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Diffusion, Costs and Learning in the Development of International Gas Transmission Lines

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Contents

Abstract

Increasing demand for clean fuels in Eurasia heightens the importance of assessing the prospects for available supplies of natural gas. Eurasia has proposed more than 60,000 kilometers of international gas transmission projects over the next 20 years. Accurately predicting the total costs of gas pipeline development is a challenge. Unfortunately, historical data on Eurasia that could inform an accurate cost assessment are limited. This paper assesses the impact of technological learning and other factors on the costs of gas pipeline development by drawing upon experience with pipeline development in the United States. Construction cost data on onshore pipeline development in the United States during the period 1985 to 1998 did not demonstrate that technological learning led to cost reduction. This was due to the relatively mature infrastructure and the bigger effects of other factors such as types of gas pipeline, economies of scale, and population density. For offshore pipelines, the learning rate was around 24 percent, which was related to the existence of the similar geographical features for offshore pipelines and the relatively immature infrastructure.

Findings in this paper suggest that, in Asia, where pipeline infrastructure is immature, significant technological learning effects can be expected if multiple pipelines are built in similar geological terrain. On the other hand, in Europe where pipeline infrastructure is relatively mature, similar to U.S. onshore pipeline development, learning effects are likely to be small. Other factors such as types of gas pipeline, economies of scale, and population density also will affect costs in both Asia and Europe.

Key words: gas pipeline, costs, technological learning.

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Diffusion, Costs, and Learning in the Development of International Gas Transmission Lines

Jimin Zhao

1 INTRODUCTION

Natural gas could be the second most important and the fastest growing primary energy source in the world over the next 25 years (EIA, 1998a). By 2020, the world's consumption of natural gas is expected to equal to 4,870 billion cubic meters (bcm), more than double the 1995 level (EIA, 1998a). A study done by the International Institute for Applied System Analysis and the World Energy Council (IIASA-WEC) suggests that natural gas demand in Eurasia could exceed 5,300 bcm in the year 2050, if natural gas is used as the transitional clean fuel for the shift to a post-fossil energy system (Nakićenović *et al*., 1998). In the IIASA-WEC study, Eurasia includes Pacific OECD (PAO), Centrally planned Asia and China (CPA), South Asia (SAS), Other Pacific Asia (PAS), newly independent states of the former Soviet Union (FSU), Central and Eastern Europe (EEU), and Western Europe (WEU). The high demand for natural gas is largely attributable to the availability of substantial gas resources, increasingly stringent environmental requirements, and the ecological advantages of gas over other fuels. Natural gas in particular will be a key factor in efforts to implement the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC). The Kyoto Protocol requires certain countries to reduce their overall emissions of six greenhouse gases by at least five percent below 1990 levels between 2008 and 2010.

The geographic distribution of gas supply and demand is however not balanced. The nuclei of supplies are found in Russia, the Asian Republics of the Former Soviet Union, and the Middle East, while the fastest growing demand for gas is in the Asian Pacific region. Western Europe exhibits the most rapid growth in natural gas consumption among industrialized countries (EIA, 1998a). Gas consumption in Western Europe is expected to rise from 368 bcm in 1995 to more than 900 bcm in 2020, while developing countries in Asia are predicted to increase their gas consumption by a factor of six in the same period (EIA, 1998a). The world energy sector thus faces a major challenge over the coming decades in dealing with the growing dependence on imported gas. Natural gas transportation through pipelines from production areas to consumer markets therefore will be critical in the development of the world's gas industry.

The characteristics of natural gas transportation—high capital cost, inflexibility, and specific technical requirements—make gas transportation more expensive than that of oil (IEA, 1994). Klaassen *et al.* (1999) concluded that the economics of the infrastructure availability is one of the main limiting factors for exporting gas in Eurasia. The US Energy Information Administration (EIA, 1998b) also indicates that a key issue for gas industry development is what kind of infrastructure changes will be required to meet this demand and what the costs—both financial and environmental—of expanding the pipeline network will be.

The IIASA-WEC study *Global Energy Perspectives* (Nakićenović *et al.*, 1998) thus proposes an analysis of an interconnected Eurasian gas infrastructure grid, emphasizing impacts of technology improvements on investment cost from a long-term and systematic perspective. This paper responds to this proposal by completing two tasks: (1) reviews and analyzes current and proposed gas pipelines in Eurasia and their spatial distribution, and (2) examines the impact of technological learning on the costs of gas pipeline construction. As long-term cost data is only available from the United States, I use the United States data to study the effect of technological learning. I also use data from Eurasia, where available, to complement the study's results.

This paper is composed of five sections. Section 2 reviews the existing and planned transnational gas pipelines in Eurasia. Section 3 examines the cost development for gas pipelines and analyzes the effects of technological learning on cost development. Section 4 evaluates the effects of other factors (such as economies of scale and type of pipeline). The concluding section proposes policy implications for gas pipeline development in Eurasia.

2 DIFFUSION OF TRANSNATIONAL GAS PIPELINES IN EURASIA

Currently, Eurasia has two regional gas markets: the European and the Asian Pacific market. The European market ranges from North Africa through Europe up to West Siberia, while the Asian Pacific market consists of CPA, PAS, SAS, and PAO. This section reviews and discusses the diffusion of gas development in these two regions and studies their different features in gas development.

2.1 EXISTING GAS PIPELINES

Europe

The FSU is the primary gas supplier to Europe. Consisting of 39 percent of total proven natural gas reserves worldwide as of 1998, the FSU is well endowed with gas (BP, 1999). Gas production in FSU supplied 46 percent of primary energy use in Europe, making the FSU the largest source of gas trade in the world (CEDIGAZ, 1995). Four countries—Russia, Turkmenistan, Uzbekistan, and Kazakhstan—own the bulk of the gas potential. In 1998, production in these four countries amounted to 580 bcm, accounting for 28 percent of the world's gas production (BP, 1999).

Currently most of the gas delivered outside the FSU flows through the Russian and Ukrainian networks. Eastern European countries are heavily dependent on the FSU to meet their currently increasing natural gas demand. Gazprom, Russia's monopoly producer and supplier of natural gas, is the world's largest gas company and gas supplier. Gazprom controls 148,800-km network of high-pressure pipelines.[1]

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[1] See Gazprom website http://www.gazprom.ru/html/english/about/transportation.html.

The 482-mile gas pipeline from Saratov to Moscow constructed in 1946 has a capacity of 500 million cubic meters (mcm) annually. It is regarded as the starting point of the modern Russian and European gas industry (PE, 1996). In the 1990s, Russia's gas was transported primarily to 17 European countries (Miyamoto, 1997:47). Turkmenistan is the second largest supplier, mainly exporting to other FSU countries (Klaassen *et al*., 1999). The total gas pipeline length in the FSU was 223,500 km in 1993. The eight Central Asian and Caucasian republics have a total of about 37,000 km of gas transmission pipelines amounting to 17-18 percent of the total gas transmission grid of the FSU (Skagen, 1997:35).

The European gas market began to develop 30 years ago and has experienced a tremendous upswing in natural gas consumption. For example, in 1993, gas accounted for 18 percent of primary energy needs in Central Europe and 21 percent in Western Europe (CEDIGAZ, 1995:89). Power generation is the major demand sector for gas in Europe, and is responsible for 15 percent of total gas consumption (EIA, 1998a). In addition to power generation, environmental concerns and the flexible use of natural gas play an important role in contributing to the steady demand and growth.

In Western Europe, natural gas supply was initially only available in small local regions. It then gradually reached a national scale in some countries in the 1950s (CEDIGAZ, 1995 and Stern, 1998). The discovery of the Groningen field in the Netherlands in the early 1960s—which initially delivered gas to the Netherlands, Belgium, Germany, France, and later to Italy—marked the beginning of the development of international pipeline networks. Since then, pipeline deliveries have been growing at an average rate of 10.8 percent per year in Western Europe (CEDIGAZ, 1995:22).

The construction of trans-European pipelines proceeded rapidly between 1970 and 1990 after the first oil crisis. The early 1970s was a period of strong growth of pipelines that transported Soviet gas into Western and Southeastern Europe (Transgas). In the mid-1970s, Norway built its first offshore pipelines from Norway through Frigg and Norpipe systems to supply the UK and other Continental European buyers; this was the first international movement of North Sea gas to Europe. In 1980, another major pipeline (Orenburg/Soyus) from Russia to central and east European countries was built. At the same time, the Megal line from Russia through Germany, France, and Austria was completed to transport Soviet gas to Western Europe. The Trans-Mediterranean pipeline system from Algeria to Italy, completed in 1983, provided the capacity for natural gas piping from Algeria to Western Europe (CEDIGAZ, 1995).

During the 1980s, the laying of long-distance pipelines increased at the annual average rate of 3.2 percent per year (CEDIGAZ, 1995). Throughout the 1980s and 1990s, the major gas pipelines were built for (1) Soviet gas to western and eastern Europe through the Urengoy (1984) and Yambur/Progress (1988), (2) Norwegian gas through the Statpipe (1986) Zeepipe I (1993) and Europipe (1995), and (3) Algerian gas through the Bazoduc Maghreb-Europe (GME) line (1996) to Spain.

In the mid-1990s, pipelines were built between Britain and both parts of Ireland, and between Britain and Continental Europe. The Balkan systems linking Bulgaria to Macedonia and then to Greece were completed in 1995 and 1996. Currently, the European gas market is the world's most complex gas market in terms of the number of international participants. More than 47 percent of the gas consumed in Western Europe crosses at least two borders before reaching the final destination (Energy Charter, 1998). Four nations (Algeria, the Netherlands, Norway, and Russia) deliver 96.4 percent of Europe's gas supply across the sea and many borders (BP, 1999). Table 1 lists the major existing trans-national gas pipelines in Europe. Gas pipelines are over 10,000 kilometers with diameters from 24 to 48 inches. Available data shows that the capacities of these gas pipelines are over 160 bcm/year.

Asian Pacific Region

Even though gas production doubled in the last decade, natural gas is a relatively new source of energy in Asia, averaging around 12 percent of total energy consumption (BP, 1999). Shipping liquefied natural gas (LNG) so far has been the main means of gas transportation. Presently, Indonesia, Malaysia, and Brunei rank as the world's biggest exporters of LNG, while Japan is the major importer of natural gas produced in the Asian Pacific rim countries. Out of 113 bcm of global LNG trade in 1998, Japan, South Korea, and Taiwan imported 85 bcm, accounting for 75 percent of the world total (BP, 1999). As of 1999, Malaysia had been the only country in the region that initiated international gas trade by pipeline. In comparison, pipelines are confined to domestic regions in countries such as China and India. Geo-politics, better market alternatives (such as LNG), and financing are regarded as factors that hinder the development of gas trade by pipelines in Asia.

With proven reserves amounting to 2,310 bcm as of 1998, Malaysia is the second-largest gas producer in the area after Indonesia (BP, 1999). The majority of gas production is exported as LNG, with Japan as the main LNG customer. In 1992, Malaysia began to export gas using a high-pressure pipeline to Singapore, delivering 1.5 bcm per year of gas through a 70-km long and 600-mm in diameter pipeline (CEDIGAZ, 1995). Ideally located between gas-rich Malaysia and Indonesia, Singapore has established a program to substitute gas for petroleum in power generation.

Most gas pipelines in Asia are confined to domestic markets. Countries like China, India, Indonesia, Malaysia, and Pakistan have gas pipelines in place within their domestic regions. By 1999, China had neither exported nor imported gas but it had a limited number of natural gas pipelines domestically (Ellsworth and Wang, 1999). China's large gas reserves are located in areas such as the Sichuan basin and Shanxi Province. Before the 1990s, most pipelines in China were regionally segmented by connecting producing fields to nearby consumers. The first pipeline was built in Sichuan province in 1958, followed by two trunk lines (a southern section in 1966 and a northern section in 1988) that form a Sichuan trunk line, with a total length of 5,000 km. Since 1990, China has begun to connect western gas to eastern gas-demand regions. The second longest gas pipeline in China, where consumers are not near the producing fields, is the 860-km pipeline that transmits gas from the Ordos basin to Beijing (Lan and Paik, 1998).

The world's second longest and Asia's longest offshore gas pipeline is the Ya 13-1 Hong Kong pipeline. It transfers 4 bcm per year of gas from China's Yinggehai basin to a power plant in Hong Kong over a distance of 778 km. The development cost was US$1.2 billion. A 91-km long and 355-mm diameter wide offshore pipeline was built to link the Ya 13-1 gas field to Sanya city of Hainan province (OGJ, 1999a). By the end of

1996, China had 8,910 km of pipelines, capable of moving 20 bcm of natural gas annually, however, most gas pipelines utilize less than 50 percent of their capacities (Lan and Paik, 1998). One of reasons for the limited capacity is the lack of storage facilities and consumers. The use of gas up to now has been mostly limited to fertilizer production.

2.2 PLANNED AND PROPOSED GAS PIPELINE PROJECTS[2]

Europe

Natural gas consumption is expected to continue to increase in Europe, reaching 410 million tons oil equivalence (Mtoe) in 2010 and 435 Mtoe in 2020 (Eurogas, 1999). Even though it is endowed with a dense, integrated gas transmission network, Europe's current pipeline capacity cannot meet this future demand. Gas pipelines from gas-rich Russia, Turkmenistan, and the Middle East are proposed (see Table 2). Most of these projects are large gas pipelines with over 40 inches (1,016 mm) in diameter and over 600 km in length. Some of these projects are already under construction. Taking into account the pipelines that are both under construction and planned, a total of nearly 23,000 km of large-diameter trans-national pipelines could be laid, and the associated investments would amount to over US$70 billion in terms of 1995 prices.

The Yamal-Europe project will open a new export corridor between Russia and Europe. The discovery of large gas reserves on the Yamal Peninsula is the basis for Russia's gas export to Eastern (Poland) and Western Europe. The project consists of three parallel lines that will extend over 5,000-km westward from Yamal, running across Russia, Belarus, and Poland to the German border (PE, 1996:44).[3] The total capital cost is about 25 to 30 billion US dollars.

Turkmenistan's export plans could provide new routes for gas export to Europe. Turkmenistan, one of the largest gas producing countries in the world, besides exporting to its current markets (Trans-Caucasian republics, Kazakhstan, Ukraine, and Russia), plans to build new gas export outlets to areas such as Pakistan, India, Western Europe, China, Japan, and Korea. In addition to building new gas pipelines, Russian and other FSU countries have to reconstruct or reinforce their existing gas pipelines and build gas storage facilities. Additional gas pipelines from Norway to other European countries are proposed, and the United Kingdom will become a new gas supplier to Europe.

[2] The projects listed in this section were proposed before 1999.
[3] This line was finished at the beginning of 2000.

Table 1 Major Existing Trans-national Gas Pipelines in Europe

Name	Source	Destination	Diameter (inch)	Length (km)	Capacity (Bcm/yr.)	Capital cost (Billion US$ original)	Capital cost (Billion US$ of 1995)	Completed year	Reference
Transgas	Russia	Europe	32,36,48	3,763	79			1972	CEDIGAZ (1998)
TAG I and II	Russia	Austria/Italy	34,36, 38,42	1,411	17			1974	CEDIGAZ (1998)
Norpipe	Norway	Germany	36	440				1977	Stern (1998)
MEGAL	Russia	Germany/ France	36,48	1,070	22			1980	CEDIGAZ (1998)
	Russia	Finland			2.9			<1984	Nakićenović and Strubegger (1984)
Transmed	Algeria	Italy/Slovinia/Tunisia		1,955	16			1984	CEDIGAZ (1998)
STEGAL	Russia	Germany/ France	32-36	316	8			1992	CEDIGAZ (1998)
Zeepipe I	Norway	Belgium		862	12			1993	CEDIGAZ (1995)
Transmed	Algeria	Italy/Slo/Tun		2,100	9			1994	CEDIGAZ (1998)
Europipe I	Norway	Germany	40	630	13	1.9	1.9	1995	Stern (1998), CEDIGAZ (1995)
Ringpipeline	Bulgaria	Macedonia		165	0.8	0.06	0.1	1995	CEDIGAZ (1995), Stern (1998)
Maghreb	Algeria	Spain/ Portland		1,861	9.7	1.9	1.8	1996	Morvan (1996), CEDIGAZ (1998)
HAG	Austria	Hungary	28	120	4.5	0.1	0.1	1996	CEDIGAZ (1995/1998)
	Bulgaria	Greece	24-36	870	7	1.5	1.5	1996	CEDIGAZ (1995/1998)
NETRA	Germany	Italy	48	291	17	0.65	0.7	1996	CEDIGAZ (1995)
	Scotland	N-Ireland	24	135	2	0.15	0.2	1996	CEDIGAZ (1995)
Interconnector	UK	Belgium	40	620	20	0.65	0.7	1998	CEDIGAZ (1995/1998)
Norfrapipe	Norway	France	40,42	860	16	1.2	1.1	1998	Stern (1998)
Total			24-48	10,785	>160				

Table 2 Planned and Proposed Gas Pipeline Projects in Europe

Source	Destination	Length (km)	Diameter (inch)	Capacity (bcm/year)	Capital cost (billion US$)	Capital cost (billion US$ of 1995)	Type	Reference
Yamal—Russia	West-Polish border	4,170	56	83	27.0	27	off	Energy Charter (1998) CEDIGAZ (1995)
Shatlyk-Turkmenistan	Erzerum-Turkey	2,700		31	2.8	3	on	OGJ (1999b)
Turkmenistan	Turkey-border	1,260		10	2.5	3	on	CEDIGAZ (1995)
Russia (Bluestream)	Turkey	400		17	2.2	2	off	OGJ (1999b)
Libya	Italy	550		9	1.3	1	off	CEDIGAZ (1995)
Syria	Turkey	200		2			on	CEDIGAZ (1995)
Qatar	Europe	4,900	56	30	12.0	12	on	CEDIGAZ (1995)
Iran	Europe	4570	48,56	32	13.0	15	on	CEDIGAZ (1995)
Iran	Armenia	160	20,24	2	0.1	0	off	CEDIGAZ (1995)
Iran	Ukraine	1060		25			on	CEDIGAZ(1995)
North Sea,UK (Polpipe)	Niechorze-Poland	965		8	2.4	2	on	CEDIGAZ (1995)
North Sea,UK (Polpipe)	Niechorze-Poland	235		8	0.6	1	off	CEDIGAZ (1995)
Norway	Germany	620	40	12	1.1	1.1		CEDIGAZ (1995) McMahon (1997)
Norway (Europipe II)	Germany	620	40,42	12	1.9	1.9		CEDIGAZ (1995)
Macedonia	Albania	200	30		0.2	0.2		CEDIGAZ (1995)
Haltenbanken- Norway	North Sea	750	40	13.50	1.9	1.9		CEDIGAZ (1995)
Total		23,360	40-56	>295	>69	>71		

Asian Pacific Region

Pipeline transmission is economically viable if trade volumes are high (Ibrahim, 1995). For many years, when trade volumes were relatively small, Asia has favored LNG shipment as a more direct means of gas transport. With increasing demand, pipelines are cheaper due to economies of scale. In addition, along with the pipeline construction, a varied range of infrastructure and economic development, e.g., road construction and building development, might spring up rapidly (Ibrahim, 1995).

The proposed gas pipelines will transfer gas either from existing gas deposits within regions such as Myanmar, Vietnam, Indonesia, and Malaysia, or from gas fields in Russia or Central Asia. There is gas shortfall in Thailand and the Philippines even though they have discovered more gas reserves. Gas imports via pipelines from Malaysia, Myanmar, and Indonesia to these countries are proposed to make up the shortfall. Singapore has sought to take a further one million cubic meters per day from Malaysia and to diversify supplies via pipeline from Indonesia (CEDIGAZ, 1995). If the Trans-ASEAN pipeline becomes a reality, east Malaysia could be the largest gas supplier in the Asian Pacific region. In addition to obtaining gas within this region, India and Pakistan proposed to import gas from the Middle East, while China, Japan, and Korea planned to transport gas from Russia and Turkmenistan. China not only continued to build domestic gas pipelines to transfer gas from western areas to gas-demand eastern areas, it also proposed international gas pipelines from Russia and Turkmenistan to serve the eastern coastal region of China and possibly extend to Japan and South Korea (Paik and Choi, 1998). In 1997, Unocal announced that Pakistan would be linked to Turkmenistan in a Central Asia Gas Pipeline project. The 1,270-km pipeline would deliver up to 2 bcm per year to Multan of Pakistan (EIA, 1998a).

Table 3 contains detailed information about proposed gas pipeline projects in the Asian Pacific region. In terms of size, the proposed pipelines in the Asian Pacific region are smaller than those in Europe, with diameters of 20 to 40 inches. The total length of the proposed pipelines is more than 38,600 km with the sum of the capacity over 90 bcm per year. Unlike Europe, however, most of these projects are in the proposal stage and some may be delayed or canceled due to the Asian economic crisis and financial constraints. Although three pipelines from Russia or Turkmenistan are proposed, around 15,000 km in length, only the pipeline from Irkutsk through northern China and to South Korea is most likely to materialize (OGJ, 1999a). Based on a prediction of CEDIGAZ (1995:57), natural gas trade by pipeline could account for some 15-20 bcm in Asia in 2010.

Despite an impressive number of gas pipeline projects, LNG is bound to remain the main component of Asian gas supplies in the short to medium-term. The present importers (Japan, South Korea, and Taiwan) have long-term plans for huge capital investment into LNG receiving terminals, while exporters (Indonesia, Malaysia, Australia, and Brunei) will retain their role as LNG exporters. The need to meet the rapid rise in energy demand, combined with the development of gas fields in the region and the construction of the appropriate transportation infrastructure, offer natural gas good opportunities.

Table 3 Planned and Proposed Gas Pipeline Projects in the Asian Pacific Region

Source	Destination	Length (km)	Diameter (inch)	Capacity (bcm/year)	Capital cost (billion US$)	Capital cost (billion US$ of 1995)	Type	Source
Vietnam	Thailand	750		7			on	CEDIGAZ (1995), Finon and Locatelli (1999)
Turkmenistan	China, Japan, S. Korea	7,000		28	12.0	11	on	McMahon (1997), World Reporter (1999)
Irkutsk-Russia	China, Japan or South Korea	4,000		30-35	12-13	12-13	on	OGJ (1999a)
Yakutsk-Russia	China, S-Korea, Japan	3,900		20	22.5	24	on	CEDIGAZ(1995)
Sakhalin-Russia	Niigata-Japan	1,300			2.1	2	off	AEN (1999b)
Dauletabad-Turkmenistan	Lultan-Pakistan	1,271	20	20	2.0	2	on	True (1998)
Daulketabad-Turkmenistan	Multan-Pakistan	1,500			3.5	3	on	AEN (1999a)
Oman	India	1,500	24,40	19	4.0	4	off/on	CEDIGAZ (1995)
Iran	Pakistan	1,600		9	3.8	4	on	CEDIGAZ (1995)
Iran (Bandar Abbas)	India	2,000	40,42	19	8.0	8	on	AEN (1997), CEDIGAZ (1995)
Qatar	Pakistan	1,600	48	25	3.4	3	off	CEDIGAZ (1995)
ASEAN countries	China, Taiwan, Japan, S. Korea	4,300			5.0	5		AEN (1998)
Trans-ASEAN: Malaysia	Philippines, Singapore, Thailand	6,000			10.0	10		CEDIGAZ (1995)
Myanmar	Thailand	720	34-36	5.4	1.0	1.0		Paik and Choi (1997)
Myanmar	Thailand	675	20-22	2				CEDIGAZ (1995)
Indonesia	Singapore	483	28	3.3				AEN (1999b)
Total		38,599	34-40	>188	89.3	89		

2.3 SUMMARY

The European gas market is the world's most complex market in terms of the number of involved international participants. The major means of transportation is gas transmission pipelines. As of 1999, over 1.2 million kilometers of national and transnational gas pipelines exist in Europe, and they are highly interconnected and developed (Eurogas, 1999a). WEU, EEU, and FSU are major consumers, while FSU, WEU (Norway, Netherlands, and United Kingdom) as well as North Africa (Algeria) are major suppliers. In the Asian Pacific gas market as of 1999, the major means of gas transport was through LNG. The major consumers were Japan, South Korea, and Taiwan, while major suppliers were Indonesia and Malaysia. Gas pipelines are rather segmented which are mainly confined to domestic market. Malaysia is the only country in the region that initiated international gas trade by pipelines.

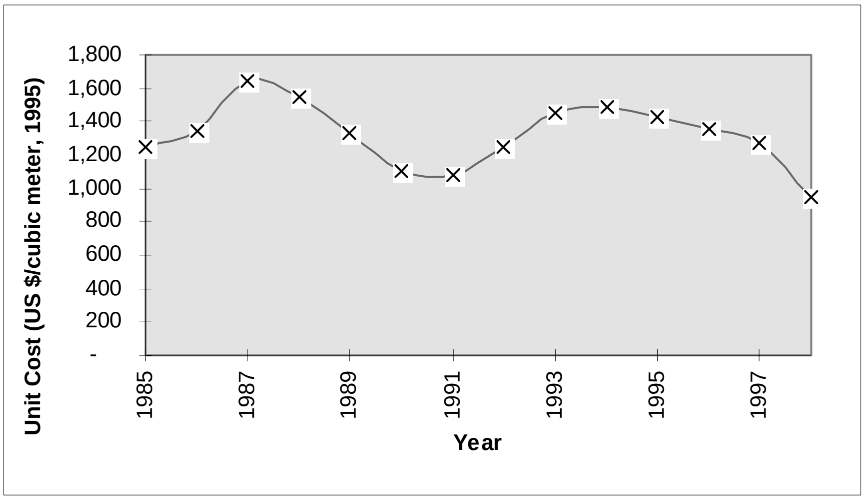
Current pipeline capacities in Eurasia, in particular in Asia, cannot meet the high gas demand in the future. Over the next 20 years, more than 60,000 km of gas transmission pipelines have therefore been proposed for Eurasia, most of which originate from the FSU. Some of the proposed pipeline projects involve large capacity with huge investment. Many projects in Europe are under construction or have a high probability of being constructed. Geo-politics, LNG alternatives, and financing difficulties due to economic crisis, however, may hinder the realization of some proposed gas pipeline projects in the Asia-Pacific region.

3 HISTORICAL COST DEVELOPMENT FOR PIPELINE CONSTRUCTION AND THE EFFECT OF TECHNOLOGICAL LEARNING

3.1 HISTORICAL COST DEVELOPMENT FOR PIPELINE CONSTRUCTION

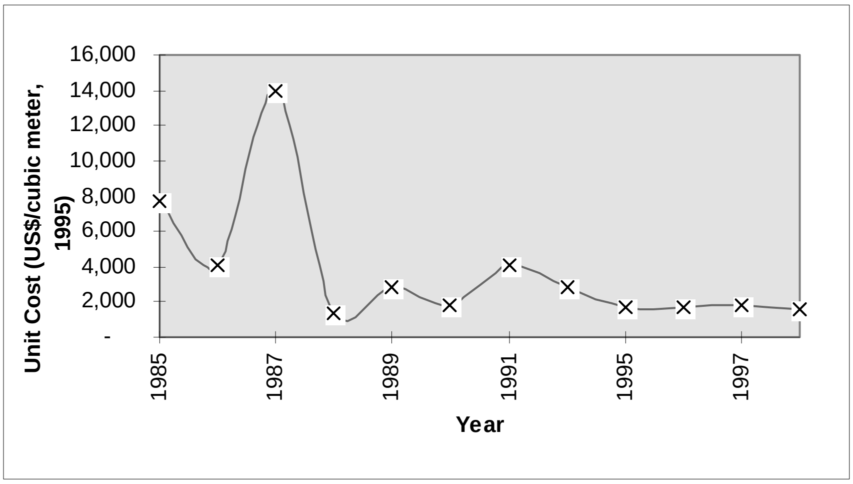
The transmission of natural gas involves the acquisition and delivery of gas through long-distance pipelines. Total transportation costs primarily depend on construction, operation and maintenance costs. The International Energy Agency (IEA, 1994) indicates that gas pipeline projects are characterized by large infrastructure cost and relatively low operating costs. This paper thus focuses on costs for constructing gas pipelines.

The capacity of gas pipelines in this paper is defined as the total volume of a gas pipeline (in cubic meters). The unit cost is referred to as the construction cost per cubic meter of pipeline capacity. The capital cost per pipeline capacity each year for onshore pipelines in the United States fluctuated between 1985 and 1998 (see Figure 1). It underwent cost increases and decreases between 1985 and 1990 and repeated a similar pattern between 1991 and 1998. The unit costs per capacity of offshore pipelines were larger than those of onshore pipelines during the 1985 to 1998 period (see Figure 2). The average unit cost for offshore gas pipelines is US$2,980 per cubic meter, but is US$1,040 for onshore gas pipelines. The average unit cost for offshore pipeline is thus close to three times of that of onshore pipelines; moreover, the variation in its unit cost over time is larger than that of onshore gas pipelines.



Source: True (1985-1998)

Figure 1 Average Unit Costs per Cubic Meter of Pipeline Capacity for Onshore Pipelines: 1985-1998



Source: Truce (1985-1998)

Figure 2 Average Unit Costs per Cubic Meter of Pipeline Capacity for Offshore Pipelines: 1985-1998

There is no historical data available for studying the construction costs for gas pipelines in Europe over time. According to Strubegger and Messner (1986), who study the construction costs of gas pipelines in Europe before the 1970s, capital needs for gas transmission and distribution dropped by only 2 to 3 percent per year. The shift of gas production from the European to the Siberian part of the former Soviet Union, however, resulted in a tripling of gas transportation costs between 1970 and mid-1986. Therefore, it is reasonable to believe that pipeline construction costs for Europe also fluctuated.

In conclusion, the unit capital cost for construction of pipelines fluctuated over time in the U.S. and in Europe. This raises the question of what factors led to these changes. The next section examines in depth whether technological learning (or experience on pipeline construction) affects cost development.

3.2 TECHNOLOGICAL LEARNING AND CONSTRUCTION COST

Learning Curve

The performance and productivity of technologies typically increase as organizations and individuals gain experience from them (e.g., learning by doing). A learning (experience) curve, which describes how unit costs decline with cumulative production, measures this learning phenomenon. Learning depends on the actual accumulation of experience and not just on the passage of time. Learning curves generally are described in the form of a power function where unit costs depend on cumulative experience, usually measured as cumulative output. The function of unit cost is defined as follows:

$y(x)=ax^{-b}$,

where *y* is the unit cost of the *x*th unit, *a* is the cost of the first unit, and *b* (learning index) is a parameter measuring the extent of learning. 2^{-b} is defined as the progress ratio, which means that the cost is reduced to 2^{-b} of the original cost each time the cumulative production is doubled. The learning rate equals $1-2^{-b}$, generally expressed in terms of percentage, that is, percentage of cost reduction for each doubling of capacity.

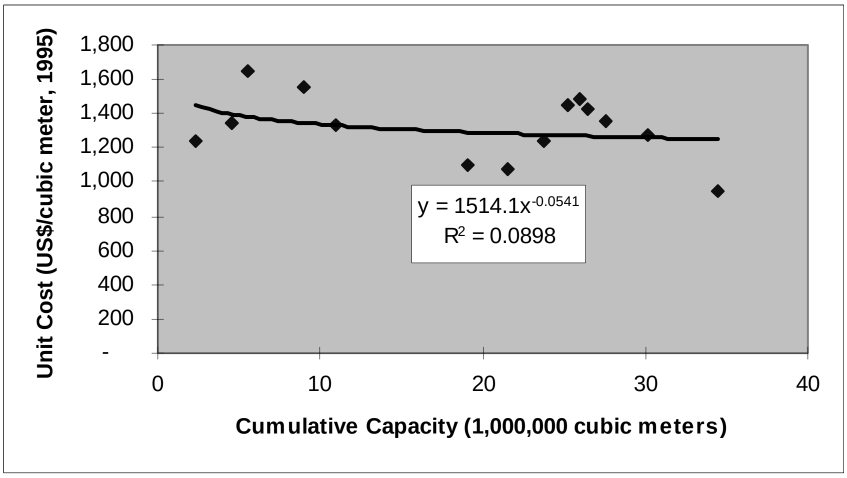
The learning rate changes over time. The unit costs of production decline at a decreasing rate because each doubling requires more production volume, and the potential for cost reductions diminishes as the technology matures. Experience curves can often be divided into two phases—a start-up (or R&D) phase and a steady state (or production) phase (Grübler, 1998). The start-up phase can be connected to intensive R&D programs resulting in steep experience curves and relatively high cost reductions. This phase is followed by a steady state (production or commercialization) phase, where cost reduction per added cumulative output is often lower than in the R&D phase.

Learning can be enhanced through R&D, actual experience (investment), and large-scale production (upscale production units, repetition or mass production, and continuous operation). Learning theory assumes a standardized product that remains largely unchanged over time. However, price can change and product design can change, and costs can increase over time.

Learning in Pipeline Construction

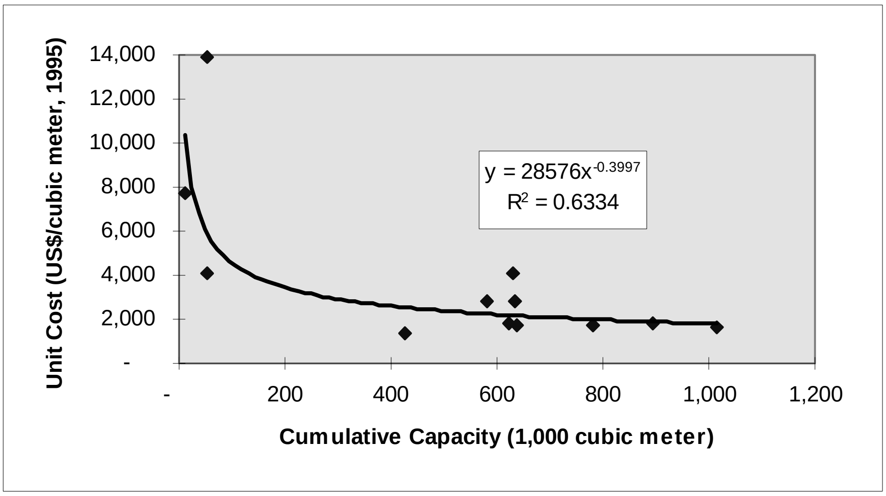
As defined earlier in this paper, the output in pipeline construction is referred to the total volume of a gas pipeline (in cubic meters). The unit cost is the cost of building a pipeline with a capacity of one cubic meter. Due to data availability, this paper examines the learning rate for onshore and offshore pipeline construction of 1985 to 1998 in the United States. The learning curve for onshore pipeline construction in the United States is presented in Figure 3. Unit cost remained more or less stable over time.

There is no obvious cost reduction for the period from 1985 to 1998, even though there are cost reduction phases during this period. There is no clear learning pattern for onshore pipeline construction.



Source: True (1985-1998)

Figure 3 Learning Curve (learning rate 3.7%) for Onshore Pipeline Construction in the US: Costs per m^3 (Pipeline Volume) over Cumulative Pipeline Volume, 1985-1998.

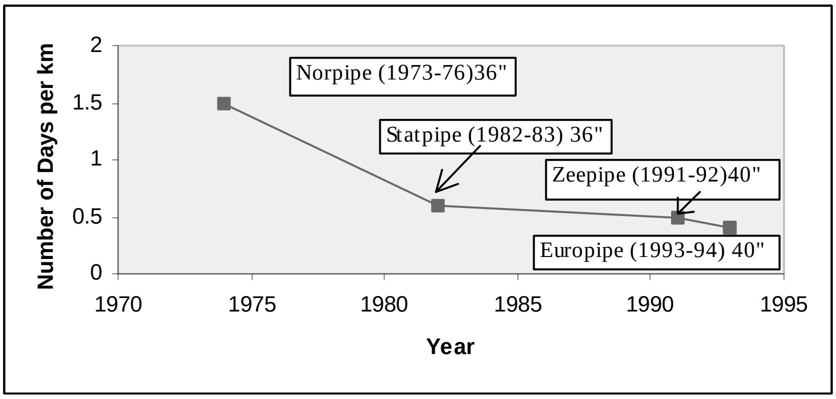


Source: True (1985-1998)

Figure 4 Learning Curve (learning rate 24.2%) for Offshore Pipeline Construction in the US: Costs per m^3 (Pipeline Volume) over Cumulative Pipeline Volume, 1985-1998

Figure 4 shows the learning curve for offshore pipeline construction in the period between 1985 and 1998. There are some extreme points, and the average learning rate for this period is 24 percent. That is, for each doubling of cumulative capacity of pipelines constructed, construction costs are reduced by 24 percent. Note however that the correlation coefficient R-square is only 0.63. The learning curve also shows that the cost reduction occurs mainly at the starting period with small cumulative capacity. Along with the increase in capacity, cost reduction becomes smaller and smaller and the unit cost remains stable.

The change of pipeline installation costs in the North Sea supports the above result in regard to offshore gas pipelines. The cost of installing the NorFra pipeline from the North Sea to France, which was commissioned in 1998, was some 44 percent lower per kilometer than the corresponding cost for Statpipe, which was commissioned in 1985 (Roland, 1998). Evidence from Bauquis (1998) on the evolution of pipe laying rates in the North Sea shows that the number of days required to lay 1 km of pipeline in the building of Norpipe dropped from over 1.5 (1973-1976) to 0.5 for the building of Europipe in 1993 to 1994 (see Figure 5). This suggests the occurrence of learning effects at least for offshore pipelines in similar geological areas.



Source: Bauquis (1998)

Figure 5 North Sea: Evolution of Pipe Laying Rate (Norway), days required to lay one kilometer of pipeline.

The available evidence shows that there were learning effects regarding offshore pipeline construction costs in the United States during the period between 1985 and 1998 and for the gas pipelines built in North Sea. However, no statistically significant learning effect has been found for the construction cost development of onshore gas pipelines for the same period. A plausible explanation for this finding would be that onshore gas pipeline construction has become a mature technology since the United States built it in the 1920s. Learning theory indicates that the longer a technology has been in operation, the smaller the cost decreases become. Even though recent technological improvement can be found in large diameter pipes, higher pressures, and automated pipe laying techniques, Roland (1998) argues that pipeline transportation of natural gas has not seen major technological breakthroughs over the last few decades.

There might be a small degree of learning through improved technologies for laying, line inspection, and welding, but these effects may be counterbalanced by other factors. Based on a three-year program assessing the potential of high strength line pipe, Sanderson and others (1999) suggest potential cost savings from using higher-strength line pipe for large-diameter gas pipelines in remote environments where societal and environmental risks are low. In populated regions, however, societal and environmental risk concerns can dominate wall-thickness selection and affect potential cost reduction incurred from use of higher strength line pipe.

Another explanation involves the application scope of learning theory. Learning theory has typically been developed for standardized products like airframes and cameras (Abernathy and Wayne, 1974). The pipeline construction is not completely standardized because the construction of a pipeline is largely influenced by its location. Learning may occur in a single task or in a complete process. For example, the pipeline installation process may be accelerated due to the expertise or experience of those working on the installation (see Figure 5). However, collectively these small effects may not lead to cost reduction over time due to the larger effects of other factors such as type of pipelines.

The similar offshore geographical features and relatively later developed technologies demonstrate the importance of learning effect on pipeline construction costs. Based on Figure 5, however, this effect will decrease after the technology becomes mature.

In conclusion, the learning effect may occur in the early period of gas pipeline development or in specific circumstances such as the offshore area. However, learning effect cannot completely explain the factors affecting cost development for gas pipeline construction. Baloff (1966) argues that a learning curve has "a narrow understanding of the causes, and hence the existence, of the productivity phenomena described by the learning curve." In order to understand the cost development of pipeline construction, it is critical to investigate other factors that may strongly influence construction costs.

4 OTHER FACTORS INFLUENCING CONSTRUCTION COST

This section first examines the cost components for building gas pipelines. It then analyzes the effects of other factors, including economies of scale, pipeline type, and population density.

4.1 COST COMPONENT

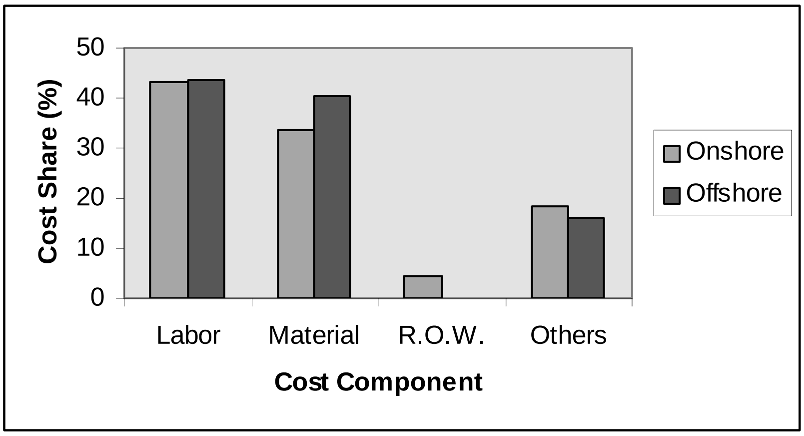
Building an entirely new pipeline in the United States includes the following tasks:

- Survey potential routes and assess environmental/historical impact;
- Acquire rights-of-way (new land or along routes of existing utility services);
- Build access roads and clear/grade/fence construction pathways;
- Dig/explode pipe ditches (padding bottom and soil upgrades);
- Lay pipe (string, bending, hot pass, fill/cap weld, wrapping, inspection);
- Build compressor stations, pipeline interconnections, and receipt and delivery metering points;
- Pad/backfill/testing and final survey; and
- Restore construction site(s).

These efforts are also required in European and Asian countries although specific details may vary.

The total construction cost represents the sum of the four major categories: material, labor, miscellaneous, and right-of-way (R.O.W.). Material costs include those for line pipe, pipe coating, cathodic protection, compressors, and telecommunications equipment. Labor costs cover survey, mapping, and installation of facilities (pipelines and compressors, etc). Right-of-way acquisition includes obtaining right-of-way and allowing for damages. Miscellaneous costs generally cover administration, supervision, contingencies, and Federal Energy Regulatory Commission (FERC) filling fees.

Labor and material costs make up around 80 percent of the total cost of onshore pipelines (Figure 6). As for offshore pipelines, material and labor accounted for around 84 percent of the total cost between 1991 and 1998. Labor costs represent the largest share of onshore pipeline construction costs. On average, material costs are more important for offshore pipeline construction than for onshore pipelines. The International Energy Agency (1998b), moreover, finds that the percentage of labor costs vary depending on the size of pipelines. Small-diameter pipes use less material, and thus labor takes a larger share of total cost for constructing pipelines. For new, long-distance pipelines, with pipe diameters greater than or equal to 36 inches, material costs approach labor costs. My study of the labor and material share of costs for different sizes of pipelines (pipelines for 1996 and 1998) supports the findings of IEA.



Source: True (1985-1998)

Figure 6 Share of Cost Components in Pipeline Construction

The cost shares of labor and material vary by country. Table 4 lists the cost shares for labor and materials for onshore pipeline construction in the United States (average share for 1991 to 1998) and China's most recent gas pipeline from Jingbian to Shaanxi. As shown in the table, the labor cost for the Jingbian-Shaanxi pipeline accounts for only 5.6 percent of the total construction cost, while the American average is as high as 43.2 percent. The cost of materials in the Jingbian-Shaanxi pipeline is very high, 67 percent of the total cost. This is because nearly all the pipeline tubing and other materials had to be imported (Lan and Paik, 1998). This finding suggests that pipeline development costs could be relatively low if China could transfer or develop technologies to produce currently imported materials.

Table 4 Shares of Cost Components for the Construction of Average Onshore American Pipelines and the Construction of the Jingbian-Shaanxi Pipeline in China (%)

	Labor	Material
United States	43.2	33.8
China*	5.6	67.0

* Lan and Paik (1998).

4.2 ECONOMIES OF SCALE

Economies of scale affect the construction cost for onshore gas pipelines. This section analyzes the relationship between construction cost per capacity (cubic meter) and length, diameter, and capacity. Figure 7 uses data for 1998-1999 and shows the change of construction cost per capacity along with the diameter. The analysis finds that relative to capacity, larger diameter pipelines cost less to build than smaller ones (see Figure 7). It also shows that for pipelines under 20 inches, construction cost per capacity varies greatly, while for pipelines above 20 inches, the construction cost per capacity varies relatively less. Similarly, Figure 8 displays the pipeline construction cost changes over capacity. Under a capacity of 2,000 cubic meters, construction cost per capacity changes greatly, but above that, it is relatively stable. It is unknown why 20 inches and 2,000 cubic meters are the dividing line. Also, note that the correlation coefficients (R-square) for these two cases are only around 0.60.

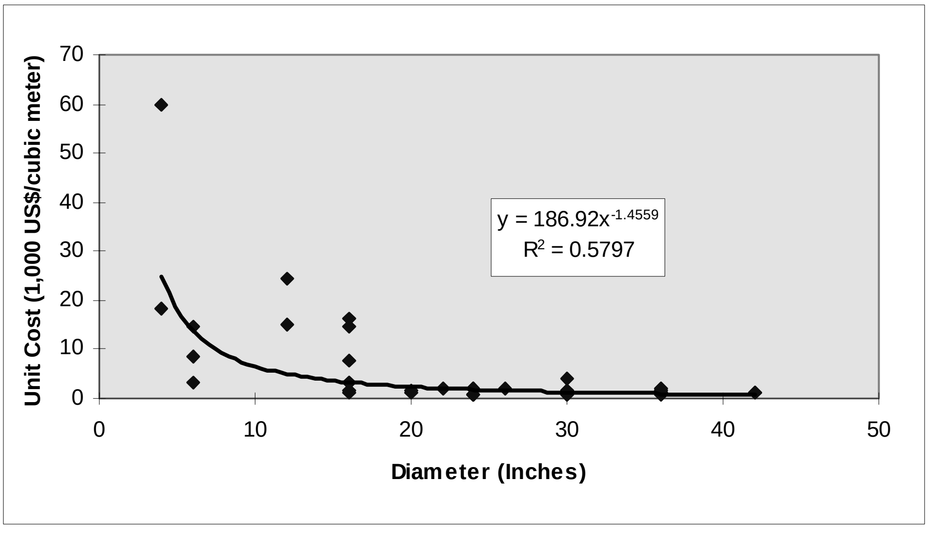
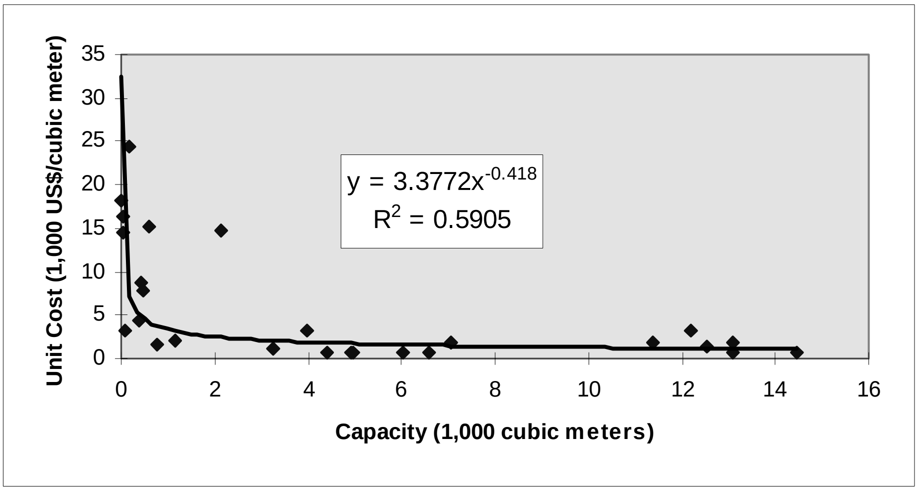


Figure 7 Pipeline Construction Cost Per Cubic Meter of Pipeline Capacity vs. Pipeline Diameter.



Source: True (1999)

Figure 8 Construction Cost per Cubic Meter of Pipeline Capacity vs. Total Pipeline Capacity.

Economies of scale help explain the change in capital cost per capacity for the United States from 1985 to 1998 (see Figure 1). For example, the year 1989-1990 exhibited the lowest unit cost for onshore pipeline construction. One of the major reasons for this low cost is the higher share of large-size pipelines. Over 92.5 percent of the length of pipelines had diameters equal to or larger than 30 inches for that period.

4.3 PIPELINE TYPE

The cost of a pipeline construction project varies with the type of facilities being built: a new pipeline or an expansion of the existing pipeline system. As mentioned above, the unit cost in 1987-1988 decreased compared to the previous year, even though most pipelines were still built in the densely populated Northeast, because many of the projects were expansions of existing ones (True, 1988).

EIA estimated the unit cost for existing and proposed pipelines from 1997 to 2000 (EIA, 1998b). Compared to the 1996-1997 period, the cost between 1999 and 2000 increased. During 1996 and 1997, the costs per added cubic foot of capacity per day averaged about US$0.21, but averaged US$0.30 to US$0.70 for the period 1999 to 2000. EIA (1998b) believes that one major reason for cost increase is that most projects (42 of 68) in 1996 and 1997 were expansions to existing pipelines systems, while a number of new pipelines and large expansion projects will be implemented in 1999 and 2000. As for completed and proposed projects between 1996 and 2000, new pipeline projects averaged about US$0.48 per added cubic foot; an expansion costs about US$0.33 per added cubic foot. In addition, the difference between new and expansion pipelines becomes larger for long pipelines.

Typically, a new pipeline, for which right-of-way land must be purchased and all new pipeline laid and operating facilities installed, will cost much more than an expansion of an existing route. Expanding an existing pipeline or converting a gas pipeline includes many of the same construction tasks as building a new pipeline, but usually to a much lesser degree.

4.4 POPULATION DENSITY

The cost of a project also varies according to the region it traverses. Projects that must go through major population areas found on average cost more than those developed in less populated regions. In the Northeast region, for example, 13 projects were completed during 1996 and 1997 at an average cost per cubic foot of US$0.22. On the other hand, in the more sparsely populated Southwest Region, the average cost per project was estimated to be US$0.20 per cubic foot of capacity, which is less than the average cost in the Northeast region (EIA, 1998b).

As Figure 1 shows, average unit cost per capacity reached the highest point during 1986-1987, in large part because most of the proposed pipelines were located in the densely populated Northeast. Of the 104 onshore projects proposed, 57 were for the U.S. Northeast market (West Virginia to New Hampshire), including high population density areas such as New York (True, 1987). The high prices of services and material for pipeline construction in this area drove up the cost.

However, population density has less effect on costs than the type of pipeline, however. The least populated area, the Central Region, has relatively high average costs per planned project, reflecting the prevalence of new pipelines and large expansion projects scheduled for development over 1995-2000. For instance, of the 18 projects proposed for the region, average costs ranged between US$0.35 and US$0.43 per cubic foot of daily capacity, in the high range among the regions (EIA, 1998b).

In their study about the influence of technological changes on the cost of gas supply in Europe, Strubegger and Messner (1986) compared the costs of constructing a new gas pipeline in areas with existing housing structures to those in areas without these structures. They concluded that the introduction of natural in region with existing housing gas had exponential increase in costs.

In summary, pipeline construction costs primarily are composed of labor and material costs. Economies of scale, type of pipeline, and population density largely affect pipeline construction costs through their influence on labor and material costs.

5 CONCLUSIONS AND IMPLICATIONS

This paper assesses the historical cost development of gas pipelines in conjunction with the impact of technological learning and other cost factors on pipeline construction. The paper arrives at the following findings. With respect to technological learning, there is no strong evidence of the learning effect on onshore pipeline construction between 1985 and 1998 for the United States. The learning rate was 24 percent for offshore gas pipeline construction from 1985 to 1998 for the United States (but the correlation coefficient is not high), and there were learning effects for North Sea Gas Pipelines. A possible explanation is that onshore pipeline construction entered a period with large cumulative capacity, and cost reduction due to learning became smaller and smaller. In addition, the technologies used for pipeline development were already very mature. There was no large breakthrough during the last few decades.

Learning effects have apparently been offset by other factors, such as economies of scale, type of pipeline, and population density. In the case of onshore gas pipeline construction in the United States, these factors had a much stronger effect than learning.

Pipeline construction costs are primarily composed of labor and material costs. Material costs approach or exceed labor costs in large-sized gas pipelines or offshore gas pipelines. The relative size of labor and material in pipeline construction varies by country due to differences in material availability and labor price. Economies of scale, type of pipeline, and population density affect pipeline construction costs by influencing labor and material costs. Large-sized (diameter or length) expansion pipelines located in lower-density population areas will cost less to build than new small-sized pipelines located in more densely populated areas.

The evidence in this paper suggests that learning effects could be observed in Asia under certain conditions, such as multiple pipelines built in similar geological terrain. Learning effects may be found in Asia also because Asia has little experience in gas pipeline construction. It may be difficult to find learning effects in Europe, however, due to the mature stage in gas pipeline development.

As for gas development in Asia, LNG transportation will continue to be the major means of gas transportation because gas pipelines involve geographical, political, and economic factors, especially for pipelines transmitted through third parties. However, gas transportation via pipelines offers potential advantages such as economies of scale, environmental benefits, and allowance for the additional diversification of sources. In addition, pipeline construction will bring about a varied range of infrastructure building and economic development along the pipeline routes. The proposed pipeline between Xinjiang and Shanghai will promote the development of China’s western region.

The construction cost per capacity may be high at the early period of pipeline construction because of the required installation of all new infrastructures and the import of some materials. The relatively lower labor cost of this region may reduce the otherwise high unit cost. During this early period of constructing pipelines with low capacity, Asian pipeline construction may experience cost reduction due to learning. It can be expected that before too long, the cost reduction and the cost would be increasingly determined by type, size, and location of pipelines.

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