Gordon Institute of Business Science
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The spatial economic impact of an airport migration on the business services sector

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Abstract

The movement of a major industry to, from or within a region has always had an impact on the overall spatial economy of a region. We study the impact from the perspective of related service-oriented business that form part of this spatial economy. This study specifically considers the impact that the movement of a regional airport in South Africa has on the ability of the business services sector to grow its contribution to GDP. We examines if the movement of the airport to another location has had an impact on GDP growth within sub-regions around the old and new location, as well as what underlying economic factors may contribute most to growing the sectors contribution to GDP

Keywords

Spatial Economics, Agglomeration Economics, Airport, Economic Geography, Business Services, GDP

Declaration

I declare that this research project is my own work. It is submitted in partial fulfilment of the requirements for the degree of Master of Business Administration at the Gordon Institute of Business Science, University of Pretoria. It has not been submitted before for any degree or examination in any other University. I further declare that I have obtained the necessary authorisation and consent to carry out this research.

Alistair Duncan Maxwell

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1 Letter to Journal

To the Editors of Journal of Regional Science and Urban Economics

We are writing this letter to motivate for the publication of our article entitled “The spatial economic impact of an airport migration on the business services sector”. This article considers the impact of the movement of a regional airport in Durban South Africa, and the impact that it has had on the business services sector in the regions’ ability to grow their contribution of GDP.

We believe that our article meets your criteria for contributing to scholarship in regional and urban economics. and will be of interest to spatial economic scholars, urban planners, and policy makers, in providing perspective on potential economic impact that the movement a major regional industry could have on related service companies that rely, directly or indirectly, on the industry.

Our article is 7440 words in length, excluding references which have been provided in APA format. We confirm that we have aligned our submission with the guidelines published in your Author Information Pack, and hope that it meets with your satisfaction.

Kind Regards

Alistair Maxwell[1 2] and Marianne Matthee [1]

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2 Literature review

2.1 Introduction

The chapter focuses on the prevailing literature that is relevant to this study and forms the basis for the research problem and objectives. The purpose of this chapter is to review literature that deals with the topic of spatial economic attributes associated with interaction of the business services sector in relation to the regional economy around airport-centric developments.

The paper draws from three strands of literature. The first relates to spatial economics, which accounts for the existence of industry clusters (or agglomerated economic activity), their performance and their importance to the broader network economy in which they exist and interact (Adão, Arkolakis, & Esposito, 2019; Fajgelbaum & Gaubert, 2019; Proost & Thisse, 2019). One of the central tenants of spatial economics is that firms will locate in a region that contributes to their comparative advantage in order to maximise returns (Ricci, 1999). This contribution may be due to their proximity to market access, key suppliers, labour, transportation network or their competitors (Porter, 2000, 2003).

The importance of network structures in the agglomeration of industries has been found to be crucial for their success. The tighter a network structure, the more interconnected the firms are, and the more reliant they are on each other for their own shared success (Gilbert, 2017). As such, Thisse (2019) emphasises that there is a fundamental trade-off between increasing returns and transport costs, with higher transport costs increasing the dispersion of economic activities, while lower costs act as a strong agglomerating factor. These trade-offs are considered by Proost and Thisse (2019) in two categories, namely that scale economies matter for the location of economic activity, and the movements of goods, people and information are costly

The literature review above, is then placed within the context of the South African economy, and more specifically the regional economy of Kwa-Zulu Natal within the context of the movement of regional airport from the Durban International Airport to the King Shaka International Airport and how the business services sector impacts on the local regional economy. The last section of this chapter summarises and concludes the literature review.

2.2 Economic theory of location

2.2.1 Economic Geography

Economic geography is a branch of economic theory that deals with the structure of the spatial economic structure, the patterns of regional specialisation and localisation that evolve over time and what the factors are that explain why this has occurred (Clark, Feldman, Gertler, & Wójcik, 2018). Its basis is grounded in the initial work done by Paul Krugman, who developed the first models to explain why spatial concentration and specialisation led to differences in regional economic performance. This was initially done to explain regional economic disparities (Krugman, 1991).

Current theory is split into two main areas of focus, New Economic Geography (NEG) and Proper Economic Geography (PEG). The main differences between these two theories are that NEG aims to highlight the impact that institutional culture has on economic performance, while PEG aims to consider the impact that the spatial environment has on economic performance (Hassink & Gong, 2019; Martin, 2011). Regardless of the strand of theory, the overall aim of economic geography is to find a way to understand economic differences, at regional levels, based on their spatial agglomeration effects.

Current literature is centred around the notion of "megaregions", specifically the amalgamation of large cities into a single economic region (Fajgelbaum & Gaubert, 2019; He, Shen, Wu, & Lou, 2018; Nelson & Rae, 2016; Shertzer, Twinam, & Walsh, 2018). As the size of cities grow, we are seeing large cities merging with others into economic regions, with there being growing consensus that the linkages between these cities and within the regions is critical to the economic success of the regions, rather than the individual cities themselves (Fei & Zhao, 2019; Yeh & Chen, 2020). While the notion of "megaregion" is relative and donates the relative size and importance of the city/region within the broader context of its own country or industry (Su et al., 2017), research does indicate that there are numerous reasons behind why these regions are formed and are successful. The primary reasons listed in the literature can be summarised as the effective integration of the spatial economy across the cities and the agglomeration of industries within them (Hassink & Gong, 2019; Krugman, 1991).

2.2.2 Spatial Economics

Spatial economics is concerned with the allocation of resources over the space and location of economic activity and concerns itself with the study of the impact that location, land and transport have on the performance of the economy (Proost & Thisse, 2019). The notion of spatial economics was first introduced in work by Ricardo, (1821) and von Thünen, (1826), where the initial theory was developed based on land usage and the cost of goods transportation to markets in relation to farming. This laid the basis for how and why producers distribute themselves in space around a central market to maximize their returns (Duranton & Puga, 2004; Kasper, n.d.). Redding and Rossi-Hansberg, (2017 pg 22) summarise spatial economics as "The impact of public policies differentiated by location (place-based policies) and of transport infrastructure investments, local taxation, and land regulation is crucially determined by how these policies affect the equilibrium balance between these centripetal and centrifugal forces".

The study of spatial economics has been used by both economists and regional scientists to develop and test theories that account for the existence of clusters, their performance and their importance to the broader network economy in which they exist and interact (Adão et al., 2019; Fajgelbaum & Gaubert, 2019; Proost & Thisse, 2019).

One of the central tenants of spatial economics is that firms will locate in a region that makes the most economic sense to give themselves a comparative advantage to maximise returns (Ricci, 1999). This advantage may be their proximity to market access, key suppliers, labour, transportation network or their competitors (Porter, 2000, 2003). The importance of each of these advantages will be different for each industry, however a direct causal relationship has been found between market access and the spatial distribution of economic activity within a city (Waddell & Sarte, 2016).

Conventional economic thinking would suggest that the primary reason of why industries are spatially located within a city is due to market forces and the need to maximise profit. However, research by Shertzer et al. (2018), highlighted that the impact of zoning may be a more significant factor than the impact of geographical or transport networks in explaining why industries cluster together. This is relevant for this study as the creation of the KSIA was directly part of a special economic zone (SEZ) in which the Dube TradePort would operate as an aerotropolis (Dube TradePort, n.d.). This spatial concentration of industries can be defined as an agglomeration as they are all creating economic value from the same good or service in a small area (Kuchiki, 2020).

2.2.3 Agglomeration

The agglomeration economy is defined as "a localized economy in which a large number of companies, services, and industries exist in close proximity to one another and benefit from the cost reductions and gains in efficiency that result from this proximity" ("agglomeration economy," 2020). Globally, we have seen that economic activity has been concentrated in limited cities and regions. Agglomeration economics tries to explain why people and economic activities gather in a few concentrated areas, why these areas fare better than others and if there is a causal relationship between them (Thisse, 2019).

Conventional economic wisdom says that these concentrations of industries can be explained by spatial differences in a natural advantage for the area, however, research has shown that the concentration of these industries is too great to be explained by a natural advantage (Ellison, Glaeser, & Kerr, 2010). What research has found is that regional differences change over time, and that the cross-fertilisation of labour movement, transportation modes, technology advances and political factors all impact on the reasons why industries agglomerate (Fujita & Thisse, 2003).

Research has also shown that there is a fundamental trade-off between increasing returns and transports costs, with higher transport costs increasing the dispersion of economic activities , while lower costs act as a strong agglomerating factor (Thisse, 2019). Research has further gone to refine these trade-offs into two main areas: (1) scale economies matter for the location of economic activity, and (2) the movements of goods, people and information is costly (Proost & Thisse, 2019).

The importance of network structures in agglomeration of industries has been found to be crucial for their success, with studies finding that the tighter a network structure the more interconnected the firms are, and the more reliant they are on each other for their own shared success (Gilbert, 2017).

As the research by Fujita and Thisse (2003), Gilbert (2017), Proost & Thisse (2019) and Thisse (2019) shows there is a strong inter-relationship between where industries choose to cluster, based on the input costs, travel costs and relationship between themselves. Applying this to the relocation of DIA to KSIA, it follows that with the movement of the airport, those industries that relied on the airport as a key factor in their operations, and had the means to do so, would move their location to new region to minimize their transportation costs and to exploit economies of scale by being in close proximity to each other and the airport. In addition to the industries that move with the airport, new industries could agglomerate due to impact of having the airport in a closer proximity. Research currently does not consider the impact to those industries that chose to not relocate and how the area in which they remain performs economically.

2.3 Role of airports in service-oriented businesses

2.3.1 Impact of aviation on regional economic performance

It is generally accepted that there is a correlation between the establishments of airports and economic growth and that the spatial economy around airport activities is the driving factor behind local and regional economic performance (Fu, Tsui, Sampaio, Tat, & Tan, 2018). Blonigen and Cristea (2015),found that even though the positive economic effects of aviation on the economy are intuitive, proving there is causal relationship is difficult due the interdependency of providing aviation services and regional growth, with Button (2010 pg 11) stating that “measuring local economic impact of airport investments is challenging and studies have often over-estimated them”. Button, (2010) found that the tertiary effects of the location of an airport to the stimulus to a local economy, that resulted from firms having access to close regional air transport, operated as hub-and-spoke model for the regional economy, and that the greater the distance from the hub, the less effective the economic stimulus to the regional economy.

Research published by Gibbons and Wu (2017) has found that the expansion of the aviation industry in China has had a direct impact on the growth of the manufacturing industry at a regional level and is “attributable to micro-level productivity improvements”(Gibbons & Wu, 2017 pg 34). A study of airports in New Zealand by Fu et al., (2018 pg 14) confirmed that there is “significant positive impact on the economic development of their respective regional communities” and research by Luthuli and Houghton, (2019) conclude that the aerotropolis around the KSIA and Dube TradePort is foundational for regional economic development in the area.

As airports are seen as major infrastructure projects within countries, they are deemed to be critical assets, and as such are not often closed, but rather retrofitted or expanded to avoid the large capital outlays that come with the construction of a new airport (Luke & Walters, 2010; Robbins, 2015). There is limited literature on the direct economic impact of closing an airport, with most literature focusing on the impact of airport closures, permanent and temporary, on the tourism sector (López, Freire-Chaglla, Sanmartín-Rojas, & Espinoza, 2018; Voltes-Dorta, Rodríguez-Déniz, & Suau-Sanchez, 2017), regional housing market (Mizrach & Neely, 2020) and ability for airports to recover operations post a temporary closure (Pejovic, Noland, Williams, & Toumi, 2009; Wu, Gao, Li, Dang, & Hu, 2017). Due the lack of direct research it is fair to consider the comparison of the regional economic impact of other major industries closing.

2.3.2 Service-oriented industries and their relationship with airports

Service-oriented companies are businesses in which the service they provide is the primary good that is sold to the market, and that any physical product is incidental to the service that has been provided (Thomas, 1978). Examples of these businesses are airlines, banks, insurance companies, auditing firms, consulting firms, estate agencies, law firms and IT companies. The service-oriented sector has been shown to be able to immediately provide input into key regional economic input by increasing the forward and backward linkages between primary and secondary industries as well as expanding on their value chains (UNCTAD, 2018b, 2018a).

A study by Tao, Ho, Luo, and Sheng, (2019) on the agglomeration impact of the creative service industries in China found that the ease of access to effective transport infrastructure, specifically airports, was a key contributor in enhancing the economic urbanization and contribution to the industry. Barlet, Briant, and Crusson, (2013) assert that service industries do not always locate themselves within close proximity to the main clients, but that there is a defined zone of distance in which they will cluster to service their clients, this would then assume that if a major industry/client moves their location outside of the zone of distance for the service industry, then they will move to be within that new zone.

The relationship between primary and secondary industries with service-oriented companies has long been established in theory (Lian & Laing, 2007), this relationship has further been cemented by work done by Strauss-Kahn and Vives, (2009), where they found that the majority of primary and secondary industry headquarters in the United States moved their headquarters to medium sized service-oriented metropolitan areas, that had a cost effective and reliable airport infrastructure in close proximity to their new location. This infers that primary and secondary industries rely heavily on the input of service industry firms, and also that service industry firms would need to locate themselves in a manner that is attractive to primary and secondary industry businesses.

The dependency of the service sector on airports has always been seen as critical in their success, due to the need for the industry to have face-to-face interactions (Percoco, 2010; Rosenthal & Strange, 2001). Literature has also highlighted that the growth in the business service sector globally, coupled flexible manufacturing techniques and more sophisticated financial markets have made labour markets more flexible to move has directly impacted on regional economies due to interconnectedness of service sector within company value chains (Baltova & Baltov, 2017; Button, 2010)

2.4 Impact of industry movement or closure on regional economic performance

The importance of major industries in regional economic development and performance has been well documented in literature (Krugman, 1991; McCann & Oort, 2019; North, 1955; Porter, 2003). The impact of a major industry shutting down can have a catastrophic impact on a regional economy, both from a direct and indirect perspective. Research agrees that the impact to a regional economy is more than just the direct impact associated with the industry, but that it has a knock-on effect to a network of suppliers and service companies as well as other industries that support the regional economy (Beer, 2018; Chapain & Murie, 2008; Dudensing & Amosson, 2019; Lendel, Piazza, & Ellerbrock, 2019; Nijhawan & Jackson, 2011).

For example, research into the informal liquor industry in the Western Cape of South Africa found that, due to changes in legislation that forced the closure of shebeens in 2008, the impact to the entire value chain around the industry made the direct economic impact unquantifiable (Wright & Louw-Potgieter, 2010). While companies do perform economic impact assessments on the gauge the potential impact of a closure, they are usually deemed to be inaccurate once the actual impact is re-examined after the closure (Dudensing & Amosson, 2019).

Where direct research into closures has been done the results have shown that the impact to a regional economy can be severe. In the case of the Lordstown General Motors plant in Ohio, the impact of its closure was a regional increase in unemployment of 6.1% and a reduction in regional GDP of 9.2% (Lendel et al., 2019). The impact of the closure of several coal mines in Chongqing, China caused a reduction in the total economic activity of the region, however, the impact to the local economies of the regions further removed from the mine closures and those who has less reliance on the mines were found to be much less severe (Andrews-Speed, Ma, Shao, & Liao, 2005).

2.5 The South African perspective

Research around economic clustering and special economics for airports in South Africa is still in its infancy. Most research focuses on the regions around the two main airport hubs of OR Tambo in Johannesburg and Cape Town International Airport. In a 2018 study, Mokhele considers the spatial economic attributes of airport centric developments in Johannesburg and Cape Town, building off her initial work into the spatial evolution of these developments in 2017 (Mokhele, 2017). She finds that firms tend to have a direct linkage to air travel by being in a close geographical proximity to the airports. Additionally, between 70% and 75% of these firms have linkages to service and nonservice-oriented firms within the vicinity of the airport, with between 30% and 40% of these firms being purely service based (Mokhele, 2018). This emphasises the interplay between airports and service-oriented firms.

In South Africa, the sector is being positioned as one of the economic growth areas for the future, with it being expected to increase its GDP contribution and employment levels by R176 billion and 237,000 people respectively by 2030 (Mckinsey Global Institute, 2016) The need for the business services sector particularly vital for the development of regional economies in South Africa, specifically in terms of providing governance and training outside of main economic areas of the country (Dihel, Fernandes, & Mattoo, 2010). This sector is diverse in its nature, as it includes both professional and support service business to the primary and secondary economy. Over the last two decades, such firms have become more and more essential for the value chains of economic production, not only locally but also globally (Baltova & Baltov, 2017). Given that there is large potential growth in the business services sector, and the impact that it can have at a regional level, it is logical to want to try and understand what can influence the performance of the sector at a regional level.

However, in order for the business services sector to grow, the region within which it is located must grow. Indeed, Rahman, Rahman and Hai-bing (2011) conclude that for a developing economy, the services sector does not have a significant influence on GDP growth. Rather, GDP growth influences the growth of the services sector (Azer, Hamzah, Aishah Abdullah 2016). However, where the economy is service led, industrial policy is deemed to be the key driver of economic growth. Bringing this back to South Africa, which is a developing market that is not service sector led (StatsSA, 2020; United Nations, 2014), we would expect the same findings to hold true. Indeed, this was found to be the case for the business service sector in North-West province of South Africa, where Pisa, Rossouw, and Viviers (2015) found that the sector's performance was highly correlated to the success of the underpinning industry it served, but that the effect was usually delayed due to a lagging effect of change in industry performance to spend with service companies.

There currently is no consensus on the drivers of economic growth, from an African perspective. Variables used in previous studies have varied and have included, amongst others, household spending, inflation, labour absorption, foreign direct investment, education level, level of government spending and numerous others (Anyanwu, 2014). Recent studies in economic growth in developing markets have differed in the variables used to estimate growth. For example, Rahman, Rana and Barua, (2019) considered inflation, GDP growth, foreign investment, household consumption, energy consumption and government spending in their recent study of economic growth in South Asia. On a regional level, studies on the impact to regional economic performance by Andrews-Speed et al. (2005) and Lendel et al. (2019) included the impact on sector employment, regional GDP growth, unemployment rate.

As the business services sector's success is directly tied to the industries they are supporting, it would seem fair to assess how the sector grows in relation to regional economy around it, and what impact input variables into the regional economy could have on the sector's ability to contribute to GDP. To this end, regional economic growth, regional unemployment, sectoral growth, wages, and employment as well as household income are being considered as variables to assess the ability of the business services sector to contribute to GDP.

2.6 Conclusion

In summary, the literature review argued that airports are critical components to the spatial economy, are a crucial driver in regional economic development and relied on by the service-oriented industry due their need for effective transportation. We also argue that the movement of an airport, even within a regional economy will have an impact on the ability of the related industries to contribute to GDP. We have placed both the spatial economic and business services perspective within a South African context, and aim to test if the movement of the regional airport in eThekwini (Durban) does indeed have an impact on the ability of the business services sector to contribute to GDP.

Literature has demonstrated, that in a developing economy, the impact of the business services sector on GDP is not as important as the impact that the growth in total GDP has on the ability of sector to grow its contribution to GDP. Literature has also shown that there is a direct link to the ability of business services sector to influence the regional economy, based on their location from the primary hub of an airport.

Currently, literature does not fully examine the potential interconnectedness, on a regional level, that the movement of an airport could have on the business services or the potential regional economic drivers that impact on its ability to grow its contribution to GDP, this paper aims to understand these factors.

2.7 Research Objectives

2.7.1 Objective 1

To understand if there is a relationship between the contribution of business services sector in an area, based on proximity to an airport

2.7.2 Objective 2

To ascertain if this relationship has been positive or negative to each region

2.7.3 Objective 3

To establish which variables are significant to the ability to change the growth in economic contribution for the business services sector

2.8 Research Hypothesis

Based on the literature review, and in conjunction with research problem the following hypothesis have been derived:

2.8.1 Hypothesis 1 – There is a significant difference in the change in contribution to GDP of the business services sector because of the movement of the airports

This hypothesis aims to ascertain if there has been a significant difference in the regional change of the ratio of business services sector GDP to GDP, without considering any other variables, post the movement of the airport from DIA to KSIA (Azer et al., 2016; Fu et al., 2018;

Fujita & Thisse, 2003; Gibbons & Wu, 2020; Green, 2007; Luke & Walters, 2010; Porter, 2000; Sheard, 2015).

H_{10i}: There is no significant difference in the business services sector contribution to GDP post the movement from DIA to KSIA

H_{11i}: There is a difference in the business services sector contribution to GDP post the movement from DIA to KSIA

Where *i* denotes the specific region or metro in Kwa-Zulu Natal

2.8.2 Hypothesis 2 – The variables are significant in influencing GDP growth for the business services sector

A range of different variables influence on the ability of an industry to contribute to GDP. Some of these variables can be empirically measured and some cannot. This hypothesis aims to ascertain, of the variables that are being considered, are associated with the business service sector have had an influence on its ability to change its contribution to GDP as a result of the movement of the airport. (Azer et al., 2016; Dihel et al., 2010; Fu et al., 2018; Fujita & Thisse, 2003; Gibbons & Wu, 2020; Green, 2007; Krugman, 1991; Luke & Walters, 2010; Mokhele, 2018; Sheard, 2015).

H_{20i}: The variables are not significant in influencing change in GDP contribution for business services sector

H_{21i}: The variables are significant in influencing change in GDP contribution for business services sector

Where *i* denotes the specific region or metro in Kwa-Zulu Natal

3 Research methodology

3.1 Choice of methodology

The fundamental decision around research is that it must inform the assumptions that will influence the way it is structured and analysed. According to Williams (2007 pg 66), quantitative research “involves the collection of data so that information can be quantified and subjected to statistical treatment”. The approach being utilised for this quantitative study follows a positivism philosophy, with the aim of testing specific hypothesis against established theory and literature. It follows that a deductive approach should be followed for this study (Saunders, Lewis, & Thornhill, 2016), in order to test the applicability of established (Hyde, 2000). This is appropriate as this research seeks to test the established theory of regional economic growth against hypotheses on the spatial and agglomeration effects caused by moving the airport. As the approach will be hypothetico-deductive and the area of investigation centred around institutional economics, the deductive approach is deemed to be a better fit for quantitative research (Johnson, 1996).

The research strategy selected for this study will be a natural experiment comparing the economic performance of the various regions prior to the event and post the event. This approach will determine if the variation in key variables can be correlated to a change in the economic outcomes of the regions (Meyer, 1995). A well designed research strategy is guided by research objectives, researcher knowledge and the time that is able to be dedicated to the research itself (Saunders & Lewis, 2018).

The main goals of the research design of this study is to find if the variation of the explanatory variables is exogenous to the dataset and how the designed hypothesis react to changes in these variables (Meyer, 1995). These types of studies look for an explanation behind why an occurrence happens through linking the causal relationships between key variables in the study to produce an accurate of events and their impact on the research variables (Saunders & Lewis, 2018).

This study will utilise longitudinal secondary data for the period of 10 years prior to the airport moving to its current location and the 10 years since it has moved, this will involve having data from 1998 to 2018. Longitudinal data are data sets, comprised on an outcome variable, observed at specific times. This is done to measure if there is pattern of change over time, or a dependence, on the outcome of certain variables to another variable (Liang & Zeger, 1986).

3.2 Population

A population is a complete group of possible participants for a study (Saunders & Lewis, 2018). For this study we will want to generalize the results, based off a sample of the population (Salkind & Rainwater, 2006), it is against this definition that we consider the population for this study to be the ten district municipalities of KwaZulu Natal (KZN) and the eThekwini Metropolitan district, these comprise 44 local municipal, including the eThekwini (Durban) metropolitan area. (RSA Government, 2020).

Figure 1: KZN District Municipalities Map

(KZN Top Business Portfolio, 2020)

Within the eThekwini region, a further refinement was utilised in this study. The eThekwini municipality is split into five subregions, North, Central, South, Inner West, and Outer West. For the purposes of this report, the subregions of North, Central and South were considered

Figure 2: Metro Region breakdown of eThekwini

(KZN Top Business Portfolio, 2020)

3.3 Unit of analysis

The first step in deciding how to analyse the data is to define the unit of analysis. This is determined by the analysis you plan to use in your study (Trochim & Donnelly, 2001). This enables the researcher to perform analysis on who and what they are studying.

The approach used in this paper leverages the work done by Andrews-Speed et al., (2005); Chapain and Murie, (2008) and Rahman et al. (2019) each utilised similar approaches to understand the impact of the movement and closure of large industries had on the regional economies of the impacted areas. To this end, the annual change of business services GDP to regional GDP will be used as the dependent variable to gauge validity against the hypothesis, with a combination of population, economic activity, household expenditure, labour absorption rate and average household expenditure being utilised as independent variables.

3.4 Sampling method

Sampling methods are informed by the level of access that a researcher has for the data they are intending to use. Given a population of eight municipal districts and one metropolitan district who's data spans from 1993 to 2019, as such purposive sampling has been used for this study. Saunders and Lewis, (2018) state that purposive sampling is used when a researcher needs to select a sample that enables achieving the objective of the study.

Due to prior and current location of the Durban airport, it does not make sense to utilise data from District Municipalities, hence for this study only the following are to be considered; Ugu, , iLembe and the eThekwini Metropolitan area, this sample results in 14 local municipalities, including the Durban metro being part of the final sample.

3.5 Measurement instrument

As noted in the literature review, previous studies on regional economic growth have used various combinations of GDP, local financial revenue, labour absorption rates, government spending, population, wages and employment numbers as a measure of the impact of moving or closing an industry to a region (Andrews-Speed et al., 2005; Anyanwu, 2014; Chapain & Murie, 2008; Rahman et al., 2019), and studies on the impact of moving or amending major industries by Nijhawan and Jackson, (2011) and Dudensing and Amosson, (2019) have used the gross value add (or destruction) to a region to determine the impact of an industry on the regional economy.

The approach used in this paper leverages the work done by Andrews-Speed et al., (2005); Chapain and Murie, (2008) and Rahman et al. (2019) as a basis to assessing the economic impact on the business services sector for the regions. The approach taken in these papers considered a range of variables for both economic growth and the impact to regional economies, in our paper these are adjusted to assess the business services sector.
The model equation utilised as the measurement instrument is defined below:

$$\Delta GDP\_Cont\_BS_i = \beta_{1i} GDPG\_BS_i + \beta_{2i} LAR_i + \beta_{3i} U_i + \beta_{4i} EC\_BS_i + \beta_{5i} GDP_i + \beta_{6i} CRW\_BS_i + \beta_{7i} CHE_i + \beta_{8i} CU_i + \varepsilon$$

Where	*i*	= specific region being assessed
	GDPG_BS	= annual business services sector GDP growth for the region
	LAR	= labour absorption rate for region
	U	= unemployment rate for the region
	EC_BS	= percentage change in employment in business services sector
	GDP	= GDP growth rate for the region
	CRW_BS	= change in business services sector real wages for the region
	CHE	= change in household expenditure for the region
	CU	= change in unemployment for the region
	ε	= model determined constant value

3.6 Data gathering process

The data used in this study was secondary data sourced from Quantec, an independent company that specialises in regional economic data for South Africa. Secondary data is defined as “data used for a research project were it was originally collected for some other purpose” (Saunders & Lewis, 2018 pg 85). This data included an aggregation of census, survey, and time series data in relation to population, GDP, employment, industry performance, industry wages, labour market, and household spending. The following databases were utilised:

Data was obtained from Quantec, a South African based consultancy that focuses on economic and financial data and country intelligence. It utilises regional economic data across a range of years to form longitudinal study. This paper considered the Quantec data on a regional level, for the variables defined above, for the years 1995 to 2019 to form a longitudinal study. Our data comprised the full extent of the data available from Quantec, however the years1993 and 1994 were not considered as part of the study due to certain variables in the model not being populated. This approach, and duration of time based data enabled a panel data analysis to be performed (Baltagi, 2008; Park, 2011). This was done to measure if there is pattern of change over time, or a dependence, on the outcome of certain variables to another variable (Liang & Zeger, 1986).

To eliminate the impact of inflationary increases on GDP, real values of GDP and wages were utilised, as well as the annual rates of change from one year to the next for each variable. Additionally, due to the one-off economic impact of the FIFA World Cup and that the migration of the airport took place in 2010, this year of data was excluded from the data set to avoid skewing results due to a large shock to GDP in one year, and, to compensate for this the rate of change in 2011 was adjusted, based on 2009 figures.

Table 1: List of Quantec Databases utilised

Level of granularity	Name	Range available	Source
Local Municipality	Labour Absorption Rate	1993 – 2019	Quantec
Local Municipality	Business Services Sector Employment (formal and informal)	1993 – 2019	Quantec
Local Municipality	Real Wages for Business Service Sector (formal and informal)	1993 – 2019	Quantec
Local Municipality	Unemployment Rate	1993 – 2019	Quantec
Local Municipality	Gross Value Add and Income (formal and informal)	1993 – 2019	Quantec
Local Municipality	Household Expenditure	1993 – 2018	Quantec

Local Municipality	Business Services GDP contribution (formal and informal)	1993 – 2019	Quantec

Source: Quantec

3.7 Analysis approach

Analysing quantitative data requires a combination of descriptive and inferential statistics that tests the validity of the specified hypothesis against the sample (Christensen, Johnson, & Turner, 2014). For this hypothesis 1, the approach followed comprised of a panel econometric event study framework to analyse the relationship between financial performance of the business service sector around the airport locations, both prior to and after the relocation of both sites (Andrews-Speed et al., 2005; Chapain & Murie, 2008; Corrado, 2011; Kothari & Warner, 2007).

Event studies were initially developed as a statistical tool to empirically test research hypothesis in finance, and have been adapted over time to economic studies (Corrado, 2011). Kothari and Warner (2007) stipulate that event studies form a fundamental tool in understanding the way in which markets react to specific events, with the effect of event either having a direct or indirect impact on the underlying capital and economic markets of an economy.

The approach for hypothesis 2, was to assess the statistical difference between the change in regional GDP growth rates for the period in which the DIA was operational versus the period for when KSIA was operational. The change in GDP rates was selected as a measure to mitigate the potential impact of inflationary increases from year to year. This hypothesis was tested utilising the t-test statistical approach. This test was selected due to the sample size for each region being less than 30 observation in total and the population variance being unknown (Wegner, 2018).

3.7.1 Data Manipulation

Data extracted from Quantec was revised to consider the annual changes from one to year to another. Data extracted for Household expenditure did not include a value for 2019, this value was estimated by considering the average growth rate for the previous five years and applying that factor to estimate 2019, based on 2018 actual numbers. Where growth ratios where available from Quantec, these were utilised, where they were not available, annual growth rates for the various metrics were calculated in MS Excel. The resulting variables that were considered for analysis are depicted in the table below:

Table 2 Data manipulation for model variables

Model Variable	Source file	Change	Calculation(s) applied
U	Unemployment Rate	No	
CU	Unemployment Rate	Yes	Annual rate of change, difference between current year and previous year divided by previous year
CRW_BS	Real Wages for Business Service Sector	Yes	Annual rate of change, difference between current year and previous year divided by previous year
GDPG_BS	Business Services GDP contribution	Yes	Annual rate of change, difference between current year and previous year divided by previous year
EC_BS	Business Services Sector Employment	Yes	Annual rate of change, difference between current year and previous year divided by previous year
CHE	Household Expenditure	Yes	Annual rate of change, difference between current year and previous year divided by previous year
LAR	Labour Absorption Rate	No	
GDP	Gross Value Add and Income	Yes	Annual rate of change, difference between current year and previous year divided by previous year
∆GDP_Cont_BS	Gross Value Add and Income, Business Services GDP contribution	Yes	Ratio of Business Services GDP to actual GDP was calculated, then an annual rate of change was calculated by finding the difference between current year and previous year divided by previous year

Source: authors own summary

As a result of utilising rate of change metric, and only data from 1993 to 2019 being available, calculated data was missing for 1993 for all calculated variables, and for 1994 for ChangeGDPContrib variable, this all data from 1993 and 1994 was excluded from the dataset.

As noted above, the DIA closed and KSIA opened within 2010, thus there is a combination of both the potential impact of each airport within the data from 2010. There is the potential for business services sector contribution simultaneously through each of these airports within 2010 and thus the decision was made to exclude all data from 2010 from the dataset so as not to bias the agglomeration and spatial effects of the airports on the business services sector as well as to provide a clear delineation for the panel data approach. An additional dummy variable was added as the panel variable to distinguish between the two sets of data within the data, corresponding to the years that each respective airport was open.

Panel data examines the group effects, time effects or both to consider the heterogeneity that may or may not be observed (Park, 2011)

3.7.2 Pooled OLS regression

The initial stage of the analysis was the estimation of a pooled OLS regression. Assumptions for this estimation is that all observations under study are of one broad data-set and that they meet five key criteria of (1) linearity, (2) exogeneity, (3) same variance (homoskedasticity) and are not related to each other (non-autocorrelation), (4) observations are not stochastic and (5) there is no exact linear relationship between independent variables (Baltagi, 2008; Greene, 2003; Kennedy, 2003). To assess the quality of the model, the coefficient of determination, R^2, is used. This determines the model fit with a higher R^2 indicating a better the fit and stronger the model. To overcome the constraints of the pooled model, fixed effects and random effects model were assumed.

3.7.3 Fixed effects model

Fixed effects models control for the effects of time invariant variables with time-invariant effects. This is true whether the variable is explicitly measured or not, thus in a fixed effects model the unobserved variables can have any association with the observed variables (Allison, 2009)

3.7.4 Random effects model

According to Allison (2009), in a random effects model, the unobserved variables are assumed to be uncorrelated with all the observed variables. Greene (2003) stipulates that within random effects models, there is no association between unobserved variable heterogeneity and all explanatory variables in the study and that all differences that exist are random. The random effects model acknowledges limitations on the heterogeneity and estimates parameters for variables that are time invariant.

3.7.5 Hausman test

To determine between utilising the fixed effects and the random effects approach, a Hausman test was performed. The Hausman test compares fixed and random effects to determine which approach is more significant (Park, 2011) . A significant p value at 5% for the Hausman test confirms fixed effects model to the best estimator, otherwise, the random effects estimate is selected (Baltagi, 2008; Kennedy, 2003). Within the data utilised in this study, the result of the Hausman test, showed that the random effects model was the best estimator for the regions in eThekwini, while the fixed effects model was utilised for the Ugu and iLembe regions.

3.7.6 Multicollinearity VIF test

Within panel event studies, there is a risk of collinearity dur to potential high correlation between explanatory variables (Baltagi, 2008), however Greene, (2003) contends that this is usually a data issue, rather than a problem with model estimation. To assess this, a multicollinearity test was utilised, where a result of more than 10 requires further investigation.

3.7.7 Pesaran CD test

The Pesaran CD test for cross-sectional independence was performed to assess the potential weakness of there being correlation between panels within the regions. Cross-sectional dependence may result in biased results (Baltagi, 2008), however due to the size of panels used (24 years) being between 20 and 30 years, theory notes the potential of weakness of these cross-sectional correlations is unlikely (Baltagi, 2008; De Hoyos & Sarafidis, 2006; Greene, 2003).

3.7.8 Breusch Pagan/Cook Weisberg test for Heteroskedasticity

The Breusch Pagan/Cook Weisberg test for conditional hetroskedacity. The test considers a null hypothesis of the data being homoskedastic (Baltagi, 2008). Greene, (2003) notes that the presence of heteroskedacity is crucial in establishing confidence intervals and levels of significance based on the relationship between regression errors across panel data observations.

3.7.9 Wooldridge test

The panels used in the study have a time series of 24 years (1995 to 2019, excluding 2010 as noted above), by virtue of the time series, serial correlation tests must apply (Baltagi, 2008). To test for this, the Wooldridge test for serial correlation among panels was used to assess any potential weakness. If serial correlation exists in the panels, then the standard errors of the model will be misleading, leading to inefficient results (Drukker, 2003). A significant test statistic indicates that serial correlation exists within the panel data.

3.8 Quality controls

To establish the quality of a quantitative research report, two conditions need to be satisfied, reliability and validity (Saunders et al., 2016). To ensure that the report has reliability, consistency is required in the collection of data and the procedures that are utilised are all done under the same conditions, this ensures that there is dependability of the information collected. To ensure validity, effective and appropriate measurement and testing tools need to be applied, this needs to be done to ensure that there is credibility from an internal perspective and transferability of results from an external perspective.

3.9 Limitations

There are both internal and external threats to validity in drawing economic conclusions from empirical studies (Meyer, 1995). Internal threats can include omitted variables or events outside of timeframe specified that could provide an alternate explanation of the results, this may include the impact of other political and policy decisions on the underlying economic performance of the regions.

External limitations can include the availability and selection of data, this may be another weakness of the study as differing levels of data granularity, as well as missing data sets may affect the study's objectives. The method with which the secondary data was initially sourced may also be a limitation as certain data may have been overlooked at source or captured incorrectly.

The research is heavily reliant on data that is compiled by third party institutions. An obvious limitation associated with secondary data is the quality of the underlying data. As the data that will be utilised in this study was compiled by external parties, the researcher has no control of the quality assurance process related to the initial collection and analysis processes of the data. As secondary data is based on what has happened in the past, there may instances where the data may have become outdated due to changes in measurement and collection methods over the timeframe under review in this study (Chatora, 2018).

The use of complex statistical analysis is another limitation of this research. The generation of this output may be difficult to interpret when reviewed by someone without enough knowledge in the complex statistical methods. The overstatement of the significance of variance of the dependent or independent variables due to timeframe of the data may also be a limitation due to potential omission of group error terms for internal correlation of sample variables (Angrist & Krueger, 2001; Meyer, 1995). Regression and correlation can only indicate the presence of a linear relationship between variables. If the data is not linear, or linearly related, the model may be misleading. In addition, if more, or different, variables are added, the revised output may also be misleading.

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5 Appendices

5.1 Ethical Clearance

GIBS ETHICAL CLEARANCE APPLICATION FORM 2020

G. APPROVALS FOR/OF THIS APPLICATION

When the applicant is a student of GIBS, the applicant must please ensure that the supervisor and co-supervisor (where relevant) has signed the form before submission

STUDENT RESEARCHER/APPLICANT:

29. I affirm that all relevant information has been provided in this form and its attachments and that all statements made are correct.

Student Researcher's Name in capital letters:	ALISTAIR MAXWELL
Date:	05 Aug 2020
Supervisor Name in capital letters:	MARIANNE MATTHEE
Date:	05 Aug 2020
Co-supervisor Name in capital letters:	
Date:	05 Aug 2020

Note: GIBS shall do everything in its power to protect the personal information supplied herein, in accordance to its company privacy policies as well the Protection of Personal Information Act, 2013. Access to all of the above provided personal information is restricted, only employees who need the information to perform a specific job are granted access to this information.

FOR DOCTORAL AND FACULTY/RESEARCH ASSOCIATE/STAFF MEMBER RESEARCH ONLY

Approved

REC comments:

Approved.

Date: 14 Aug 2020

5.2 Plagiarism declaration form

I declare that this research project is my own work. It is submitted in partial fulfilment of the requirements for the degree of Master of Business Administration at the Gordon Institute of Business Science, University of Pretoria. It has not been submitted before for any degree or examination in any other University. I further declare that I have obtained the necessary authorisation and consent to carry out this research.

Alistair Duncan Maxwell

5.3 Copyright Declaration

Student details			
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Qualification details			
Degree:	MBA	Year completed:	**2020**
Title of research:	GIBS		
Supervisor:	**Prof Marianne Matthee**		
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Access

A.	My research is not confidential and may be made available in the GIBS Information Centre and on UPSpace.

I give permission to display my email address on the UPSpace website

Yes	X	No	

B.

	My research is confidential and may NOT be made available in the GIBS Information Centre nor on UPSpace.

Please indicate embargo period requested

Two years		Please attach a letter of motivation to substantiate your request. Without a letter embargo will not be granted.
Permanent		Permission from the Vice-Principal: Research and Postgraduate Studies at UP is required for permanent embargo. Please attach a copy permission letter. Without a letter permanent embargo will not be granted.

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I hereby declare that I have not used unethical research practices nor gained material dishonesty in this electronic version of my research submitted. Where appropriate, written permission statement(s) were obtained from the owner(s) of third-party copyrighted matter included in my research, allowing distribution as specified below.

I hereby assign, transfer and make over to the University of Pretoria my rights of copyright in the submitted work to the extent that it has not already been affected in terms of the contract I entered into at registration. I understand that all rights with regard to the intellectual property of my research, vest in the University who has the right to reproduce, distribute and/or publish the work in any manner it may deem fit.

Signature:	Date: **29 November 2020**
Supervisor signature:	Date:

5.4 Certification of Data Analysis Support form

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5.5 Journal Author Guide

REGIONAL SCIENCE AND URBAN ECONOMICS

AUTHOR INFORMATION PACK

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5.6 Example Journal Article

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Where and when to invest in infrastructure☆

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ABSTRACT

This paper analyzes an irreversible "where-and-when" investment decision, in which a government must decide not only when to invest in income-increasing infrastructure but also where to make the investment, doing so under imperfect observability of the investment gains. The two models considered in the paper differ in the source of the imperfection. In the signal model, the imperfection comes from imperfect observability of initial income gains from the investment, while in the option model, it comes from the stochastic nature of the income gains in the second period. In addition to providing the first treatment of this type of problem, the analysis shows that the influences of underlying parameters on whether or not the government waits to invest are similar in the two models.

1. Introduction

Starting with Aschauer (1989), a large literature has developed studying the productivity effects of public infrastructure investment. Most recently, Michaels (2008) and Duranton and Turner (2012) focus on the effect of transportation infrastructure, exploring the impact of highway investments on economic development in studies that build on earlier work.[1] The related connectivity benefits provided by airports can also stimulate local economies, and papers measuring this effect include Brueckner (2003), Sheard (2014) and others.[2] For earlier contributions to the infrastructure literature whose focus is broader than simply transportation investment, see the survey paper by Munnell (1992).[3]

All of this prior work has generated a broad consensus that public investment typically stimulates regional economies, and this view provides the starting point for the present paper.[4] The paper, however, considers a question that has received no attention (to our knowledge) in the infrastructure literature. Suppose that a government, facing a constraint on funds, can make only a single infrastructure investment and seeks to maximize the gain from investment. The question is: when faced with two location choices with different investment gains, as well as a timing choice (invest in period 1 or period 2), where and when should a government make its infrastructure investment? In other words, if the government can make one irreversible investment, which of the regions it serves should get the investment? Moreover, should the investment be made now, or should it be deferred until a later period?

These where-and-when questions are potentially intertwined because the regional impacts of the investment may be only partly observable, raising the possibility that the wrong location (with inferior gains) is chosen. Waiting to invest, however, may fully reveal the different regional gains from the investment, which allows the best location to be selected. The downside from waiting, though, is the foregone (but perhaps suboptimal) benefit from investing immediately.

There are two natural ways of portraying this lack of observability, which in turn lead to two different models of the government's decision problem. In the first model, the gains from the investments in the two regions, if made immediately, are observable. But region-specific random shocks shift the subsequent gains in an unpredictable fashion, possibly reversing the initial ranking. The realizations of these random shocks are observable, however, if the government waits to invest, allowing a better location (from the perspective of subsequent gains) to be chosen. This version of the decision problem is called the "option model" since it bears some connection to a standard investment problem under uncertainty, where waiting helps to resolve future risks.

The presence of two investment choices, however, creates some notable differences between the present option model and the standard one. Although greater uncertainty delays the investment date in the standard option model with a single potential investment, a higher return variance in the current option model need not making waiting more desirable. However, the benefit from waiting does depend on

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[1] See Fernald (1999) and Chandra and Thompson (2000). See also Donaldson (forthcoming) for recent work on the impact of railroads.

[2] See Green (2007) and Tittle et al. (2012).

[3] See also Morrison and Schwartz (1996) and Haughwout (2002).

[4] There are dissenting views: see, for example, Baade and Dye (1990)'s evidence that investment in a sports stadium need not benefit a city's economy.

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0166-0462/

the covariance between the two random influences that help determine the second period's investment gains in the regions. If the covariance is high, the future is still uncertain but the gains from waiting are low because the random effects are unlikely to reverse the advantage of the region with the higher initial investment gain. This type of outcome, where waiting may not be optimal despite high future uncertainty, is not present in models with only a single investment opportunity.

Under the second model, the regional gains from the investment are initially unobservable, although they become observable if the government waits to invest. Despite their first-period unobservability, the gains are partly revealed by random signals received by the government in that period, which provide partial information about the business climates in the two regions. The government must decide whether to invest based on this (possibly misleading) signal information or to wait and act using full information. This version of the decision problem is called the "signal model." As seen in the next section of the paper, the option and signal models can be derived as special cases of a single framework. Observe that the two models are distinguished by the sources and the timing of the uncertainty they contain: uncertainty in the signal model comes from random signals, received in the first period, about (nonstochastic) investment gains in the two regions, and uncertainty in the option model comes from random shocks, occurring in the second period, affecting investment gains in that period.[5]

Like in the signal model, the role of information acquisition in determining the timing of investment has been studied by Cukierman (1980), Demers (1991), and Thijssen et al. (2001), although in contexts very different from the current one. Similarly, the option model is connected to previous work on investment decisions because both analyze the question of "when" to invest (see Dixit and Pindyck, 1994 and the references therein).[6] However, the existence of two different investment locations introduces a departure from the standard option model, making the question not only when but also where to invest. This departure is like the one studied by Dixit (1993) and Décamps et al. (2006), where the investor decides when to invest and which among a menu of production technologies to use, faced with stochastic evolution of the output price.

Several transportation-investment examples serve to illustrate the option and signal models. The first example concerns the Green Line, a portion of the Los Angeles light rail system whose routing was chosen based on job location patterns that had changed dramatically by the time the system was complete, impairing ridership and making a different routing look better with hindsight. This outcome illustrates the option model, with the job-pattern change corresponding to an unfavorable realization of future uncertainty for one investment location. The relevant details are presented in the following excerpt from Wikipedia (n.d., b):

> Construction on the Green Line began in 1987. One of the reasons for construction was that the Green Line would serve the aerospace and defense industries in the El Segundo area. Construction of the line cost $718 million. By the time the Green Line opened in 1995, the Cold War was over, and the aerospace sector was hemorrhaging jobs. … As a result, ridership has been below projected estimates, averaging approximately 44,000 daily weekday boardings in June 2008.
>
> The Green Line's western alignment was originally planned and partially constructed to connect with LAX [Los Angeles International Airport], but the airport was planning a major remodeling during the line's construction. Los Angeles World Airports wanted the connection to LAX to be integrated with this construction, but there were concerns that the overhead lines of the rail would interfere with the landing paths of airplanes. In addition, citizens of neighboring communities to LAX opposed the expansion of the airport. …
>
> The Green Line's eastern terminus also suffers from the fact that it stops two miles (3 km) short of the heavily used Norwalk/Santa Fe Springs Metrolink station, where several Metrolink lines operate. Because of this, and the Green Line's re-routed western alignment away from LAX, critics have labeled the Green Line as a train that goes "from nowhere to nowhere."

This discussion shows that, while the initial employment pattern made a Green Line routing to El Segundo look attractive relative to a routing to LAX, shocks to the economy (analogous to the random future influences in the option model) reduced aerospace employment and made the routing inferior ex post. If the future had been predictable, the LAX routing would presumably have been chosen despite the hurdles it faced, which appear relatively minor in retrospect. In the absence of such foresight, the poor Green Line routing decision could have been avoided by waiting to make the choice.[7]

Two other transportation examples illustrate the signal model. Both involve privately financed tollways designed to extend existing highway networks. The Dulles Greenway was completed in 1995 as an extension of the Dulles Toll Road, which connects Dulles International Airport to central Washington, D.C. The Greenway extended 12 miles beyond the airport, serving Virginia's Loudoun county, and initial traffic was projected at 20,000 vehicles per day (Jain, 2010). As explained by Jain, the outcome was different:

> Within six months of opening in late 1995, the project was in financial distress. Average daily traffic demand was an abysmally low 10,500. Toll rates were reduced from an initial $1.75 to $1.00 by March 1996, and future toll hikes were deferred in an attempt to increase ridership… By July 1996, road usage increased to 21,000 daily travelers, averaging 1% to 2% monthly growth. However, the net effect on projected revenues was marginal, as decreased toll rates offset the increase in ridership.

The result was default on the project's debt, with the owners beginning "discussions with the … creditors in the summer of 1996 to work out a plan for deferring debt payments and restructuring loan contracts…" (Jain, 2010).

This outcome can be viewed in the context of the signal model, with the project planners relying on signals that proved to be faulty predictors of latent transportation demand in the area, either because of low quality or randomly favorable realizations. Waiting for more demand information could have led to a different decision, with the developers choosing a project designed to increase freeway capacity elsewhere in the highly congested Washington region.

A similar example involves the State Route 125 tollway in San Diego, built to extend an existing highway network in the inland part of the region closer to the Mexican border. Like the Dulles Greenway, traffic on the SR 125 fell seriously short of projections, leading to bankruptcy of its developer in 2010 (Schmidt, 2010). Moreover, misleading signals appeared to have played a role, with the toll road built partly in anticipation of relocation of the San Diego International Airport to an inland location near its route, an event that never took place.[8] Again, waiting to invest (allowing resolution of the airport issue) might have led the developers to a different decision, building elsewhere in a region that, like the Washington area, is highly congested and in need of extra freeway capacity.

[5] A different approach would be to assume that the benefit of an investment is not observed until it is actually carried out. However, this approach would require a different type of analysis.

[6] For studies that use the option approach to land development, see Capozza and Helsley (1990) and Capozza and Li (1994).

[7] Redding et al. (2011) show that the location of misplaced infrastructure may be hard to alter, focusing on the location of the major German hub airport in Frankfurt. The hub would have been located in Berlin had the country not been divided prior to the 1990s, but irreversibility of the investment means that relocation of the airport to Berlin in the current unified country is impractical.

[8] This view is due to Professor Gordon J. Fielding, a noted expert on transportation policy in the Southern California region (expressed in private conversation).

Another more-dramatic example of infrastructure located in wrong place is the Ciudad Real Central Airport in Spain. Built at a cost of 1.1 billion euros and located on the high speed Madrid–Seville rail line, the airport was intended to serve as an overflow facility for Madrid's Barajas airport, 150 miles distant. Completed in 2009, the airport closed in 2012 after the last of a handful of carriers offering service terminated their operations due to low passenger volumes. The failure of the airport, which is now in receivership, reflected "poor planning and overoptimism on the part of large financial investors" and the fact that "the airport is situated alongside the high-speed line to Seville, yet has no high-speed station" (Wikipedia(n.d., a); see also Harter, 2012; Busch, 2013). From the perspective of the model, the investors evidently relied on faulty signals or misinterpreted more-reliable ones, although the failure of the airport also coincided with Great Recession, complicating the picture. Waiting to invest could have led to a better decision, perhaps involving a different location for the airport.

Building on these examples, the paper analyzes a government's investment problem using the option and signal frameworks. The main contribution of the paper is to draw attention to the existence of "where-and-when" investment decisions and to show how they might be analyzed. Since such decisions have received almost no treatment in the literature, this contribution is significant, especially given the real world importance of these where-and-when decisions.

A more specific objective of the paper is to understand the effect of the various parameters of the model on the waiting decision. These parameters include the cost of the investment, the income gains from investing in the two regions, the discount factor, the length of the period-2 income stream, and the parameters governing the stochastic elements of the models (the signal variance, and the variances and covariance of period-2 incomes in the option model). Although the variance and covariance effects in the option model (mentioned above) are noteworthy, the rest of the paper's comparative-static results are mostly natural and not particularly surprising, while being common to both models. For example, in both models, waiting to invest is more likely when the investment cost is high or the income stream beyond the initial period is long, and it is less likely when the income-gain differential between the productive and unproductive regions is large. The paper's most important contribution thus lies not in these particular results but rather in exposing the issues involved in where-and-when investment decisions. In doing so, the analysis offers a general lesson for policy makers by showing that precipitous infrastructure-investment decisions may have a downside, with waiting being potentially beneficial.

Section 2 of the paper presents the general framework, which yields the two models as special cases. Section 3 analyzes the option model, while Section 4 analyzes the signal model. Section 5 presents conclusions.

2. The general framework

Consider an economy with two regions, a and b and two time periods, 1 and 2. Let I_a and I_b represent the investment decisions in regions a and b, which are mutually exclusive and irreversible (I stands for "invest"). These variables satisfy

$$I_a = 0 \text{ or } 1 \tag{1}$$

$$I_b = 1 - I_a. \tag{2}$$

The investment can be made in either period 1 or period 2, and the variable W indicates whether the decision maker waits until period 2 to make the investment (W stands for "wait"). $W = 1$ holds if the investment occurs in period 2 (if the decision maker waits), and $W = 0$ holds if it occurs in period 1.

The investment entails a one-time cost of c, which is constant over time, and it raises a region's income. The investment is productive in one region and less productive in the other, but the identity of the productive region may not be initially observable. The income gain equals $\theta + \delta$ in the productive region and θ in the unproductive region, where $\theta, \delta > 0$ (θ is referred to below as the "base income gain," while δ is called the "productive income advantage"). The identity of the productive region is indicated by the variable P_a, with $P_a = 1$ holding when a is the productive region and $P_a = 0$ holding when the productive region is b (P stands for "productive"). Note that the use of upper-case letters in I_a, P_a and W signifies that they are indicator variables, taking values of either zero or one.

While the income gains in period 1 contain only these nonstochastic elements, the gains in period 2 include stochastic components, which consist of random shocks that multiply the nonstochastic expressions. If region a is the productive region, its income gain in period 2 is $(\theta + \delta)\epsilon_a$, where ϵ_a is a positive random variable. If region a is instead the unproductive region, its period-2 income gain is $\theta\epsilon_a$. Corresponding income gains for region b in these two cases are $\theta\epsilon_b$ and $(\theta + \delta)\epsilon_b$.

Note that, even if region a is productive, region b could have the higher period-2 income due to stochastic influences, an outcome that arises if $(\theta + \delta)\epsilon_a < \theta\epsilon_b$ holds. However, since the realizations of ϵ_a and ϵ_b are observed once period 2 is reached, it follows that if government waits to invest, the investment can be made in the region where it yields the highest gain.

Let y denote regional income in the absence of an investment, which is supplemented by the above income gains. Then, incomes in the two regions in the periods 1 and 2 depend on where the investment is made (I_a), when it occurs (W) and which region is productive (P_a). Using the above information, these incomes (denoted by y_{a1}, y_{a2}, y_{b1}, and y_{b2}) are given by

$$y_{a1} = y + (1-W)I_a(\theta + P_a\delta) \tag{3}$$

$$y_{a2} = y + I_a(\theta + P_a\delta)\epsilon_a \tag{4}$$

$$y_{b1} = y + (1-W)(1-I_a)(\theta + (1-P_a)\delta) \tag{5}$$

$$y_{b2} = y + (1-I_a)(\theta + (1-P_a)\delta)\epsilon_b. \tag{6}$$

From Eqs. (3) and (4), if the investment occurs immediately ($W = 0$) and if region a is chosen ($I_a = 1$), then $y_{a1} = y + \theta + \delta$ and $y_{a2} = y + (\theta + \delta)\epsilon_a$ hold if a is the productive region ($P_a = 1$). If instead region b is productive ($P_a = 0$), then $y_{a1} = y + \theta$ and $y_{a2} = y + \theta\epsilon_a$ hold. In either case, $y_{b1} = y_{b2} = y$ holds from Eqs. (5) and (6) since $1 - I_a = 0$. If, on the other hand, region b is chosen, then the regional incomes are gotten by swapping the a and b subscripts in the previous expressions. If waiting occurs ($W = 1$), then period-1 incomes equal y in both regions, while the previous expressions continue to apply for period-2 incomes.

The identity of the productive region is indicated by signals, which may reveal this identify imperfectly. Concretely, the signals are pieces of information about the business climate that contain evidence about the likely income gains from the investment in the two regions. Note that these signals are not produced by some other optimizing economic agent whose goal is to influence the government's decision; they are generated instead by "nature." One possible interpretation of the signals is that they come from observing the outcomes of investments undertaken by other governments in regions similar to those under consideration. For example, another regional government may have made a highway investment in an outlying area like one of the regions under consideration, and the benefits of that investment may be apparent at the time the current investment decision must be made. However, since the other region would not be identical to the similar one under consideration, the signal is imperfectly informative.

Let s_a and s_b denote the random signals, which are received in period 1 and are indicators of the nonstochastic portion of the income from investment in the two regions. The signals take the form

$$s_a = \theta + P_a\delta + \beta v_a \tag{7}$$

$$s_b = \theta + (1 - P_a)\delta + \beta v_b, \tag{8}$$

where v_a and v_b are random variables and where β equals 0 or 1. Note that the difference between the nonstochastic parts of the signals (equal to $(2P_a - 1)\delta$) is larger in absolute value the greater is the productive income advantage δ. Thus, a large productivity difference between the regions is more readily revealed by the signals than a smaller one. When $\beta = 0$, this revelation is perfect, with the signals fully revealing the identity of the productive region, but it is imperfect when $\beta = 1$, with the signals not fully informative.

The ensuing analysis considers two cases. The "option" case is characterized by the restriction $\beta = 0$, so that the signal perfectly reveals the productive region but income uncertainty is present in period 2. In this case, waiting to invest means sacrificing guaranteed income in period 1 to ensure that the highest possible income is earned in period 2.

In the "signal" case, $\beta = 1$ holds, so that the signal contains noise. But ϵ_a and ϵ_b are constant and equal to 1, so that the income gains have no random element in period 2. Since the identity of the productive region is not fully revealed until period 2, waiting is necessary to ensure that the investment occurs there, but at a cost of lost income in period 1. Figs. 1 and 2 show the time lines for the option and signal models.

It is important to note that paper focuses on the behavior of an optimizing agent, in this case a regional government. However, the government does not choose, in familiar fashion, the values of continuous decision variables such as prices or quantities, but rather selects the values of two discrete indicator variables: I_a, indicating whether region a or b receives the investment, and W, indicating whether the government waits until period 2 to make the investment. Despite this difference, the optimization problem nevertheless has the same fundamental structure as problems usually considered in economic analysis. To begin the consideration of the two frameworks, the next section analyzes the option model, pointing out differences relative to the standard option framework, while Section 4 analyzes the less-familiar and more-complex signal model.

3. The option model

3.1. The setup

Consider first the discounting of future income. Let $\rho < 1$ be the discount factor used to value period 2 income in period 1. Next, let period 2 be viewed as a sequence of possibly multiple (and stationary) future periods over which an income flow given by Eq. (3) or (5) is earned, and let λ be the factor used to discount this income stream back to the beginning of period 2. With multiple future periods $\lambda > 1$ will hold, while λ would equal 1 if period 2 encompasses just a single period. Thus, λ is an indicator of the length of the period-2 income stream. Note that $\rho\lambda$ is the factor that discounts the period-2 income stream income back to period 1.[9]

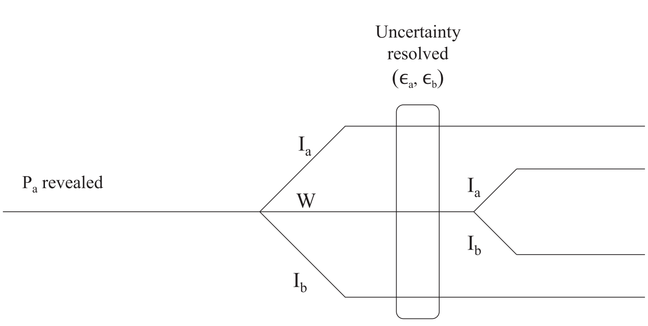

Fig. 1. Option framework.

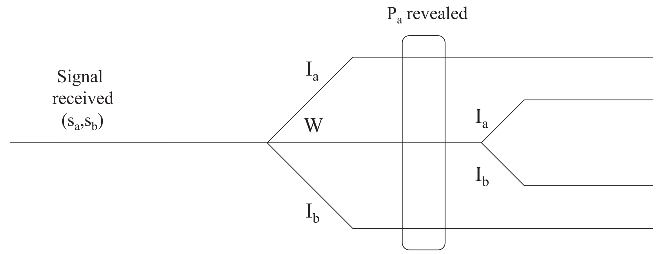

Fig. 2. Signal framework.

Recall that in the option model, the signal is perfectly informative rather than noisy, with $\beta = 0$ in Eqs. (7) and (8). But income earned in period 2 is stochastic, governed by the random variables ϵ_a and ϵ_b in Eqs. (3) and (5). To simplify the analysis, these variables are assumed to have the same mean, denoted $\mu > 0$. Using Eq. (2) with $W = 0$ as well as Eq. (3), the discounted expected income from investing in region a in period 1, net of the cost c of the investment, is then

$$E(y_{a1} + \rho\lambda y_{a2} - c) = y + \theta + P_a\delta - c + \rho\lambda[y + (\theta + P_a\delta)\mu], \tag{9}$$

where the expectation operator is applied to ϵ_a in y_{a2}, yielding $E(y_{a2}) = \mu$. Since $E(\epsilon_b)$ also equals μ, the only change required to generate the analogous expression for investing in region b is to replace P_a in Eq. (9) with $1 - P_a$. Since the investment then yields higher expected income in the region with $P_a = 1$ (whose identity is observable), if the government makes the investment in period 1, it will invest in that region, which is assumed without loss of generality to be region a. From Eq. (9), the resulting expected net income equals

$$(1 + \rho\lambda)y - c + (\theta + \delta)(1 + \rho\lambda\mu), \tag{10}$$

which is assumed to be positive.

By waiting to invest and thus observing the realizations of ϵ_a and ϵ_b, the government can secure the higher of the two future income streams, which may be offered by region b, not region a, if ϵ_a is small relative to ϵ_b. Since a is the (ex-ante) productive region, the discounted expected income from waiting, net of the investment cost, is given by

$$y + \rho E[max\{\lambda(y + (\theta + \delta)\epsilon_a) - c, \lambda(y + \theta\epsilon_b) - c\}]. \tag{11}$$

The choice of making no investment in period 2 is assumed to be unattractive, which requires a sufficiently small cost c (footnote 10 below gives the relevant condition). This assumption marks a key difference relative to the standard option model, where a single investment is available and where that investment may turn out to be undesirable

[9] It should be noted that the problem analyzed in the paper is not an intertemporal decision problem that, looking forward, has the same structure regardless of the current period. In such a setup, upon reaching period 2 after waiting, the decision maker would face exactly the same problem as in period 1: invest now or wait again. While such a model could be analyzed, the current structure is intentionally different to maintain tractability, allowing only one waiting decision.

once future uncertainty is resolved. Therefore, in the standard model, waiting may result in no investment being undertaken, in contrast to the present model, where some investment always occurs, either in period 1 or 2.

Waiting to invest is optimal when Eq. (10) is less than Eq. (11). Canceling the common $(1+\rho\lambda)y$ terms, waiting is then optimal when

$$\theta+\delta-c+\rho\lambda(\theta+\delta)\mu < \rho E[max\{\lambda(\theta+\delta)\epsilon_a-c, \lambda\theta\epsilon_b-c\}]. \tag{12}$$

To generate the formula for the expected value in Eq. (12), note that the first term is maximal when $\epsilon_a > g\epsilon_b$, where

$$g\equiv\frac{\theta}{\theta+\delta}<1 \tag{13}$$

is the relative gain from investing in the unproductive region, and that the second term is maximal when $\epsilon_a < g\epsilon_b$. Letting $t(\epsilon_a, \epsilon_b)$ denote the joint density of ϵ_a and ϵ_b, and assuming these random variables both have support $[\underline{\epsilon}, \overline{\epsilon}]$, with $\overline{\epsilon}>\underline{\epsilon}>0$,[10] the RHS of Eq. (12) can be written

$$\rho\int_{\epsilon_b=\underline{\epsilon}}^{\overline{\epsilon}}\left[\int_{\epsilon_a=g\epsilon_b}^{\overline{\epsilon}}\lambda(\theta+\delta)\epsilon_a t(\epsilon_a,\epsilon_b)d\epsilon_a+\int_{\epsilon_a=\underline{\epsilon}}^{g\epsilon_b}\lambda\theta\epsilon_b t(\epsilon_a,\epsilon_b)d\epsilon_a\right]d\epsilon_b-\rho c. \tag{14}$$

Noting that the $\rho\lambda(\theta+\delta)\mu$ term in Eq. (12) equals

$$\rho\lambda(\theta+\delta)\int_{\epsilon_b=\underline{\epsilon}}^{\epsilon}\int_{\epsilon_a=\underline{\epsilon}}^{\epsilon}\epsilon_a t(\epsilon_a,\epsilon_b)d\epsilon_a d\epsilon_b, \tag{15}$$

and subtracting Eq. (15) from the integral expression in Eq. (14), that expression reduces to

$$\rho\int_{\epsilon_b=\underline{\epsilon}}^{\overline{\epsilon}}\left[\int_{\epsilon_a=\underline{\epsilon}}^{g\epsilon_b}-\lambda(\theta+\delta)\epsilon_a t(\epsilon_a,\epsilon_b)d\epsilon_a+\int_{\epsilon_a=\underline{\epsilon}}^{g\epsilon_b}\lambda\theta\epsilon_b t(\epsilon_a,\epsilon_b)d\epsilon_a\right]d\epsilon_b = \rho\lambda(\theta+\delta)\int_{\epsilon_b=\underline{\epsilon}}^{\overline{\epsilon}}\int_{\epsilon_a=\underline{\epsilon}}^{g\epsilon_b}(g\epsilon_b-\epsilon_a)t(\epsilon_a,\epsilon_b)d\epsilon_a d\epsilon_b. \tag{16}$$

This expression gives the option value of waiting to invest, which equals the expected discounted income gain from putting the investment in the region where it earns the highest period-2 income. This gain is measured relative to the expected discounted gain in period-2 income from investing in region a in period 1, given by $\rho\lambda(\theta+\delta)\mu$ in Eq. (12), an expression that is subtracted from Eq. (14) to reach Eq. (16). It is important to note that this option value differs from that in a standard option framework because it reflects the ability to choose between two investment locations once future conditions become clear. While waiting in the usual model gives the investor a choice between investing or not investing once the future is revealed, the choice here is between two alternate investment locations.

After moving ρc in Eq. (14) to the LHS of Eq. (12), that expression reduces to $\theta+\delta-(1-\rho)c$. Since ρ is the factor for discounting period 2 income back to period 1, it embodies a discount rate r satisfying $\rho=1/(1+r)$. After substitution, the previous expression then reduces to $\theta+\delta-rc/(1+r)$. The last term equals the period-1 present value of the interest earned in period 2 on a bank deposit of c made in period 1 as an alternative to the infrastructure investment. Since the first two terms capture the forgone period-1 income gain from not investing in period 1, the LHS in the rearranged version of (12) $(\theta+\delta-(1-\rho)c)$ equals the net period-1 income loss from waiting.

Therefore, waiting to invest is desirable when the option value of waiting from Eq. (16) exceeds the net period-1 income loss due to waiting, or

$$\theta+\delta-(1-\rho)c < \rho\lambda(\theta+\delta)\int_{\epsilon_b=\underline{\epsilon}}^{\overline{\epsilon}}\int_{\epsilon_a=\underline{\epsilon}}^{g\epsilon_b}(g\epsilon_b-\epsilon_a)t(\epsilon_a,\epsilon_b)d\epsilon_a d\epsilon_b. \tag{17}$$

Note that if the largest possible value of $g\epsilon_b$, which equals $g\overline{\epsilon}<\overline{\epsilon}$, is less than $\underline{\epsilon}$, then no ϵ_a values lie in the range of the inner integral in Eq. (17), making the RHS equal to zero. To rule out this case, so that waiting has a chance to be optimal, $g\overline{\epsilon}>\underline{\epsilon}$ is assumed to hold.

3.2. The effects of parameter changes on the waiting decision

Any parameter change that reduces the magnitude of the LHS of Eq. (17) relative to the RHS magnitude favors waiting. Such changes include an increase in the investment cost c, which raises the incentive to postpone that cost, as reflected in a decrease in the net period-1 income loss from waiting (LHS of Eq. (17)). In addition, an increase in the length of the period-2 income stream, as captured by λ, raises the option value of waiting, making it more desirable. However, an increase in the discount factor ρ raises both sides of Eq. (17), thus having an ambiguous effect on the desirability of waiting. This is a sensible conclusion given that a higher valuation of the future applies to both income gains and investment costs. An increase in the base income gain θ increases g, raising both the second upper limit of integration in Eq. (17) as well as the integrand. Since the $\theta+\delta$ terms on both sides of Eq. (17) also increase, both the LHS and RHS expressions increase, leading to an ambiguous effect of θ on the desirability of waiting. On the other hand, since an increase in the productive income advantage δ lowers g (reducing the value of the integral in Eq. (17)) while raising $\theta+\delta$, the RHS changes in an ambiguous direction. However, dividing both sides of Eq. (17) by $\theta+\delta$, the LHS becomes $1-(1-\rho)/(\theta+\delta)$, which is increasing in δ. With the integral decreasing, it follows that an increase in δ reduces the desirability of waiting.

To understand the different effects of θ and δ, note that a higher θ increases the option value of waiting by increasing incomes in both regions (an effect captured by the $\theta+\delta$ factor on the RHS of Eq. (17)), and by increasing the chance that region a's initial productivity advantage will be reversed by the random shocks (captured in the larger value of the integral). By contrast, a higher δ reduces the chance that region a's productivity advantage will be reversed, thus exerting downward pressure on the option value that makes δ's overall effect on that value ambiguous. Rearrangement of Eq. (17) then shows that this ambiguity can be transformed into a definitive conclusion about the effect of δ. Summarizing yields

Proposition 1. In the option model, an increase in the investment cost c or the income-stream length λ raises the desirability of waiting, while an increase in the productive income advantage δ reduces it. The effects of the discount factor ρ and the base income gain θ are ambiguous.

Intuition suggests that a higher variance in the present option model may have no clearcut effect on the value of waiting, a conclusion that contrasts with the outcome in the usual option framework. The reason is that greater variability in both epsilon's need not raise the likelihood that ϵ_b is large enough relative to ϵ_a to reverse region a's initial productivity advantage. As a result, the gain from waiting to observe the actual outcome may be no higher (even smaller) with a larger variance.

Although the normal distribution is a natural choice in analyzing the effect of variance changes, both here and in the signal model below, using it to address the effect of a higher variance for the ϵ's proves to be intractable. As a result, the uniform distribution is employed instead to evaluate the above intuition, with $t(\epsilon_a, \epsilon_b)\equiv1/\tau$, $\overline{\epsilon}=k+\tau/2$, and $\underline{\epsilon}=k-\tau/2>0$. Then, ϵ_a and ϵ_b are independent with variances of $\tau^2/12$. The intuition is confirmed by computing the value of the integral in

[10] The condition that makes investment desirable conditional on waiting is positivity of the arguments of the max operator in Eq. (11). Given the support of the ϵ's, the inequality $\lambda(y+\theta\underline{\epsilon})>c$ is sufficient for satisfaction of this condition.

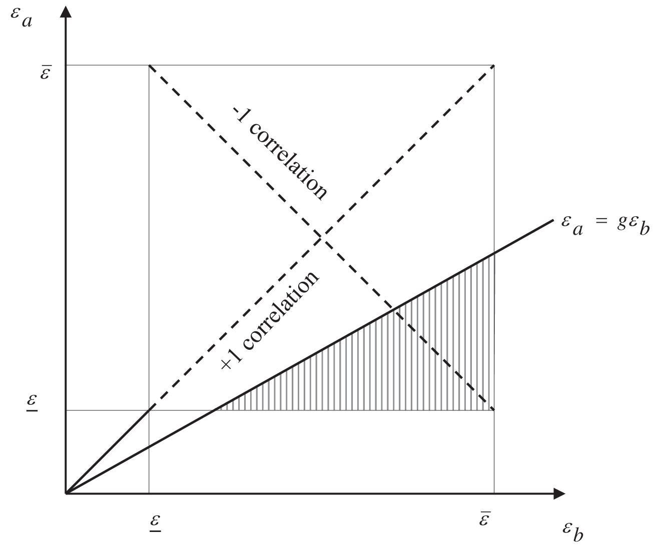

Fig. 3. Option model.

Eq. (17) for the uniform case and evaluating the derivative with respect to τ, which is ambiguous in sign, as predicted.[11]

In contrast to this ambiguity regarding the variance, intuition suggests that a greater covariance between ϵ_a and ϵ_b should reduce the desirability of waiting. When the covariance between the ϵ's is higher, the random influences move more nearly in step with one another, so that the period-1 income gain from investing in the productive region is less likely to be reversed in period 2. The higher covariance thus lowers the benefit from waiting. To investigate this question, the following analysis compares cases where the correlations between ϵ_a and ϵ_b are $+1$ and -1, showing that waiting is not desirable in the first case but may be desirable in the second, as intuition would predict. The demonstration applies generally, not relying on the uniform distribution.

The case where ϵ_a and ϵ_b have a correlation of $+1$ can be generated by starting with an arbitrary marginal distribution for ϵ_b, denoted $t_b(\epsilon_b)$, and then assuming that $\epsilon_a = \epsilon_b$. The joint distribution of ϵ_a and ϵ_b then satisfies $t(\epsilon_a, \epsilon_b) = t_b(\epsilon_b)$ for $\epsilon_a = \epsilon_b$ and $t(\epsilon_a, \epsilon_b) = 0$ otherwise. Alternatively, a correlation of -1 is generated by assuming $\epsilon_a = \bar{\epsilon} + \underline{\epsilon} - \epsilon_b$, which correspondingly alters the definition of the joint distribution. Note that these two alternate cases preserve the maintained assumptions that ϵ_a and ϵ_b have the same support and the same means (an outcome that would not necessarily obtain if the coefficients relating ϵ_a to ϵ_b were not $+1$ and -1).

In the $+1$ case, all realizations of ϵ_a and ϵ_b lie outside the range of integration for the integral in (17). The reason is that $\epsilon_a < g\epsilon_b$ holds over this range, implying $\epsilon_a < \epsilon_b$ given $g < 1$, while a $+1$ correlation requires $\epsilon_a = \epsilon_b$. As a result, the integral equals zero, indicating that there is no benefit from waiting. This conclusion highlights the difference between the current setup and the standard option framework. Even though future uncertainty is still present, the option to wait is worthless because the returns from the two location choices are perfectly correlated. Because of this correlation, no additional information about the best investment location is gained by waiting.

Note that with perfect correlation, the model effectively contains just a single investment opportunity, with region a dominating region b since it is initially more productive and cannot become less productive in period 2. As a result, the model reduces to the standard option framework augmented by the auxiliary assumption that investment in period 2 is always worthwhile once that period is reached. While waiting is suboptimal in this setting, it may become desirable when the auxiliary assumption is dropped (allowing truly bad investments), with waiting then providing the opportunity to entirely avoid such an investment once resolution of uncertainty reveals its quality.

Returning to the current framework, suppose that instead of having a correlation of $+1$, ϵ_a and ϵ_b have a correlation equal to -1. Then $\epsilon_a = \bar{\epsilon} + \underline{\epsilon} - \epsilon_b$ holds, implying that ϵ_a ranges from $\bar{\epsilon}$ to $\underline{\epsilon}$ as ϵ_b ranges from $\underline{\epsilon}$ to $\bar{\epsilon}$. Since some of the resulting ϵ_a values satisfy $\epsilon_a < g\epsilon_b$ under the maintained assumptions (recall the discussion following Eq. (17)), the integral in Eq. (17) is positive rather than zero, indicating a benefit to waiting.

This argument is illustrated in Fig. 3, where the shaded area shows the range of integration for the integral in Eq. (17). With a correlation of $+1$, the possible combinations of ϵ_a and ϵ_b lie along the dotted portion of the 45 degree line. Because this segment has no overlap with the shaded area, the value of the integral in Eq. (17) equals zero. With a correlation of -1, the possible ϵ combinations lie along the dotted line with slope -1 in Fig. 3. Since this segment passes through the shaded area, it gives a positive value for the integral in Eq. (17). Summarizing yields

Proposition 2. If the correlation between the random regional income variables ϵ_a and ϵ_b in the option model equals $+1$, then waiting to invest is undesirable. But waiting may be desirable when the correlation equals -1.

Numerical examples suggest that the message of Proposition 2 applies more generally. Although analytical results are not available, calculations show that if $t(\epsilon_a, \epsilon_b)$ is bivariate normal, then the integral in Eq. (17) monotonically decreases as the distribution's correlation coefficient increases over the $(-1, 1)$ range, regardless of the values of g and the other distribution parameters. Thus, the benefit from waiting falls as ϵ_a and ϵ_b become more closely associated.

4. The signal model

4.1. Form of the investment decision rule

In the signal model, the period-2 investment returns are nonstochastic rather than random, with $\epsilon_a \equiv \epsilon_b \equiv 1$, but the identity of the productive region is unobservable in period one though partly revealed by signals. The government makes decisions based on the difference between the signals from the two regions, $s_a - s_b$. Using Eqs. (7) and (8) and setting $\beta = 1$, the signal difference is given by

$$z \equiv s_a - s_b = v_a - v_b + (2P_a - 1)\delta. \tag{18}$$

If z takes a large value, pointing toward higher productivity in region a, the government invests in region a in period 1. If z takes a small value, pointing toward higher productivity in region b, the government again invests in period 1 but chooses region b. However, if z takes an intermediate value, the signals are less clear about the identity of the higher productivity region. In this case, the government waits, deferring the investment until period 2. This assumed behavior on the part of the government, under which z is compared to critical values to reach an investment decision, represents optimizing behavior that can be properly derived from first principles, as explained in Appendix A. That behavior leads to the same final decision rule as the one implied by the use of critical z values, as Appendix A demonstrates.

Letting $\bar{z}$ and $\bar{z} \geq \underline{z}$ denote the upper and lower critical values for z, the decision rule is to invest in region a if $z > \bar{z}$, invest in b if $z < \underline{z}$, and wait if $\underline{z} \leq z \leq \bar{z}$. The government's goal is to choose $\bar{z}$ and $\underline{z}$ in optimal fashion, so as to maximize the expected income gain from the investment. Note that if the constraint $\bar{z} \geq \underline{z}$ were to bind at the solution, no values of the signals would lead the government to wait before investing.

[11] Extensive manipulation shows that the integral equals

$$\frac{1}{2\tau}\left[g^2\left(3k^2 + \tau^2/4\right) + g\left(2\tau k - 4k^2\right) + (k - \tau/2)^2\right],$$

an expression whose τ derivative is ambiguous in sign.

The previous inequalities imply particular ranges for the value of $v_a - v_b$, the difference between the signals' random elements, in the three cases. Letting $x \equiv v_a - v_b$ denote this difference, the decision rule implies that the government will

$$\begin{aligned} &\text{Invest in } a \text{ in period } 1\ (W=0, I_a=1) \quad \text{when} \quad x > (1-2P_a)\delta + \bar{z} \\ &\text{Wait } (W=1) \quad \text{when} \quad (1-2P_a)\delta + \underline{z} \le x \le (1-2P_a)\delta + \bar{z} \\ &\text{Invest in } b \text{ in period } 1\ (W=0, I_a=0) \quad \text{when} \quad x < (1-2P_a)\delta + \underline{z}. \end{aligned} \tag{19}$$

4.2. Objective function

Using the decision rule in Eq. (19), the expected income gain from the investment can be computed conditional on $\bar{z}$ and $\underline{z}$, and it serves as the government's objective function. This computation involves a number of different steps. To begin, let G_a^1 denote the discounted value of the income gain from investing in region a in period 1 when a is the productive region ($P_a = 1$). Similarly, let G_a^0 denote the discounted income gain from investing in region a when b is the productive region ($P_a = 0$), and let G_b^1 and G_b^0 denote the analogous discounted income gains from investing in region b when it is, respectively, unproductive and productive. Finally, let G_w denote the discounted income gain from waiting, which is not region specific. Since these expressions give income gains from the investment and thus exclude the y terms in Eqs. (2)–(5), they are given by

$$\begin{aligned} G_a^1 &= G_b^0 = \theta + \delta - c + \rho\lambda(\theta+\delta) \\ G_a^0 &= G_b^1 = \theta - c + \rho\lambda\theta \\ G_w &= \rho[\lambda(\theta+\delta) - c]. \end{aligned} \tag{20}$$

To interpret Eq. (20), note first that, when the government does not wait to invest (lines 1 and 2), the present value of the income gain equals $(1+\rho\lambda)(\theta+\delta)$ if the investment is made in the productive region but equals $(1+\rho\lambda)\theta$ otherwise. Second, since productivity can be observed when the government waits, the investment is always then made in the productive region, generating a discounted income gain of $\rho\lambda(\theta+\delta)$ (no period-1 gain occurs). Third, note that the cost c is incurred in period 1 in the first two cases and is thus not discounted, while with waiting, the cost appears in period 2 and is thus discounted by ρ. Finally, in order for the investment to be worth undertaking after waiting until period 2, the inequality

$$\lambda(\theta+\delta) > c \tag{21}$$

must hold, indicating that the present value of the stream of subsequent income gains must be larger than the cost of the investment. This inequality is assumed to be satisfied.

With this background, the overall discounted expected income gain from the investment can be computed. Letting $prob(E)$ denote the probability of the event E, this expression is given by

$$\begin{aligned} &prob(P_a=1)\cdot prob(x>(1-2P_a)\delta+\bar{z}|P_a=1)\cdot G_a^1 + \\ &prob(P_a=0)\cdot prob(x>(1-2P_a)\delta+\bar{z}|P_a=0)\cdot G_a^0 + \\ &prob(P_a=1)\cdot prob(x<(1-2P_a)\delta+\underline{z}|P_a=1)\cdot G_b^1 + \\ &prob(P_a=0)\cdot prob(x<(1-2P_a)\delta+\underline{z}|P_a=0)\cdot G_b^0 + \\ &prob(P_a=1)\cdot prob((1-2P_a)\delta+\underline{z}\le x\le(1-2P_a)\delta+\bar{z}|P_a=1)\cdot G_w + \\ &prob(P_a=0)\cdot prob((1-2P_a)\delta+\underline{z}\le x\le(1-2P_a)\delta+\bar{z}|P_a=0)\cdot G_w. \end{aligned} \tag{22}$$

Note that $prob(P_a=1)$ and $prob(P_a=0)$ give the government's prior probabilities that the productive region is a (b). Since the government has no knowledge prior to receipt of the signal, these probabilities equal 1/2. To interpret Eq. (22), observe that the first line equals the probability that region a is productive times the probability that region a is chosen under the decision rule, given that it is productive, times the income gain from this choice. Region a could be chosen, however, when it is unproductive, and the second line of Eq. (22) gives the probability of this occurrence times the associated income gain. The remaining lines of Eq. (22) are interpreted in an analogous fashion.

To rewrite Eq. (22) in a usable form, the prior probabilities can be suppressed since they are all 1/2, and the second probability expressions can be rewritten using the cumulative distribution function of the signals' noise difference x, denoted $F(\cdot)$. Then, after inserting the G expressions from Eq. (20) into Eq. (22) and ignoring the 1/2 factor, the government's objective function can be rewritten as

$$\begin{aligned} \Phi(\bar{z},\underline{z}) = {} & [1-F(-\delta+\bar{z})]\cdot[\theta+\delta-c+\rho\lambda(\theta+\delta)] \\ & + [1-F(\delta+\bar{z})]\cdot[\theta-c+\rho\lambda\theta] + F(-\delta+\underline{z})\cdot[\theta-c+\rho\lambda\theta] \\ & + F(\delta+\underline{z})\cdot[\theta+\delta-c+\rho\lambda(\theta+\delta)] \\ & + [F(\delta+\bar{z})-F(-\delta+\underline{z})]\cdot\rho[\lambda(\theta+\delta)-c] \\ & + F[(\delta+\bar{z})-F(\delta+\underline{z})]\cdot[\rho\lambda(\theta+\delta)-c]. \end{aligned} \tag{23}$$

The lines of Eq. (23) correspond to the lines of Eq. (22). Note that, in writing the second probabilities in Eq. (22) in terms of F, the conditioning factors $P_a = 0{,}1$ are used in evaluating the $(1-2P_a)\delta$ terms, which then equal either δ or $-\delta$. For example, $prob(x>(1-2P_a)\delta+\bar{z}|P_a=1)$ in Eq. (22) becomes $[1-F(-\delta+\bar{z})]$ after substitution of $P_a = 1$ into the inequality, yielding $x > -\delta+\bar{z}$, and then using F.

4.3. Optimization problem

The government's goal is to maximize Φ in Eq. (23) by choice of $\bar{z}$ and $\underline{z}$ subject to the constraint $\bar{z}\ge\underline{z}$. Letting f denote the density corresponding to F, and derivatives of Eq. (23) with respect to $\bar{z}$ and $\underline{z}$ are

$$\frac{\partial\Omega}{\partial\bar{z}} = -f(-\delta+\bar{z})(\theta+\delta-(1-\rho)c) + f(\delta+\bar{z})(\rho\lambda\delta+(1-\rho)c-\theta), \tag{24}$$

$$\frac{\partial\Omega}{\partial\underline{z}} = -f(-\delta+\underline{z})(\rho\lambda\delta+(1-\rho)c-\theta) + f(\delta+\underline{z})(\theta+\delta-(1-\rho)c). \tag{25}$$

The derivatives in Eqs. (24) and (25) equal zero, respectively, at interior solutions for $\bar{z}$ and $\underline{z}$, but the noninterior solutions may also exist.

To make the analysis manageable, the distribution of $x = v_a - v_b$ is assumed to be symmetric and unimodal with mean zero, so that $f(x) = f(-x)$. This outcome emerges if the distributions of v_a and v_b are themselves identical, symmetric and unimodal with zero means. In this case, the critical $\bar{z}$ and $\underline{z}$ values will be symmetric around zero, as can be seen by comparing Eqs. (24) and (25). Symmetry allows $\bar{z}$ and $\underline{z}$ to be replaced by u and $-u$, with the constraint $\bar{z}\ge\underline{z}$ reducing to $2u \ge 0$ or $u \ge 0$. Thus, $[-u, u]$ is the signal range over which waiting is optimal.

With this substitution, only one first-order condition is needed, and Eq. (24) can be used with $\bar{z}$ replaced by u. Setting Eq. (24) equal to zero, the first-order condition for an interior solution can then be written as

$$[\rho\lambda\delta+(1-\rho)c-\theta]f(-\delta+u)\left[-R+\frac{f(\delta+u)}{f(-\delta+u)}\right] = 0, \tag{26}$$

where

$$R = \frac{\theta+\delta-(1-\rho)c}{\rho\lambda\delta+(1-\rho)c-\theta}. \tag{27}$$

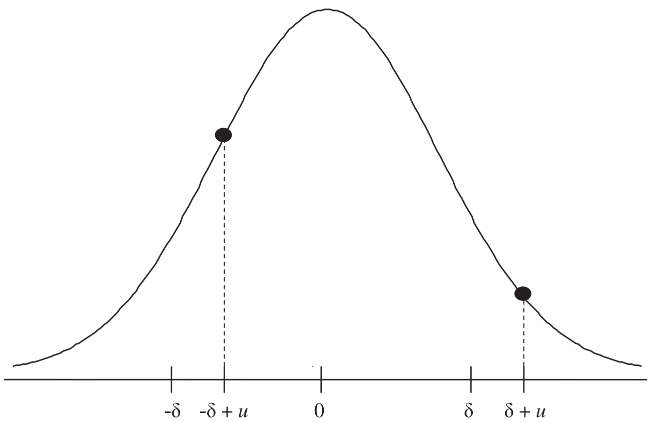

Fig. 4. Elements of density ratio.

A fully general analysis of Eqs. (26) and (27) is complex because the numerator and denominator of R can take either sign, making additional assumptions necessary. Specifically, the base income gain θ is assumed to be small enough relative to the productive income advantage δ and the investment cost c that the denominator of Eq. (27) is positive[12]:

$$\rho\lambda\delta + (1-\rho)c - \theta > 0. \tag{28}$$

Using Eq. (24), an interior solution for u satisfies

$$-R + \frac{f(\delta+u)}{f(-\delta+u)} \equiv -R + H(u,\delta) = 0, \tag{29}$$

where $H(u, \delta)$ denotes the density ratio in Eq. (29). To insure that the second-order condition holds at an interior solution, the expression in Eq. (29) must be decreasing in u at the solution, with the expression changing sign from positive to negative. For an interior solution to be unique, this sign change must only occur once. This requirement in turn implies that $H(u, \delta)$ changes sign just once, which means that H is (weakly) monotonically decreasing in u, with $\partial H/\partial u \le 0$. This condition constitutes a third maintained assumption, along with Eqs. (22) and (28).

To understand the behavior of the $H(u, \delta)$ function, consider Fig. 4. Recalling that $H(u, \delta)$ is the density ratio from above, note that H equals 1 when $u = 0$, and that as u rises above zero, H decreases until u equals δ, at which point $-\delta + u = 0$ holds and density's mode is reached. But further increases in u, which put both $-\delta + u$ and $\delta + u$ on the downward-sloping part of the density, have an ambiguous effect on H, although it remains below 1. However, for several familiar densities, including the normal and triangular cases, H continues to decrease as u increases beyond δ.[13] In the normal case with variance σ^2, which is considered further below,

$$H(u,\delta) = \frac{exp[-(\delta+u)^2/2\sigma^2]}{exp[-(-\delta+u)^2/2\sigma^2]} = exp[-2\delta u/\sigma^2], \tag{30}$$

a decreasing function of u, and a calculation for the triangular density yields the same conclusion. These examples lend plausibility to the assumption $\partial H/\partial u \le 0$. Note that the weak inequality covers the case of a uniform distribution, where H is constant at 1 over the density's support (see below).

4.4. Non-interior solutions

Eventually, a comparative-static analysis is carried out to show how parameter changes affect the value of u at an interior solution. But non-interior solutions are of considerable interest, and they are considered first. To begin, observe that if

$$\theta + \delta \le (1-\rho)c, \tag{31}$$

then $R \le 0$ holds given Eq. (28), and the expression in Eq. (26) is then positive for all u. In this case, an infinite u is desirable. Thus, waiting is always optimal, with no signal values inducing the investor to invest in period 1.[14]

Substituting $rc/(1 + r)$ for $1 - \rho$ as before, Eq. (31) reduces to $\theta + \delta < rc/(1 + r)$. Recall that the RHS of this inequality equals the period-1 present value of the interest earned in period 2 on a bank deposit of c made in period 1 as an alternative to the infrastructure investment. If this present value is greater than the forgone period-1 income gain from the investment, equal to $\theta + \delta$, then waiting is preferable regardless of the signal values.

By contrast, suppose that $R \ge 1$. Then, since $H \le 1$, the LHS of Eq. (26) is negative for $u > 0$, implying that $u = 0$ holds at the optimum. In this case, no values of the two signals lead the government to wait: it always invests in period 1, choosing region a if $z > 0$ and region b if $z < 0$. Rearrangement of Eq. (27) shows that $R \ge 1$ holds when

$$(\theta+\delta)(1-\rho\lambda) \ge 2(1-\rho)c. \tag{32}$$

Note that this condition cannot be satisfied if $\rho\lambda \ge 1$, which rules out no waiting as an optimal choice.[15] This inequality states that the future income stream is sufficiently long (λ is sufficient large) that an extra dollar of stream income has a present value that equals or exceeds 1. This high present value amplifies the loss from investing in the unproductive region, which makes waiting to invest optimal for at least some range of signal values, ruling out $u = 0$.

Using Eqs. (31) and (32), a simple statement about the conditions leading to noninterior solutions can be made, as follows:

Proposition 3. In addition to the maintained assumptions in the signal model, suppose that $\rho\lambda < 1$ holds, so that no waiting may be an optimal choice. Then, unconditional waiting (an infinite u) is optimal if and only if $\theta + \delta \le (1 - \rho)c$, while no waiting (a zero u) is optimal if and only if $\theta + \delta \ge [2(1 - \rho)/(1 - \rho\lambda)]c$.

Intuitively, the proposition says that unconditional (no) waiting is optimal when the forgone period-1 income from investing in the productive region ($\theta + \delta$) is sufficiently small (large). Note that the critical $\theta + \delta$ above which no waiting is optimal is more than twice as large as the critical value below which unconditional waiting is optimal.

4.5. Interior solutions and comparative statics

In contrast to these non-interior solutions, an interior solution to Eq. (26) may exist when $0 < R < 1$. To rule out inessential complications, a fourth assumption (which is satisfied in the normal and triangular cases) is imposed. This assumption is $H(\infty, 0) = 0$, which states that the limit of the monotonically decreasing H function as u increases without bound is zero. Under this assumption, an interior solution for u is

[12] It is easily seen that satisfaction of Eq. (21) carries no implication regarding satisfaction of Eq. (28), which thus constitutes an independent condition.

[13] When $\delta + u$ is outside the support of the density but $-\delta + u$ is inside it, H equals zero. When both points are outside the support, H is undefined but is set at zero for consistency.

[14] It can be shown that satisfaction of Eq. (21) carries no implication regarding satisfaction of Eq. (31). In addition, while satisfaction of Eq. (31) implies satisfaction of Eq. (28), the reverse is not true. Thus, Eq. (31) imposes a further condition beyond the maintained assumptions in Eqs. (21) and (28).

[15] It can be shown that satisfaction of Eq. (28) carries no implication regarding satisfaction of Eq. (32). In addition, although satisfaction of Eq. (32) implies satisfaction of Eq. (21), the reverse is not true. Thus, like Eq. (31), Eq. (32) imposes a further condition beyond the maintained assumptions in Eqs. (21) and (28).

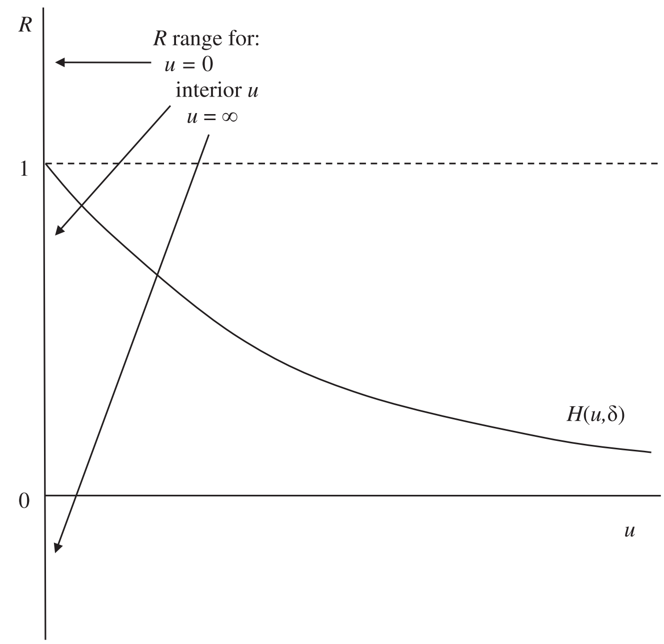

Fig. 5. First-order condition.

guaranteed to exist since $H(u, \delta)$ starts at 1 when $u = 0$ and decreases to zero as u increases without bound. Therefore, H must equal R at some interior u when $0 < R < 1$. This conclusion, along with the previous results for noninterior solutions, is illustrated in Fig. 5. The figure graphs the H function, showing how it lies between zero and 1 for $u \geq 0$ and thus cannot yield an interior solution when R is outside this interval.

Comparative-static analysis showing the effect of individual parameters on u can be carried out. The analysis relies on the assumption that $H(u, \delta)$ is decreasing in u, which implies that parameter changes that raise R (but do not directly affect H) serve to reduce u.

Inspection of Eq. (27) shows that $\partial R/\partial c, \partial R/\partial\lambda < 0$ and $\partial R/\partial\theta > 0$ hold, implying

$$\frac{\partial u}{\partial c}, \frac{\partial u}{\partial \lambda} > 0, \quad \frac{\partial u}{\partial \theta} < 0. \tag{33}$$

Therefore, the signal range over which waiting is optimal widens when the investment cost or the length of the future income stream rises or when the base income gain θ from investing in either region falls. Note that the first two effects parallel those in the option model, but that the effect of θ, which was previously ambiguous, is now determinate. The effect on R of a higher ρ (and thus the effect on u) is ambiguous, as in the option model.

A higher δ affects both R and H, and differentiation of Eq. (27) shows that

$$\frac{\partial u}{\partial \delta} = -\frac{\partial H/\partial\delta - \partial R/\partial\delta}{\partial H/\partial u}. \tag{34}$$

The sign of $\partial H/\partial\delta$ is ambiguous, and

$$sign\frac{\partial R}{\partial \delta} = sign[(1-\rho)c - \theta], \tag{35}$$

which is also ambiguous. Although the sign of $\partial u/\partial\delta$ is thus ambiguous, consideration of the normal case provides an answer. Setting H for the case of a normal probability distribution, given by Eq. (30), equal to R and solving for u yields

$$u = -\frac{\sigma^2}{2\delta}\, logR. \tag{36}$$

Note that $logR$ is negative given $R < 1$, making Eq. (36) positive. Differentiation of Eq. (36) shows that $\partial u/\partial\delta$ has the sign of $logR - (\delta/R)(\partial R/\partial\delta)$, which is negative provided that θ is small, making $\partial R/\partial\delta$ in Eq. (35) positive. Under these assumptions, the effect of a higher productive income advantage δ matches that of a higher base income gain θ, narrowing the range of signals over which waiting is optimal.

Intuition would suggest that a greater signal variance should have the opposite effect, widening the signal range over which waiting is optimal. Using Eq. (36), this intuition in confirmed, with differentiation yielding[16]

$$\frac{\partial u}{\partial \sigma^2} > 0. \tag{37}$$

Recall that, while the variance effect was ambiguous in the option model (matching intuition), the variance effect in the signal model captures a different type of impact, which makes its sign determinate. Summarizing yields

Proposition 4. Using the maintained assumptions and focusing on the range of interior solutions in the signal model, a higher investment cost c, income-stream length λ, or signal variance σ^2 (in the normal-distribution case) widens the range of signal values over which waiting to invest is optimal. A higher base income gain θ narrows the range of signal values over which waiting is optimal, and the same effect occurs when the productive income advantage δ increases, assuming normality and that θ is small. The effect of an increase in the discount factor ρ is ambiguous.

Several of the conclusions in Proposition 4 match those in Proposition 1 and again make sense intuitively. When the investment cost rises, incurring it later by waiting becomes more attractive. When the length of the period-2 income stream rises, waiting to observe which region is more productive before investing becomes more desirable. When the productive income advantage rises, the sacrifice from postponing a correct investment-location choice increases, making waiting less attractive. Recall that, in contrast to the option model, where the period-1 productivities of the two regions can be observed in that period but may be stochastically reversed in period 2, the productivities in the signal model are unobservable in period 1 but constant over time. Nevertheless, when δ increases, raising the productivity advantage of the productive region, the effect on the desirability of waiting is in the same direction as in the option model provided that that the signal distribution is normal and θ is small, requirements that reflect the different structures of the models. However, unlike in the option model, where the base income gain θ has an ambiguous effect on the desirability of waiting, an increase in that gain (like an increase in δ) makes waiting less desirable, again reflecting the different structures of the models. Note that, in contrast to the option model, where the pathways by which θ and δ affect the desirability of waiting are fairly transparent, the pathways in the signal model are more

[16] This conclusion also holds when u has a uniform distribution. In the uniform case, $f(x) = 1/\tau$ for $x \in [-\tau/2, \tau/2]$ and zero elsewhere (recall from Eq. (10) that x is the signal difference). Then, assuming $\delta < \tau/2$, $H(u, \delta) = 1$ for $u \in [\delta - \tau/2, -\delta + \tau/2]$, $H(u, \delta) = 0$ for $u \in (\tau/2 - \delta, \tau/2 + \delta]$, $H(u, \delta) = \infty$ for $u \in (-\tau/2 - \delta, -\tau/2 + \delta]$ and is undefined elsewhere. Therefore, the optimal u is zero for $R > 1$, infinite for $R \leq 0$, lies anywhere in the interval $[-\tau/2 + \delta, \tau/2 - \delta]$ for $R = 1$, and equals $\tau/2 - \delta$ for $0 < R < 1$. In the latter case, note that u is increasing in the variance of the uniform distribution, which rises with τ.

opaque, making it difficult to fully explain the different θ effects on waiting or the need for auxiliary assumptions to generate a determinate δ effect.[17]

4.6. Signal enhancement by local governments

A natural question is how the model would change if the local government in a region could send its own productivity signal (possibly based on superior information) that could influence the investment choice of the super-regional government. Suppose that the local governments send signals of q_a and q_b that augment nature's signal in an additive fashion, and that the costs of sending the signals are kq_a and kq_b, where $k > 0$. Focusing on region a, z in Eq. (18) is then replaced by $v_a - v_b + q_a - q_b$, and modifying Eq. (19), region a is chosen when $x > (1-2P_a)\delta + q_b - q_a + \bar{z}$.

Let α_a denote the prior probability of region a's government that its region is productive. Then, with the income gain being zero if the investment is not carried out in region a, the expected gain from the local government's viewpoint is

$$\Gamma_a \equiv \alpha_a[1-F(-\delta+q_b-q_a+\bar{z})](\theta+\delta) + (1-\alpha_a)[1-F(\delta+q_b-q_a+\bar{z})]\theta - kq_a, \tag{38}$$

using the original variable $\bar{z}$ instead of u. An analogous expression applies to region b.

It is not clear how the standard signaling analysis could be applied to this model, given the difference between current structure and the usual signaling context. However, one limited conclusion can be reached under atypical assumptions. Suppose that the local governments are leaders with respect to the super-regional government but Cournot competitors with one another. In other words, each local government anticipates the response of the super-regional government's u choice to a change in its own q, while treating the other local government's q as parametric. Under these assumptions, it is easy to see that $\partial\bar{z}/\partial q_a = 1$ using Eq. (29), which would be written as $-R + H(\bar{z}+q_b-q_a, \delta) = 0$ in the presence of government signals (with $\bar{z}$ replacing u). Since the first H argument must be constant, it follows that $\partial\bar{z}/\partial q_a = 1$ and $\partial\bar{z}/\partial q_b = -1$. As a result, Eq. (38) implies that $\partial\Gamma_a/\partial q_a = -k < 0$ holds and thus that $q_a = 0$ is optimal. With the same conclusion holding for region b, neither local government finds it optimal to send a signal. Because government signals are fully offset in the choice of $\bar{z}$, it is not worthwhile to incur the cost of sending them.[18]

Thus, adding local government signaling to the "nature's signal" model has no effect given that signals are not sent. Since this conclusion rests on atypical assumptions, however, further work that attempts to wed the current model to a standard signaling framework would be useful, possibly being a subject for future research. Generally, a more complete model would presumably show that signaling is in the interest of local governments as they try to attract investment, with the signals perhaps neutralizing one another, with little effect on the final investment decision.

5. Conclusion

This paper has analyzed an irreversible "where-and-when" investment decision, in which a government must decide not only when to invest in income-increasing infrastructure but also where to make the investment, doing so under imperfect observability of the investment gains. The two models considered in the paper differ in the source of the imperfection. In the signal model, the imperfection comes from initially imperfect observability of the income gains from the investment, while in the option model, it comes from the stochastic nature of the income gains in the second period. In addition to providing the first treatment of this type of problem, the analysis shows that the influences of underlying parameters on the waiting decision are similar in the two models. Waiting to invest is more likely when the investment cost is high or the income stream beyond the initial period is long, and it is less likely when the income-gain differential between the productive and unproductive regions is large. Greater uncertainty makes waiting more likely when it comes in the form of a larger signal variance (with actual returns being nonstochastic). But if the greater uncertainty comes from a higher variance in the investment gains themselves (in period 2 of the option model), then the effect on waiting is ambiguous, reflecting the availability of two investment choices in period 2 rather than a single choice. However, a greater covariance of returns between the two choices makes waiting less likely.

Although the paper attempts to incorporate local-government signaling in a highly restricted fashion, recasting the signal model in the tradition of the standard signaling framework remains a (possibly challenging) task for future research. Among other extensions of the analysis, a simple one would allow the investment cost c to be rising over time. For example, urban land prices may be rising due to exogenous growth, making the investment more expensive to undertake in period 2 than in period 1. This added feature would reduce the benefit from waiting, making a period-1 investment more likely.[19] A more demanding extension would be to relax the assumption that the investment is always worth undertaking. In the option model, for example, the worst period-2 realizations of the random ϵ variables could be small enough to make a no-investment decision optimal after waiting, making the model match the standard option framework more closely. Another extension, leading to more fundamental changes in the analysis, would allow two investments to be undertaken, rather than a single one. However, in order to distinguish this approach from two separable investment problems, the required outlay should be more than double the cost of a single investment (say, due to an increasing marginal cost of public funds). Then, making a single investment could still be optimal, and in this case, the question would again be where to make it. Finally, as mentioned in the introduction, the type of model analyzed in the paper can be applied to other problems, such as the competing technology choices analyzed by Dixit (1993) and Décamps et al. (2006) in frameworks that are related to the current one, but differ substantially in their details. Another such application would be public investments targeted to one of two different populations (say, young versus old, immigrant versus nonimmigrant), where observability of the benefits may be imperfect.

To summarize, the paper's main contribution has been to draw attention to "where-and-when" investment decisions, which have received virtually no treatment in the literature. In doing so, the paper carries a lesson for policymakers. By demonstrating the potential

[17] It is also interesting to ask whether, starting at an interior solution, divergence in the values of the parameters c, λ, θ, and δ is capable of pushing the solution to one of the non-interior cases (where $u = 0$ or infinity). Assuming $\rho\lambda < 1$, a zero solution for u ($R \geq 1$) is ensured when the investment cost c is sufficiently small, given Eq. (32), and an infinite u becomes optimal ($R \leq 0$) when c is sufficiently large, given Eq. (31). But a zero u need not become optimal when income-stream length λ approaches its lower bound of 1 (see Eq. (32)), and an infinite u need not become optimal as λ increases since λ does not appear in Eq. (31). A zero value of the productive income advantage δ need not make an infinite u optimal (see Eq. (31)), but (provided $\rho\lambda < 1$) increasing δ eventually makes $u = 0$ optimal, given Eq. (32) (the same conclusions apply to the base income gain θ). Since σ^2 plays no role in Eq. (31) or (32), changes in its value cannot produce satisfaction of one of these inequalities. The upshot of this discussion is that, in only a few cases are extreme values of the parameters capable of pushing an interior u solution to either zero or infinity.

[18] It is easy to see that the same conclusion holds with corner solutions (when $R > 1$ or $R < 0$).

[19] In the option model, for example, it can be shown that, with period-specific costs of c_1 and c_2, the $(1-\rho)c$ term in Eq. (17) is replaced $c_1 - \rho c_2$, so that an increase in c_2 with c_1 held fixed makes waiting less desirable while and increase in c_1 with c_2 held fixed has the opposite effect.

benefit of waiting, the analysis highlights the possible downside from precipitous infrastructure-investment decisions. Before deciding where to invest in infrastructure, policymakers should seriously consider whether adequate information has been accumulated about the available options.

Appendix A

This appendix shows that the approach to analysis of the signal model used in the text, which relies on critical values for z, is equivalent to an approach that proceeds from first principles. To carry out this approach, let $A(z)$ and $B(z)$ denote the probabilities that the investment is made in regions a and b in period 1, respectively, and let $C(z)$ denote the probability that the investment involves waiting, being made in period 2. Each of these probabilities is conditional on the signal difference z, and they must satisfy $A(z)+B(z)+C(z)=1$ as well as $0\le A(z)\le 1$, $0\le B(z)\le 1$, and $0\le C(z)\le 1$. The probabilities will be chosen optimally, eventually taking values of either 0 or 1. Recalling that $f(z\pm\delta)$ gives the density of z when $P_a=0,1$, the objective function, equal to the expected income gain from the investment, can be written as

$$\Phi = \frac{1}{2}\int\begin{bmatrix} G_a^1\cdot A(z)\cdot f(z-\delta) \\ +G_a^0\cdot A(z)\cdot f(z+\delta) \\ +G_b^1\cdot B(z)\cdot f(z-\delta) \\ +G_b^0\cdot B(z)\cdot f(z+\delta) \\ +G_w\cdot C(z)\cdot f(z-\delta) \\ +G_w\cdot C(z)\cdot f(z+\delta)\end{bmatrix}dz \equiv \frac{1}{2}\int\phi(z)dz, \quad (a1)$$

where $\phi(z)$ denotes the integrand in $(a1)$.

The government's problem is to maximize Φ subject to the previous constraints, and pointwise optimization with respect to $A(z)$, $B(z)$ and $C(z)$ can be use for each z. Note that since the objective function and constraints are linear in $A(z)$, $B(z)$ and $C(z)$, the solutions must lie at the borders of the set defined by the constraints, yielding solutions of 0 or 1, as noted above.

To simplify the analysis, the first constraint is used to replace $C(z)$ by $1-A(z)-B(z)$. So, for each z, the point-wise problem is to maximize the following expression subject to the constraints $A(z)+B(z)\le 1$, $0\le A(z)\le 1$, and $0\le B(z)\le 1$:

$$\phi(z)\equiv\phi_0(z)+\phi_A(z)A(z)+\phi_B(z)B(z), \quad (a2)$$

where $\phi_0(z)$ is independent of $A(z)$ and $B(z)$ while

$$\phi_A(z)\equiv\frac{d\phi(z)}{dA(z)} = \frac{1}{2}\left[\left(G_a^1-G_w\right)f(z-\delta)+\left(G_a^0-G_w\right)f(z+\delta)\right] \quad (a3)$$

$$\phi_B(z)\equiv\frac{d\phi(z)}{dB(z)} = \frac{1}{2}\left[\left(G_b^1-G_w\right)f(z-\delta)+\left(G_b^0-G_w\right)f(z+\delta)\right]. \quad (a4)$$

The solution of this constrained linear optimization problem is

$$(A(z),B(z)) = \begin{cases}(0,0) & \text{if } \phi_A(z)<0 \text{ and } \phi_B(z)<0 \\ (1,0) & \text{if } \phi_A(z)\ge 0 \text{ and } \phi_A(z)\ge\phi_B(z) \\ (0,1) & \text{if } \phi_B(z)\ge 0 \text{ and } \phi_B(z)>\phi_A(z)\end{cases}. \quad (a5)$$

Using Eq. (12),

$$\phi_A(z)=\frac{1}{2}f(z-\delta)\{[\theta+\delta-c(1-\rho)]+[\theta-\lambda\delta\rho-c(1-\rho)]H(z)\} \quad (a6)$$

$$\phi_B(z)=\frac{1}{2}f(z-\delta)\{[\theta-\lambda\delta\rho-c(1-\rho)]+[\theta+\delta-c(1-\rho)]H(z)\}, \quad (a7)$$

where

$$H(z)=\frac{f(z+\delta)}{f(z-\delta)} \quad (a8)$$

is a decreasing function on the interval $[-\delta,\delta]$ as before and where $H(0)=1$. As before, the assumption in Eq. (28) is imposed and R is defined by Eq. (27). Then, using Eqs. (a6) and (a7),

$$\begin{aligned}&\phi_A(z)\ge(<)\,0 \text{ as } R\ge(<)\,H(z)\\ &\phi_B(z)\ge(<)\,0 \text{ as } RH(z)\ge(<)\,1\\ &\phi_A(z)\ge(<)\,\phi_B(z) \text{ as } 1\ge(<)\,H(z).\end{aligned} \quad (a9)$$

Combining Eqs. (a9) and (a5) then yields

$$(A(z),B(z)) = \begin{cases}(0,0) & \text{if } R<H(z) \text{ and } RH(z)<1 \\ (1,0) & \text{if } R\ge H(z) \text{ and } 1\ge H(z) \\ (0,1) & \text{if } RH(z)\ge 1 \text{ and } 1<H(z).\end{cases} \quad (a10)$$

Defining $\underline{z}$ and $\overline{z}$ such that

$$H(\underline{z}) = R \text{ and } H(\overline{z}) = 1/R \quad (a11)$$

and using Eq. (a9), the following decision rule emerges:

$$(A(z),B(z)) = \begin{cases}(0,0) & \text{if } (R<0) \text{ or } (0<R<1 \text{ and } \underline{z}<z<\overline{z}) \\ (1,0) & \text{if } (0<R<1 \text{ and } z>\overline{z}) \text{ or } (R\ge 1 \text{ and } z>0) \\ (0,1) & \text{if } (0<R<1 \text{ and } z<\underline{z}) \text{ or } (R\ge 1 \text{ and } z<0)).\end{cases} \quad (a12)$$

After imposing symmetry, so that $\overline{z}=u$ and $\underline{z}=-u$, it can be seen that Eq. (a12) is the same as the decision rule developed in Section 4.

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