph.)		
Trajectories at different *time intervals* describe follower project development rates:		
Linear	**Asymptotic**	**Stepped**
A relatively constant rate of project development that has remained fairly steady through time. 	A saturation effect where rapid development quickly approaches or reaches an upper limit. 	Characterized by few follower projects, each followed by a period of hiatus. 
Fanning out of trajectories at different *distances* describes the spatial distribution of development:		
Radial	**Areal**	**Clustered**
Project development opportunities are along a limited number of linear pathways radiating away from the initial project. 	Project development is distributed across the landscape. 	Where projects effectively create focal points of activity. 

Figure B.3. Space-time spillover graph of travel time analysis results for precursor hydro plants, 1900 to 1949.



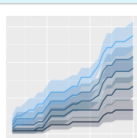
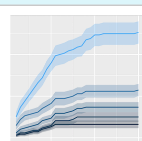
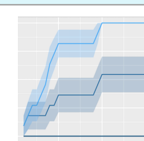
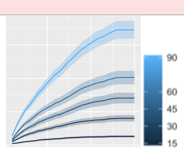
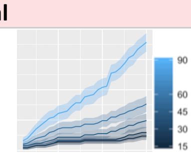
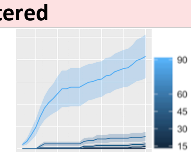
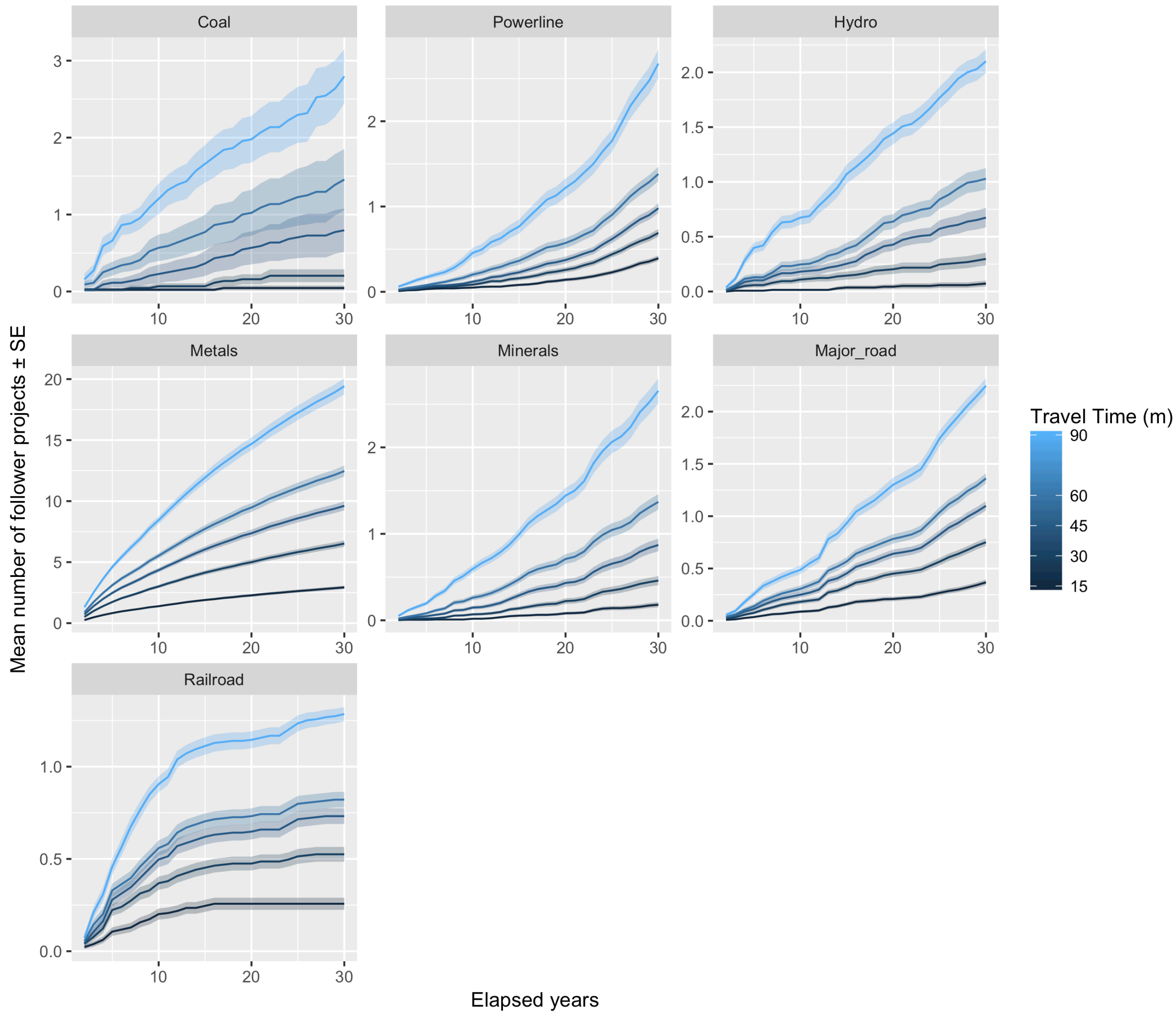
<table>
<tr><th colspan="3">KEY (see text above for a more detailed guide to interpreting this graph.)</th></tr>
<tr><td colspan="3">Trajectories at different time intervals describe follower project development rates:</td></tr>
<tr><td>Linear</td><td>Asymptotic</td><td>Stepped</td></tr>
<tr><td>A relatively constant rate of project development that has remained fairly steady through time. </td><td>A saturation effect where rapid development quickly approaches or reaches an upper limit. </td><td>Characterized by few follower projects, each followed by a period of hiatus. </td></tr>
<tr><td colspan="3">Fanning out of trajectories at different distances describes the spatial distribution of development:</td></tr>
<tr><td>Radial</td><td>Areal</td><td>Clustered</td></tr>
<tr><td>Project development opportunities are along a limited number of linear pathways radiating away from the initial project. </td><td>Project development is distributed across the landscape. </td><td>Where projects effectively create focal points of activity. </td></tr>
</table>

Figure B.4. Space-time spillover graph of travel time analysis results for precursor metal mines, 1900 to 1949.



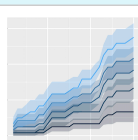
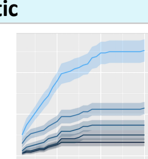
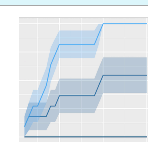
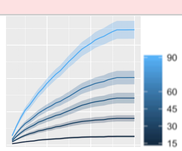
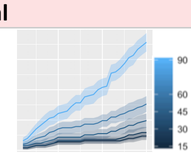
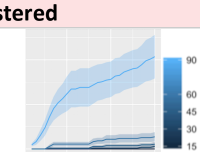
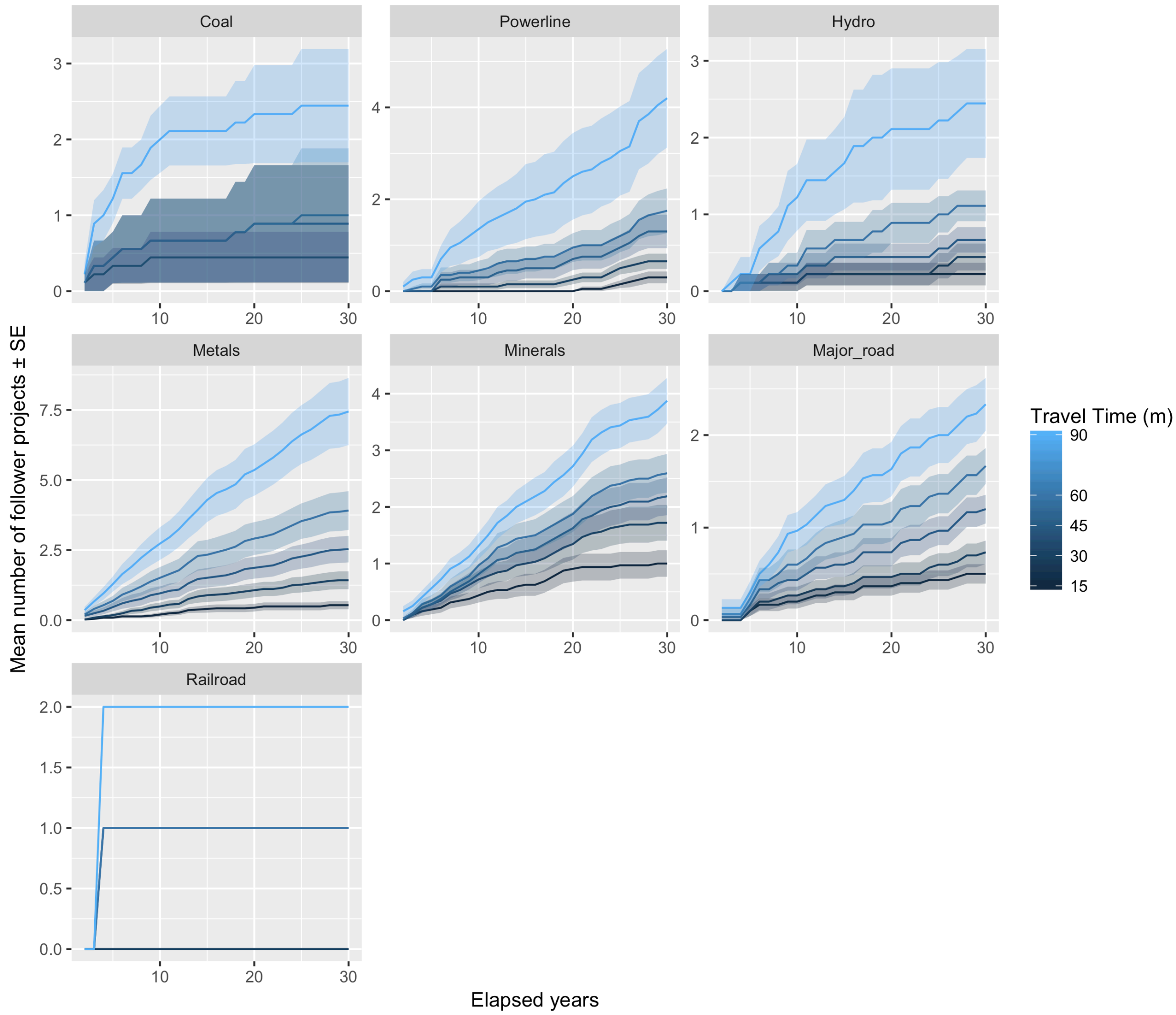
KEY (see text above for a more detailed guide to interpreting this graph.)		
Trajectories at different *time intervals* describe follower project development rates:		
Linear	**Asymptotic**	**Stepped**
A relatively constant rate of project development that has remained fairly steady through time. 	A saturation effect where rapid development quickly approaches or reaches an upper limit. 	Characterized by few follower projects, each followed by a period of hiatus. 
Fanning out of trajectories at different *distances* describes the spatial distribution of development:		
Radial	**Areal**	**Clustered**
Project development opportunities are along a limited number of linear pathways radiating away from the initial project. 	Project development is distributed across the landscape. 	Where projects effectively create focal points of activity. 

Figure B.5. Space-time spillover graph of travel time analysis results for precursor mineral mines, 1900 to 1949.



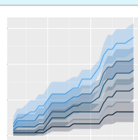
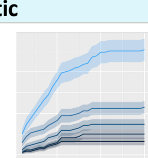
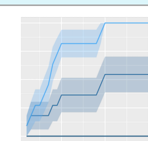
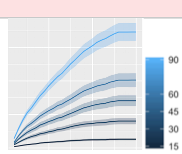
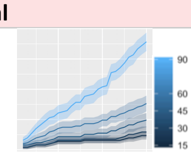
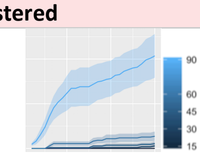
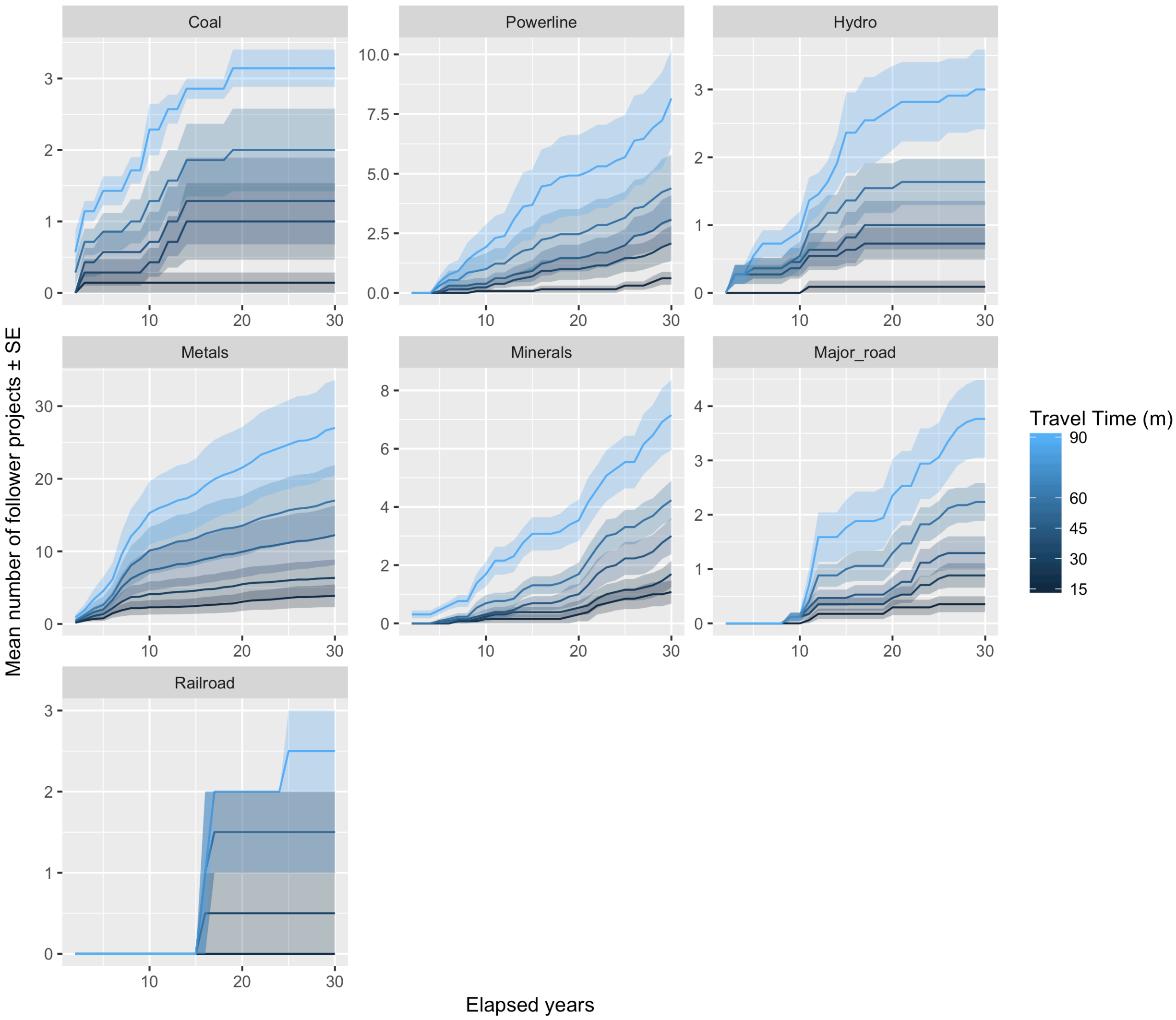
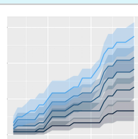
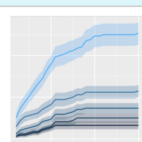
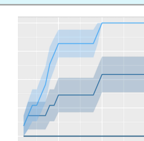
KEY (see text above for a more detailed guide to interpreting this graph.)		
Trajectories at different *time intervals* describe follower project development rates:		
Linear	**Asymptotic**	**Stepped**
A relatively constant rate of project development that has remained fairly steady through time. 	A saturation effect where rapid development quickly approaches or reaches an upper limit. 	Characterized by few follower projects, each followed by a period of hiatus. 
Fanning out of trajectories at different *distances* describes the spatial distribution of development:		
Radial	**Areal**	**Clustered**
Project development opportunities are along a limited number of linear pathways radiating away from the initial project. 	Project development is distributed across the landscape. 	Where projects effectively create focal points of activity. 

Figure B.6. Space-time spillover graph of travel time analysis results for precursor major roads, 1900 to 1949.



KEY (see text above for a more detailed guide to interpreting this graph.)

Trajectories at different *time intervals* describe follower project development rates:

Linear	Asymptotic	Stepped
A relatively constant rate of project development that has remained fairly steady through time. 	A saturation effect where rapid development quickly approaches or reaches an upper limit. 	Characterized by few follower projects, each followed by a period of hiatus. 

Fanning out of trajectories at different *distances* describes the spatial distribution of development:

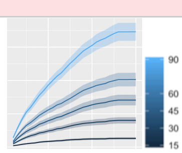
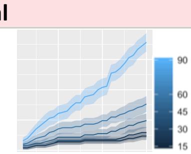
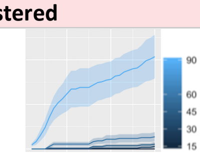
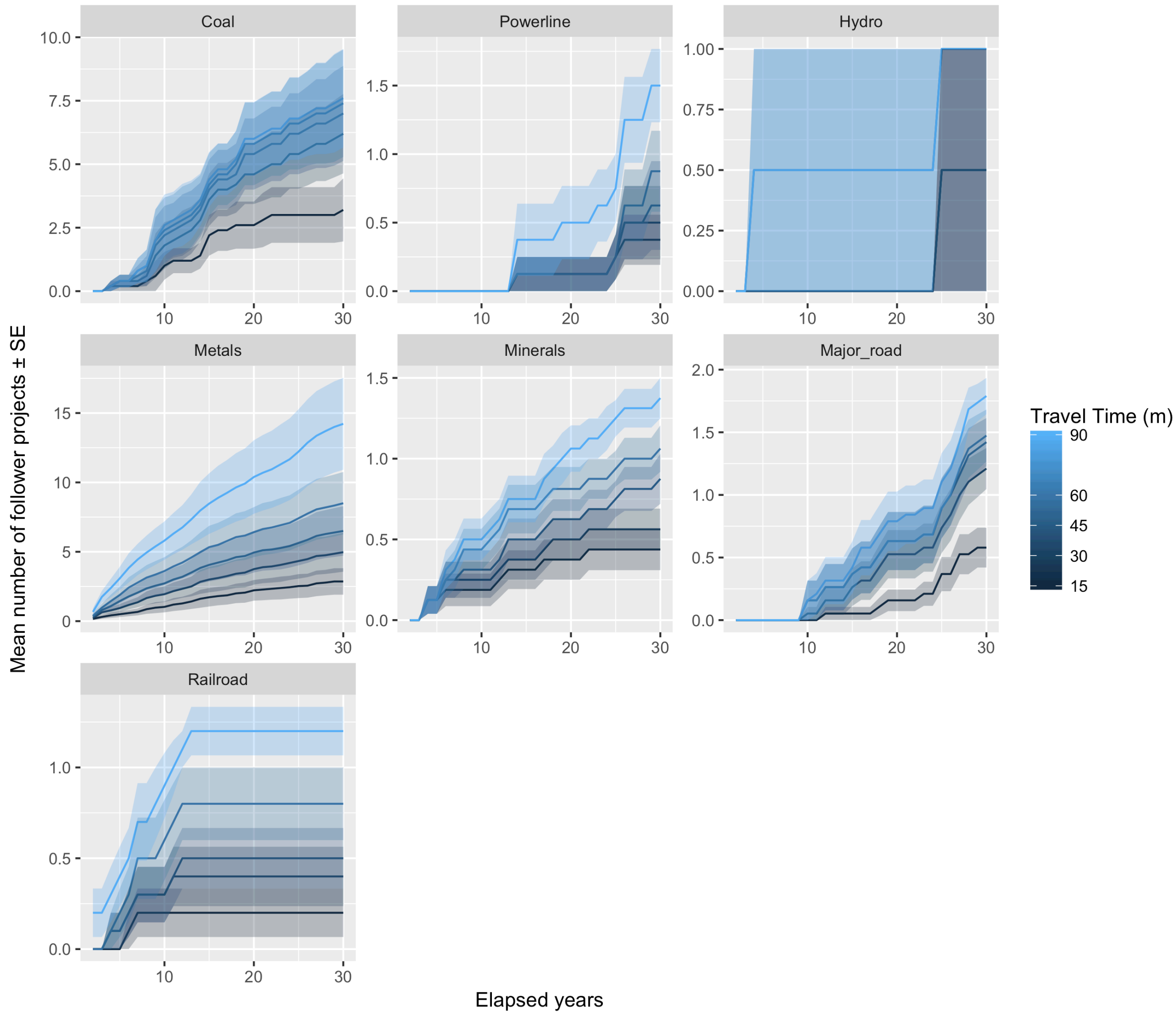
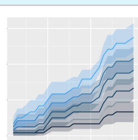
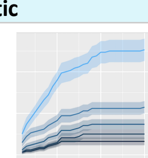
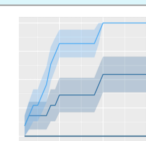
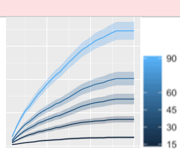
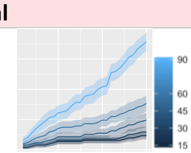
Radial	Areal	Clustered
Project development opportunities are along a limited number of linear pathways radiating away from the initial project. 	Project development is distributed across the landscape. 	Where projects effectively create focal points of activity. 

Figure B.7. Space-time spillover graph of travel time analysis results for precursor railroads, 1900 to 1949.



KEY (see text above for a more detailed guide to interpreting this graph.)		
Trajectories at different *time intervals* describe follower project development rates:		
Linear	**Asymptotic**	**Stepped**
A relatively constant rate of project development that has remained fairly steady through time. 	A saturation effect where rapid development quickly approaches or reaches an upper limit. 	Characterized by few follower projects, each followed by a period of hiatus. 
Fanning out of trajectories at different *distances* describes the spatial distribution of development:		
Radial	**Areal**	**Clustered**
Project development opportunities are along a limited number of linear pathways radiating away from the initial project. 	Project development is distributed across the landscape. 	Where projects effectively create focal points of activity.