From Templates to Results: Policy Models and Technological Learning in the Mexican and Brazilian Automotive and Petroleum Industries, 1975-2000

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Abstract: Although technological learning is indispensable for economic transformation in developing countries, the development literature remains unclear on the conditions most likely to foster it. This study builds on recent research on industrial policy by investigating the relationship between national-level industrial policy models and industry-level technological learning. Through a controlled case comparison of the automotive and petroleum industries in Mexico and Brazil from 1975 to 2000, we develop a framework to predict industry-level learning that emphasizes prior investment in learning, exogenous shocks, and the sequenced alternation between policy paradigms over time.

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I. Identifying the Place of Policy Models in Technological Learning Processes

The ability of developing countries to raise incomes by diversifying and upgrading industries is encountering several strong headwinds. Some note the spreading of long-distance production networks as a danger sign that economic progress has become more uneven and competition less under domestic control than before.[1] Others surmise that the days of "easy" rapid industrialization are over, requiring more deliberate emphasis on "harder" tasks, such as education and a focus on institutional capacity.[2] These challenges appear to intensify as the pendulum swings against international trade and advanced countries more wholeheartedly embrace nationalist policies.[3] Yet, the imperative of

[1] Whittaker et al. 2010
[2] Rodrik 2014
[3] Blyth 2016, The Economist 2017

technological learning as a means to escape low-skill economic "traps" and invest in long-term economic transformation persists undiminished.[4]

We must therefore identify the factors that facilitate new technological learning in emerging economy industries. This article builds on debates regarding industrial policy by inquiring into the role of overarching development policy models in these learning processes. It traces the impacts of two highly influential policy models – state-led and market-led approaches – in two large medium-income developing countries – Brazil and Mexico – that have become emblematic of divergent policy models since the 1980s. The investigation focuses on controlled case comparison of two important capital-intensive industries, automobiles and petroleum, in both countries.

By tracing the divergent pathways of technological learning taken by these four industries from 1975 to 2000, a framework emerges that recognizes a central explanatory role for national-level policy paradigms. But, in shifting the focus to the subnational level of specific industries, the framework also refines our understanding of how paradigms play this role. Specifically, it suggests that technological learning is impacted by, first, the extent of prior industry-level investment in learning, both in terms of capital invested and organizational dedication; second, by the number of exogenous shocks that disrupt the industry's status quo operations and force industry-level actors to reconsider how they compete; and finally, by the degree to which alternations between the distinct learning approaches of state-led and market-led policy models occur across such reconsiderations. Accounting for all three allows for a much more thorough understanding of what roles policy models play in learning outcomes, and in particular, what intervenes between the level of the national adoption of a policy model and specific learning results in a given industry. This approach addresses a major gap in the industrial policy literature, which has tended to assume greater generalizability from one policy setting to the next than many consider warranted.[5]

Such findings hold several implications for future research on economic transformation and industrial policy in middle-income countries. Unlike other models, it offers a cumulative approach that accounts for how the magnitude and type of prior learning affects new learning. It also clarifies the role of

[4] Amsden 2001, Doner 2009, Perez Aleman and Chaves Alves 2017
[5] Pack and Saggi 2006, Warwick 2013

punctuated exogenous shocks in creating crucial opportunities for shifts in direction in ongoing learning processes. Finally, and perhaps the greatest departure from prior research, it identifies complementary relations between policy models that have long been viewed as comprehensive and mutually exclusive. This offers novel policy proposals relative to previous literature that has either primarily endorsed one approach or attempted to graft the more desirable aspects of each into a new hybrid.

In the following sections we elaborate upon this subnational ideational framework for technological learning. Section 2 reviews the literature on technological learning and the ideational approach. Section 3 discusses our case selection and research methods. In Section 4 we undertake a review of our empirical argument. Section 5 discusses some of the main theoretical implications of the argument.

II. Learning from Past Approaches to Technological Development

Technological learning is crucial to the broader development challenges of both specialization and diversification. Here we define technological learning as movement toward an industry's global frontier, which can be observed in terms of the value-added of a given activity,[6] but also more functionally, in terms of novel product or process innovations.[7] Such innovations can be described as "knowledge-based assets"[8] involving some combination of capital technology and organizational capabilities. It is firms' successful formation of such assets that increases surplus for investment in further economic transformation.[9] Because such endeavors require both technological and organizational learning, their crucial importance has been highlighted in contemporary approaches to development policy.[10] Yet there is little consensus regarding what policy tools are most essential for achieving it.

Until recently, there have been two main policy models for generating technological learning in developing countries: state-led and market-led. State-led approaches, as exemplified in Latin America by the import substitution industrialization (ISI) model, focuses on the coordination problems and organizational impediments to technological learning. It is especially concerned

[6] Gereffi 1999
[7] Perez-Aleman and Chaves 2016:7
[8] Lall 1992, Amsden and Hikino 1994
[9] Amsden 2001:3
[10] Doner 2009, Whittaker et al. 2010, Rodrik 2014

with asymmetrical power relations between domestic and foreign market actors and offers solutions to these problems by advocating for a strong state role in guiding investment decisions, industry structure, and firm-level learning.[11]

Yet, as the debt required to maintain these programs became more burdensome by the late 1970s, leading to a "lost decade" of state retrenchment and austerity, another policy approach, known as the Washington Consensus, came to the fore. Under this market-led model, states no longer actively coordinated learning in the private sector. Instead they worked to minimize friction in private investment decisions through macroeconomic stability, deregulation, privatization and liberalization, all of which economists postulated would enhance efficiency.[12] This increased efficiency would in turn ostensibly generate surplus and encourage new investments to move on to further technological challenges.[13]

Like the state-led model that preceded it, however, the market-led model fell out of fashion when many of its adopters suffered severe economic crises, and a number of prominent non-adopters performed far better.[14] With both contending policy paradigms discredited, scholars of economic development attempted to rectify the problems of each. They sought to combine their respective strengths by proposing a return to state involvement and supervision, but this time tempered with a respect for market signals and discipline.[15] Under this "new industrial policy" approach, states would embrace flexibility and learn quickly from "experiments" in market-based learning.[16] Markets would be buttressed by public investments in infrastructure, training institutions, and other public goods supportive of technological learning and innovation.[17]

This "new industrial policy" approach has offered a number of insights with potential to overcome barriers and spur prosperity in the Global South. At the same time, it faces challenges that must be addressed before it can prove its adequacy as an alternative as clear and comprehensive as its forebears. The first

[11] Prebisch 1950, Bruton 1998
[12] Williamson 1989
[13] Lin and Chang 2009:485
[14] Rodrik 2005, Stiglitz 2008
[15] Hausmann and Rodrik 2003
[16] O'Riain 2000
[17] Cimoli et al. 2009

relates to a paucity of empirical tests of the proposed prescriptions.[18] Within this broader issue, according to Warwick, "the biggest gap in the [industrial policy] literature is the evaluation of broad industrial strategies."[19] To understand what is most worth taking from past approaches and how best to adapt them to today's conditions, the literature needs more recent historical case comparisons of the kind undertaken here.

Second, the new industrial policy literature faces criticism regarding the appropriateness of its prescriptions to address the contemporary challenges of global economic competition. That is because it extrapolates from examples, primarily the East Asian "newly industrialized economies" (NICs), that thrived under very different terms of global economic competition from those prevailing today – for instance, when far less developing countries had manufacturing capacity and manufacturing supply chains were more concentrated geographically.[20] This creates a risk that new industrial policy's prescriptions will exacerbate a "21st-century Prebisch Singer trap" in which the widespread diffusion of manufacturing capacity only further dilutes the advantages available from competing in such industries.[21] Thus, more attention should be placed upon cases that took place during and after the global shifts of the 1980s and 1990s towards increased trade liberalization and prominence of multinational corporations.

While there is no denying the value of re-engaging with industrial policy as a potential response to today's considerable development challenges, these two critiques underscore the need to learn from recent experience. Such learning should pursue close observation of both the successes and failures of broad policy strategies as they manifest at the industry level. In this vein, this study complements and extends the "new industrial policy" research agenda through a closer comparative analysis of how state- and market-led policy models generate cumulative technological learning results over time at the meso-level interface between state and market actors.

This suggests a case-based approach where the differences between policy models can be set in relief, a purpose for which the Mexican and Brazilian

[18] Lerner 2009
[19] Warwick 2013:46
[20] Pack and Saggi 2006, Whittaker et al. 2010
[21] Milberg and Winkler 2013

automotive and petroleum industries are ideally suited. The two countries provide stark contrasts in adoption of the two policy models. At the same time, the two sectors – which exemplify technology at the higher end of what is generally found in developing countries – capture significant variation of industry structure. By following the learning trajectories of these industries, this study endeavors to both better isolate how national policy models affect industry learning outcomes, and reveal additional explanatory variables. From the case comparison, we induce an argument that highlights three main factors as necessary and sufficient for successful technological learning: prior investment in learning, shocks that provoke reassessments of learning efforts, and responses that alternate between state- and market-led models across successive learning episodes.

This first of these factors, prior investment in learning, captures the degree to which focused organizational efforts, along with investment capital, are dedicated to domestic technological learning. The rationale for introducing this variable is supported by previous research, extending from foundational development economics through later industry-level studies, which affirm the need for high investment rates to increase learning, productivity and growth.[22]

Prior investments establish a baseline that is updated as new reforms emerge over time. The main mechanism prompting these updates is a form of crisis or shock that mobilizes public- and private-sector actors to reconsider an industry's basis of competitiveness and the means of enhancing it. Previous research shows that the search for new approaches to learning in both the public and private sector may not be automatic, and that significant exogenous shocks may be necessary to motivate reconsiderations of the status quo.[23] The industry cases in this study corroborate these findings insofar as new industry-level approaches correspond with moments of economic crisis such as a severe recession or new foreign competition. At the same time, the cases examined here confirm and extend these "punctuated" or "vulnerability"-oriented frameworks of institutional learning by illustrating how an industry's relative status in an economy affects whether it will be a source of stability or an object of reform in times of crisis.

[22] Rosenstein-Rodan 1943, Sen 1983, Lall 1992
[23] Hall 1993, Doner et al. 2005

The final consideration central to the four cases is the sequencing of different learning modes. Like any ideology or theoretical framework, state- and market-led policy models provide guidance and direction by highlighting some issues, problems, and means of resolution while overlooking others.[24] State-led approaches are primarily oriented toward overcoming power asymmetries that prevent local access to complex, tacit knowledge-based assets. Market-led approaches force actors to make the best possible use of existing assets and capabilities by exposing them to stringent tests of market competition. An interesting insight from the case comparisons in this study involves how these two approaches may be complementary when placed sequentially over time.

In underscoring the blessings of these policy paradigm alternations, the proposed argument offers suggestions not found in the new industrial policy literature. Whereas most contemporary industrial policy approaches attempt splice aspects of each paradigm into a new composite, the learning sequences in our four cases reveal a different possibility: that the more an industry alternates capability-forming episodes of state-led learning with efficiency-building ones of market-led learning, the greater the cumulative impact. The finding echoes March's (1991) observation that organizations must strike a balance between the two very distinct tasks of "exploration" of new capacities and "exploitation" of existing ones. As in March (1991), it emphasizes complementarity rather than synthesis or rivalry. These implications are explored further in the Discussion section below.

In sum, these three variables – prior investment, total number of shocks, and number of alternations between state- and market-led learning episodes – allow us to understand previously unexplained variation in learning outcomes across the industries. Based on the four industries' trajectories from 1975 to 2000, one observes movement toward the global technological frontier insofar as all three variables are maximized. When any of them falters, so too does learning.

III. Establishing Contrasts between the Brazilian and Mexican Automotive and Petroleum Industries

Case selection

Between 1975 and 2000, Latin American experience rapid changes and polarizing policy debates. As a "lost decade" in the 1980s challenged national economies, governments across the region re-evaluated their overarching policy approaches.

[24] Kuhn 1962, Silbey 1997

Some adopted the market-led alternative, while others favored a state-led paradigm. These two approaches, though now largely discredited as stand-alone models, not only proved to be highly influential in shaping policymaking in the region during that last quarter of the twentieth century; they continue to serve as templates for contemporary industrial policies.

Brazil and Mexico, Latin America's two largest and most industrialized economies (see Table 1), emerged as the region's leading national representatives of these two approaches. The market-led paradigm gained overwhelming influence in Mexico. Even before the crippling debt crisis, Mexican policymakers had begun subscribing to market-friendly policies that sought to spur exports, liberalize markets, and attract investment, especially FDI, as a way to generate domestic technological learning – even at the cost of losing national ownership of production. Policymakers opened up key sectors of the economy (e.g. the financial system), removed barriers to trade, eliminated restrictions on foreign ownership of land and publicly traded Mexican firms, and joined the North American Free Trade Agreement (NAFTA).[25]

Table 1. Descriptive statistics for the selected countries and industries

	Population (millions) (2015)	**GDP (trillions of current $) (2014)**	**Manufacturing value added (% of GDP) (2014)**	**Oil rents* (% of GDP) (2011-2015)**	**Auto/parts output (% of GDP) (2012)**
Brazil	207.8	2.417	11.7	2.2	2.57**
Mexico	127.0	1.295	17.7	4.9	3.17***
Rest of Latin America & the Caribbean	288.5	2.3098	N/A	N/A	N/A

Source (unless otherwise stated): Authors with World Bank (2016) data
*Oil rents capture the difference between the value added of crude oil production at world prices and the total costs of production.
**Source: ANFAVEA 2016 (Yearbook)
***Source: Secretaria de Economia 2012, World Bank 2012

By contrast, Brazil embraced state-led development. Despite opening up the economy to trade, Brazilian policymakers maintained a strategic role for the state, and national capital, in the promotion of industrial development through "selective outward orientation." The state supported research and development (R&D); welcomed majority or minority state ownership in leading firms; and incorporated a number of instruments (e.g. credits, subsidies, stakeholder

[25] Babb 2001, Moreno-Brid and Ros 2009

coordination) to enhance the competitiveness of domestically-owned "national champions." The state-led paradigm also favored a menu of redistributive policies to stoke domestic demand.[26] The assumption was that such state intervention would be necessary to foster longer-term investment in domestic learning.

Given the contrasting policy paradigms in Brazil and Mexico, the question that follows is how they shaped technological learning at the meso-level. This meso-level refers to firms in the same industry, as well as the state agencies that monitor, regulate and support their development. It is akin to DiMaggio and Powell's "organizational fields," incorporating "those organizations that…constitute a recognized area of institutional life: key suppliers, resource and product consumers, regulatory agencies, and other organizations that produce similar services and products."[27]

At this level, domestic technological learning is observed as the degree of technological sophistication and innovation relative to industry peers globally at the end of the studied period, in the year 2000. The studied industries' learning can be characterized as reaching high, medium or low levels. An industry in which domestic firms achieved sustained advancements extending the global frontier in crucial high-value, high-knowledge functions attained high levels of technological learning. An industry whose technological advancements failed to reach the world frontier in original product or process innovation received a low score. Between these two extremes, industries achieved medium levels of technological learning when they exhibited sporadic advancements that reached the global frontier, but only momentarily, failing to permanently establish a position for the industry at the global forefront.

In addressing this meso-level, we selected the petroleum and automobile industries both for their central roles in the national economies of Mexico and Brazil (see Table 1 above), and for their ranking as leaders in the technological spectrum for developing countries during the studied period.[28] At the same time, these industries varied in terms of their structures, and the role played by the state in their historical development, two factors that, by influencing prior investment, may affect learning.

[26] Ban 2013
[27] DiMaggio and Powell 1983:148.
[28] Amsden 2001, Lema et al. 2012

Petroleum, a much more capital-intensive industry, has a history of very strong state involvement in establishing the organizational and physical infrastructure for exploration, extraction, and processing.[29] The petroleum industries of both Mexico and Brazil were state-owned monopolies for most of the 20th century, and entered the studied period with high initial investment in learning. On the other hand, the automobile industry tended to be considerably less capital-intensive than petroleum, typifying a "producer-led" industry structure in which an established auto assembler from an advanced country orchestrates the production process through supplier networks among firms in other countries.[30] As such, automobile industries in developing countries, including Mexico and Brazil, had historically seen far less state participation than petroleum industries, rendering their initial investment in learning much lower.

By following these four industries' evolution over 25 years (see Table 2), this study focuses on explaining *how* policy paradigms impacted technological learning at the meso-level. As the empirical sections below explain, the four industries displayed substantial variation from each other in their levels of technological learning. The challenge was thus to account for those observed differences.

Table 2. Industry-level policy paradigms, stocks of initial investment in learning

		National Level Policy Paradigm	
		Market-led	**State-led**
Prior Investments in Learning	**High**	Mexican Petroleum	Brazilian Petroleum
	Low	Mexican Auto	Brazilian Auto

Data Collection and Analysis

To explain cross-industry differences in technological learning, this study draws from a thorough review of published literature and statistical sources. The historical accounts provided by this review describe the experiences of domestic technological learning of each industry since its founding, though the time period

[29] Victor et al. 2011
[30] Gereffi 1999, McDermott and Corredoira 2010

of focus is 1975-2000. They allow for cross-industry comparisons that clarify useful explanatory patterns.

At the same time, our case selection has advantages as well as limitations, including the questions of selection bias and scope of generalizability. To allay these concerns, it is important to note three points. First, as the empirical sections below describe, the levels of technological development and learning across these industries varied significantly, facilitating informative comparisons. Second, the cases were chosen not based on their technological learning outcomes, but on two key independent factors: the national-level policy paradigm and the stock of initial investment in learning (Table 2).

Finally, these industries encompass a substantial range of the overall technological sophistication observed in developing countries. In particular, the explanatory account developed here is pertinent primarily to relatively technology- and capital-intensive industries in middle-income countries.[31] After all, these industries and countries occupy a significant portion of the space in which policymakers and business leaders are searching for ways to move into more knowledge-intensive, higher-technology fields that may spur economic growth.

IV. Accounting for Industry-Level Technological Learning Trajectories

To address the question of how the contrasting policy paradigms shaped technological learning in the industry cases, we begin by comparing their levels of technological development in 2000. Table 3 establishes the significant cross-case variation, with the Brazilian petroleum industry displaying the highest level of domestic technological development. The industry achieved sustained advances and established itself at the global frontier in deep-water exploration and production, serving as a leader in joint ventures with the world's most advanced private firms. It also identified massive reserves that vaulted Brazil from a heavily import-dependent energy economy to one of the major exporting prospects of the coming century.[32]

[31] This includes 104 countries out of 215 classified by the World Bank, with a GNI per capita anywhere from $1,046 to $12,734 per year (World Bank 2016a).

[32] Dantas and Bell 2009, Ubiraci Sennes and Narciso 2009, de Oliveira 2012

Table 3. Expected and observed levels of technological learning for the studied industries, 2000

	National-level policy paradigm	Observed level of technological learning
Brazil Petroleum	State-led	High
Mexico Petroleum	Market-led	Medium
Brazil Auto	State-led	Medium
Mexico Auto	Market-led	Low

The Mexican auto industry languished at the opposite extreme, with little domestic innovation. Almost all of its product design and development took place abroad, with the country maintaining a largely unchanged position as an assembly site since the 1970s. This occurred despite high levels of FDI – including the large majority of the most renowned auto MNCs – at both the assembly and tier 1 production segments.[33]

Between these ends, the Mexican petroleum and Brazilian auto industries both reached intermediate learning outcomes, with sporadic advances that reached the global frontier momentarily, without consistently remaining at the cutting edge of technological learning. The Mexican petroleum industry was able to achieve high productivity within a largely vertically integrated domestically-owned industry structure. It exploited the supermassive fields in the South of the country and became one of the world's largest oil exporters for quite some time.[34] Moreover, the industry was able to make inroads in the research and development of petrochemicals that were, for a short period, internationally competitive.[35]

For its part, the Brazilian auto industry, which hosted the largest number of MNC assemblers of any country in the world,[36] stood out for a number of noteworthy achievements. These include a cost-effective "flex" engine, VW Brazil's introduction of its Fox family of vehicles, and GM Brazil's successful Meriva

[33] Carrillo 1995, Barragan and Usher 2009, Ruiz Garcia 2015
[34] Grayson 1980, Quintanilla and Bauer 1995, Reyes Hernández et al. 2014
[35] Aboites and Beltrán 2011
[36] Zilbovicius et al. 2002

Project.[37] Most notably, as Lema et al (2012) explain, not only did R&D occur in Brazil, but the country became a hub for subsidiaries' development of new products geared toward Global South markets.

Gaps between national-level policy paradigms and industry-level outcomes

While Table 3 demonstrates the remarkable variation across the four studied industries, their rank order also challenges the expectation of a simple linear relationship between national-level paradigms and this meso-level outcome. Were national-level policy paradigms to offer a sufficient account (i.e that one or another consistently elicits higher levels of technological learning at the meso-level), then we would observe consistent differences at the national level. But such an expectation finds no support in Table 3.

Beyond an imperfect relationship to long-term results, the role of national policy paradigms is complicated further when one considers intermediate steps along the way. As we discuss below in further detail, over the course of the studied period, industries sometimes adopted policies and reforms counter to the then-dominant approach in their home countries. For instance, in market-led Mexico, Pemex remained a state-owned vertical monopoly well beyond 2000. In state-led Brazil, Petrobras faced liberalization early on, well before its Mexican counterpart. The Brazilian auto industry underwent significant bouts of market liberalization during the 1990s despite growing under a state-led national-level paradigm. In many crucial instances, then, individual industries pursued approaches and encountered meso-level conditions that at some crucial moments contrasted with, and diluted the impact of, national-level paradigms.

This first-glance comparison of the cases thus sets the stage for an analysis of policy changes at the industry level in relation to not only national paradigms, but also other important factors. The following sections pursue these concerns inductively and step-wise to develop a meso-level explanatory framework.

Prior investments in learning

In comparing across the four industries, the first factor that arises as necessary for learning outcomes was the degree to which focused organizational and capital investments were dedicated to industry-level domestic technological learning prior to 1975. The importance of this factor, which is well established in

[37] Shapiro 1994, Posthuma 1995, Zilbovicius et al 2002, Ciravegna 2003, Quadros and Consoni 2006, Schneider 2015

the literature,[38] emerges most forcefully from the contrast between the petroleum and auto industries, and their relation to the state.

Consider the interventions of the Mexican and Brazilian governments in their petroleum industries. Both were state-owned, with large employment bases. The Brazilian government spent billions of dollars from the 1950s through the 1970s to establish a strong domestic petroleum industry. It invested in long-term capacity by creating owned subsidiaries to the state-owned petroleum firm, Petrobras, in petrochemicals (1967), distribution (1971), overseas exploration (1972), foreign trade (1976), fertilizer (1976), and mining (1977). In the 1950s and 1960s the energy sector regularly received 35-40% of all government investment.[39] Likewise, Mexico's Pemex has been described as "the most perfect self-contained, vertically integrated monopoly."[40] In both of these industries, investments in technological know-how included the creation of national institutes for research and training, large infrastructure such as pipelines and refineries, and commitments to send citizens abroad for technical training.[41]

Table 4. Prior investment in learning, circa 1975

Industry	Prior investment in learning	Level of technological development
Brazilian petroleum	High	High
Mexican petroleum	High	Medium
Brazilian auto	Low	Medium
Mexican auto	Low	Low

By contrast, the studied auto industries, led by MNCs, lacked comparable prior investments in domestic learning. Their organizational, technological and engineering know-how in both industries largely remained in overseas MNC headquarters.[42] Governments in both countries largely avoided intervention and investment. That is not to say that there was no variation in the prior investment in domestic technological capacity between the two: whereas auto parts suppliers were largely denationalized in Mexico, Addis (1993) has shown that a promising domestic auto parts industry had emerged in Brazil by the 1950s. However, even though their investments allowed them to manufacture relatively

[38] See footnote #22.
[39] Randall 1993, Singh 2014
[40] Prager 1992:116
[41] Reyes Hernández et al. 2014, de Oliveira 2012
[42] Bennett and Sharpe 1985, Shapiro 1994, Carrillo 2004

sophisticated parts for MNC assemblers, their scale and extent lagged far behind those observed in the petroleum industries.

Considering prior investment as an explanatory variable contributes to our understanding of within-country meso-level variations by revealing an important source of resources for ongoing advancement in technological expertise. Yet, while necessary, this factor is not sufficient to account for within-industry or cross-country variations. Table 4 shows this: while the Brazilian petroleum industry was thriving by the 2000s, the Mexican petroleum industry attained only sporadic advances, its medium level of technological learning comparable to the Brazilian auto industry. Mexico's auto industry, for its part, achieved limited technological learning, lagging behind the technological frontier.

Exogenous shocks and new attempts to learn

To account for variation left unexplained by national paradigms and the basic expectations based on prior investments, we turn to another noteworthy factor that helps to explain the cases: the influence of exogenous shocks on learning attempts within an industry. This factor has been discussed in previous scholarly work.[43] It arises as particularly pertinent in contexts like the Brazilian and Mexican economies, which have elsewhere been termed "inertial" due to oligopolistic market structures and conservative investment strategies (Authors previous), and where strong shocks have the potential to shake industry leaders into experimenting with novel approaches conducive to advances in technological learning. In this sense, it makes sense to say that the greater the number of shocks encountered by a given industry, the more its main actors are prompted to reconfigure it and generate new technological learning. And as Table 5 shows, the four industries diverged when it came to this number.

Table 5. Number of shocks, 1975 – 2000

Industry	Prior investment in learning	Number of shocks	Level of technological development
Brazilian petroleum	High	High	High
Mexican petroleum	High	Low	Medium
Brazilian auto	Low	High	Medium
Mexican auto	Low	High	Low

[43] See footnote #23.

The historical record shows that both of the auto industries and the Brazilian petroleum industry faced numerous shocks during the time period, providing opportunities for nearly continuous reassessment and readjustment (see Appendix A). The Brazilian auto industry encountered consistent balance of payments problems in the 1970s, the oil shock of 1973, and back-to-back recessions in the 1980s and 1990s, among other shocks. They were felt particularly acutely by the industry as they affected producers in two ways. First, and especially throughout the 1970s, assemblers came under pressure to change their sourcing and sales patterns in order to lower their foreign exchange deficits. Second, recessions severely curtailed the revenues of an industry heavily dependent on domestic sales, as in the 1980s, when vehicle sales fell by almost a third.[44]

As the Brazilian auto industry and state actors acutely felt the impact of these shocks, their responses exhibited remarkable shifts in the policy models employed. In the late 1970s, the Brazilian state played a significant role by, for instance, raising local content requirements for the industry and investing in ethanol-related research and production.[45] Yet, by the 1980s, industry-level responses involved not new state regulations and investments, but rather support for export promotion and domestic market liberalization.[46] Then, in the late 1990s, the industry turned to renewed state involvement, including the well-known Carro Popular program to spur demand, and a new round of support for flex engine production.[47]

The Mexican auto industry also faced a high number of shocks, including balance of payments crises in the 1970s, labor unrest in the 1980s, and recessions in the 1980s and 1990s. All of these severely challenged and ultimately undermined the industry's traditional production model, which relied heavily on imported parts from the US, unrivaled access to Mexican and American national markets, and concentration in heavily-unionized central Mexico. As in Brazil, industry leaders and policymakers responded vigorously. However, the Mexican industry differed from its counterpart in consistently employing market-led policy approaches. For instance, during the 1970s, industry leaders and policymakers responded to challenges brought on by balance of payments promises by focusing primarily on

[44] Addis 1993, Shapiro 1994, Abreu et al 1998
[45] Barzelay 1986, Addis 1993, Shapiro 1994
[46] Abreu et al. 1998
[47] Posthuma 1995, Quadros and Consoni 2006

export promotion – including active support for the industry's movement to the northern border – and internationalization of the supplier base.[48] That same approach continued during the 1980s and 1990s, as labor unrest and a recession threatened the industry. Once again, facing unexpected shocks, industry leaders and policymakers sought foreign investment, increased focus on exports, geographic shifts northward, and liberalization of imports.[49]

For the Brazilian petroleum industry, in turn, shocks included balance of payments problems in the 1970s, oil shocks in the 1970s and 1980s, growing competition in the 1970s, and the debt crisis and consequent austerity of the 1980s. The industry felt these acutely largely via the impacts of high energy costs on national development policies. From the 1960s forward, the country's need to import nearly all of its petroleum consistently challenged its heavy investments in national industrialization.[50] The country's balance of payments repeatedly reached crisis levels during the 1970s and 1980s, forcing re-examinations of the state's expenditures. One of the first culprits sought to alleviate the pressure on the state's finances was Petrobras, the centerpiece in Brazil's pursuit of national energy independence.

As with the Brazilian auto industry, industry leaders and policymakers pursued varied responses. In the 1970s and early 1980s, offshore exploration came to the fore as hopes dwindled that onshore reserves would afford any meaningful response to oil crises and strained balance of payments. President Ernesto Geisel (1974-1979) responded in 1975 to slow progress from Petrobras by unilaterally declaring legal risk service contracts for foreign firms to invest in the country's badly-needed exploration. This placed immediate pressure on Petrobras to exploit the Campos Basin,[51] leading to the discovery of the giant Albacora and Marlim fields in 1984 and 85, respectively. Yet even these accomplishments did not resolve the persistent threats to the country's economic and energy security. The recession and austerity programs of the mid-1980s left Petrobras unable to make the investments required to effectively extract from its recent deep water discoveries.[52] The long-sought goal of national energy sovereignty would therefore have to wait for an opposing set of reforms in the 1990s, when economic liberalization forced Petrobras to compete directly with international

[48] Bennett and Sharpe 1985
[49] Carrillo 1995, Carillo 2004, Contreras et al 2012, Barragan and Usher 2009
[50] Randall 1993, Priest 2016
[51] de Oliveira 2012
[52] Galano III 1994, Randall 1993:90

firms, focus on operational efficiency, and follow international business practices in order to increase its investment capital.[53]

Finally, the Mexican petroleum industry provides a counterpoint to the three other cases in terms of how exogenous shocks impact industries. Although the Mexican economy went through massive structural transformation from 1975-2000, its national petroleum industry remained surprisingly stable after a shift early in the studied time period from more state-led domestic investment to a market-led focus on exports.[54] In fact, the subsequent debt crises, austerity initiatives and the shift to market-led development at a national level failed to trigger fundamental changes to PEMEX, underscoring the importance of a specific focus on the meso industry-level.

In this case, the industry's phase of massive expansion in the late 1970s-early 1980s established it as a bastion of stability and even 'slack,'[55] insulating it from those national-level shocks. In contrast to PETROBRAS, which absorbed a major portion of the state's coffers, at the height of the 1980s debt crisis Pemex accounted for as much as 40% of government revenue.[56] Although this number fluctuated subsequently, it remained elevated, rising again to 40% in the early 2000s.[57] In the 1980s and beyond, Pemex's vast resources supported national debt payments and Mexico's transition from a state-led to a market-led policy model (including the retrenchment of social welfare and subsidies). The ability of Mexico's Institutional Revolutionary Party (PRI) to maintain unity and momentum for its reforms during this time was remarkable, and accomplishing this depended heavily on using Pemex's stability to support such difficult shifts elsewhere.[58] As a result, Pemex failed to retool during these crises, as it supplied the resources for retooling efforts elsewhere in Mexico.

The foregoing analysis therefore shows that the quantity of shocks that immediately and gravely threatened an industry's fortunes played a necessary role in shaping the industries' trajectories of technological learning. Most notably, this factor clarifies why, despite relatively similar prior investments, PEMEX did not keep up with PETROBRAS. At the same time, significant

[53] Dantas and Bell 2011, Bridgman et al. 2011
[54] Prager 1992, Philip 1999
[55] Cyert and March 1963
[56] Quintanilla and Bauer 1995:30
[57] Fuentes Berain 2009
[58] Lustig 1998, Philip 1999

unaccounted-for variation in 2000 levels of technological learning remains across the cases. For example, although both automotive industries entered late 1970s and early 1980s with comparably low prior investments and faced a similar number of shocks thereafter, the Brazilian auto industry emerged in 2000 with significant advantages. This suggests that at least one more factor played a role.

Policy Paradigm Alternations

It is at this point that the market- and state-led development policy paradigms re-enter the picture. At nearly every instance of local responses to major shocks, reformers drew largely either from state-led or market-led policy toolkits. Interestingly, and contrary to conventional expectations, we do not observe discernibly different effects on technological learning deriving from which policy model was selected. Nor do we find that crucial successes in learning are associated specifically with attempts to create "hybrid" versions of the two models, as the new industrial policy literature has proposed. Rather, case histories show that alternations between the two policy approaches provide the final factor necessary to explain the observed results.

Specifically, increased alternations between paradigms proved beneficial for technological learning. That is because each policy paradigm embodied a particular ideology, or set of shared beliefs and assumptions that emphasized some issues, problems and mechanisms to resolve them, while also obscuring others. As a result, shifting between paradigms offered the possibility of considering a broader scope of challenges, and addressing those challenges with a wider set of possible solutions.

Table 6 illustrates how industries experiencing a high number of direct shocks (all but Mexican petroleum) diverged in terms of policy model alternations (see also Appendix A). While Brazil adopted a state-led policy approach at the national level, its auto and petroleum industries underwent significant swings between state- and market-led responses to their shocks. These alternations emerged clearly in the foregoing discussion of responses to shocks across different crises. In Mexican automobiles, by contrast, the market-led paradigm remained remarkably hegemonic both before and after its adoption at the national level. Not once did the Mexican auto industry experiment with a state-led approach, instead consistently drawing upon the market-based recipes (e.g. export promotion, FDI attraction) as it faced each incoming shock .

Table 6. Number of paradigm alternations, 1975 – 2000

Industry	Prior investment in learning	Number of shocks	Degree of paradigm alternations	Level of technological development
Brazilian petroleum	High	High	High	High
Mexican petroleum	High	Low	Low	Medium
Brazilian auto	Low	High	High	Medium
Mexican auto	Low	High	Low	Low

The inclusion of this final necessary variable completes a proposed explanatory framework that is sufficient to account for industry-level technological learning in all four cases. A combination of high prior investments, numerous shocks registering at the industry level, and significant paradigm alternations allowed the Brazilian petroleum industry to forge ahead with its domestic technological development. The Mexican petroleum industry, for its part, may have started with similar prior investments, but the absence of industry-level shocks and associated paradigm alternations produced few technological advances. In Brazil's auto industry, low levels of prior investment were compensated by high rates of shocks and policy paradigm alternations, which fostered rapid learning and "catch up." Finally, bereft of high prior investments, the Mexican auto industry faced a high number of shocks but failed to exploit them through policy paradigm alternations, thereby stagnating and falling behind the rest.

V. Industry-level Technological Learning: Punctuated, Dialectical and Political

The case analyses reveal an explanation of meso-level learning that encompasses all four industries and addresses important gaps in research on "new industrial policy" and technological learning in developing countries. This explanation draws from three key factors: prior investments in learning, exogenous shocks that occasion attempts to learn, and sequential alternations between policy paradigms across learning attempts. What are the benefits and limitations of this approach, and how can future research build on its findings?

First, while overall investment in industry-level technological learning helps to clarify distinctions between industries, it leaves significant unaccounted-for variation. Thus, both petroleum industries showed varying levels of learning despite sharing high initial investments. Furthermore, the Mexican petroleum industry's relatively mid-level degree of technological learning parallels the Brazilian auto industry's achievements, despite the latter's low prior state investment.

Second, the importance of exogenous shocks is apparent throughout the cases. Across industries, when a shock disrupts an industry's capacity to compete effectively or to meet existing demand, public and private sector actors mobilize to diagnose the problem and enact corresponding shifts in learning objectives. While this pattern is consistent across the cases and documented elsewhere,[59] two caveats arise from our analysis: first, although major shocks mobilize responses, not all will result in successful industry-level advances in learning. The Mexican automobile industry shows how multiple opportunities to learn can fail to deliver significant local technological advancement. The conditions for success in learning attempts in developing industries are still not widely understood in the literature, and are the subject of ongoing investigation.[60] Nevertheless, it is clear that exogenous shocks are a consequential factor that has been previously under-researched in the literature on industrial policy.

The second qualification pertains to the place of an industry in broader national context. Although the Mexican economy went through numerous painful shocks and structural reform efforts throughout studied period, the structure and technological capacity of its petroleum industry remained remarkably stable. This negative case suggests that actors can either view an industry as a source of "slack"[61] to provide resources to help respond to crises, or as the site of crisis itself. Pemex's considerable growth in capacity and revenue in the 1970s and early 1980s made it an irresistible resource base for politicians, who sought to maintain its stability over any possible attempts to engage in economically and politically risky learning endeavors on yet another front. Investments in new capacity were left for Pemex to seek through foreign private sources.[62] Thus, the response to a shock must be taken contextually. While the shock may be felt widely, if one industry is a locus of strength relative to others, it may remain stable while actors attend to more acute crises elsewhere.

The final key explanatory factor involves the extent to which an industry underwent successive policy paradigm alternations from one shock response to the next. In the case sequences, if an industry employed a state-led approach in one episode, and turned to a market-led approach in the next, it was likely to

[59] Doner et al. 2005
[60] Authors forthcoming
[61] Cyert and March 1963
[62] As the state withdrew investment in exploration and capacity-building at PEMEX, private debt financing grew to comprise over 90% of all of its annual investment (Reyes Hernandez et al. 2014:136).

attain better overall cumulative learning results than if the same approach was applied consecutively. This finding appears paradoxical through a lens that views policy models as comprehensive and mutually exclusive. However, the four case studies reveal benefits from such sequential shifts insofar as different paradigms highlighted distinct issues, problems, and means of resolving them.

Prominent in both Brazilian industry cases, this phenomenon is also provided a counterfactual in the case of Mexican autos, with its frequent shocks devoid of paradigm alternations. It challenges assumptions about the inherent advantages of any one paradigm. For example, the Mexican petroleum industry's growth in the 1970s under a state-led paradigm benefited in the early 1980s from a change to a market-led one insofar as it led to a massive increase in output capacity and overall efficiency. Likewise, both Brazilian industries achieved several advances that, though initiated under state-led approaches, only bore fruit after the adoption of market-led reforms. In contrast, Mexican autos' market-only approach produced the worst learning results of the group, further corroborating the finding that the movement between the two policy models offers distinct advantages. Finally, while some instances of "hybrid" policy reforms of the kind recommended by the new industrial policy literature did occur – for example, in some of the reforms to the Brazilian auto sector in the 1990s – the majority of the learning episodes represented across the cases more closely aligned with the adoption of one of the two paradigms.

This discussion of policy model alternations inevitably raises the question of the mechanisms through which they affect processes of learning. The information available from the cases suggests a notable pattern. During the application of state-led approaches to reform, industries tend to invest in new functional capacities, as was the case in both petroleum industries in the 1970s. In contrast, during episodes of market-led reform, industries were exposed to foreign competition and pressured to pursue efficiency gains with respect to existing capacities. Such was the case in the Brazilian petroleum industry, both in the surprise policy shift to risk contracts in 1975 and liberalization process of the 1990s. In both, the introduction of strong competitive pressures followed previous episodes of significant investment in technological learning, forcing actors to hone previous capacity gains to deliver clear market results.

Such a movement between capacity-building episodes under state-led reforms and efficiency-building ones under market-led ones also shares striking resemblances with March's (1991) distinction between "exploration" and

"exploitation" in organizational learning. According to March, exploration is characterized by "search, variation, risk taking, experimentation, play, flexibility, discovery [and] innovation." It is more uncertain and long-term than exploitation, which is characterized by "refinement, choice, production, efficiency, selection, implementation, [and] execution."[63] The distinct and complementary features of these learning modes led March to conclude that both are necessary but also in inherent competition for scarce resources.

This tension is pertinent to developing countries, where intensifying global competition, power asymmetries along geographically dispersed industry "value chains", and uncertain global demand render decisions of whether to engage in new capacities or shore up existing ones especially salient.[64] March's proposed relationship between learning modes also fits with other analyses of past developmental learning successes, such as the East Asian NICs, where many of the successes of market-led export-oriented development from the 1980s forward owed their foundations to advancements made under the prior state-led ISI paradigm.[65]

In sum, the three-part framework holds several important implications for both economic development research and policy. First, the mechanism of an exogenous shock is a highly prevalent yet under-researched condition for collective learning, and introduces a crucial missing piece to both classical economic and contemporary theories of industrial policy. Taking into account the potential salutary effects of exogenous shocks on industries also requires more nuance in future research – both to understand how learning communities use shocks as occasions to effectively build new capabilities as well as to assess how the relative status of an industry in an economy can result in its position as either a bastion of stability or a locus of reform. If current political and economic trends continue to shift against the dominant global trade regime and more towards nationalistic economic competition,[66] we can expect more shocks and heightened urgency for local learning in developing countries.

Second, the observed advantages of sequential alternations between exploration under state-led reforms and exploitation under market-led ones suggests that future research and policy needs to recognize a place for both paradigms, and

[63] March 1991:71, 73
[64] Rodrik 2014
[65] Bruton 1998
[66] Blyth 2016, Economist 2017

perhaps healthy competition between them. As pronouncements of the "death" of one policy paradigm after another arise, the natural response has been to look for something entirely new, often with negligible results. An alternative identified here is that more attention is needed on the relationships *between* existing models. This can hopefully facilitate further discovery regarding the formation of appropriate long-term learning sequences. Future research could build on the findings offered here by identifying more precisely the indicators of an industry's position in a learning sequence, as well as what policies help industries make effective transition between episodes of exploration and exploitation.

Finally, one noteworthy limitation of this framework is its incorporation of policy paradigm choice only as an independent variable. Although it extends beyond the scope of this paper, a clear understanding of how such paradigm balances are established is central to the research agenda outlined here. Already in evidence in the industry cases are some dynamics that would have to be addressed in a causal account of a policy paradigm's political strength. For example, shifting coalitions that form in response to changes in the relationship between domestic industries and the global economy. Such coalitions involve alliances between actors in the public sector, distinct subsets of firms (e.g. domestically vs. foreign-owned, clusters in different regions), organized labor and other civil society groups. Coalitional approaches to policy reform in developing countries have been introduced through a number of informative political science studies[67] and could be usefully connected to our explanatory framework in future research.

In this vein, future studies should broaden the sample of cases to test for whether and how different institutional contexts affect the independent variables introduced in this framework. They should also focus on how to improve the framework's predictive power, in particular by addressing the mechanisms through which external market shocks register at the industry level and the steps involved both within and between cycles of exploration and exploitation.

By undertaking these tasks, and integrating and building on the framework, this paper suggests that scholarship on development can move forward on the long-important question of how industries learn and specialize in a competitive global

[67] see e.g. Adler 1987, Kingstone 1999

market. Such efforts hold the promise of helping to respond to emergent shifts in the contours of globalization - shifts poised to alter fundamental aspects of the established opportunity structure for development and trade.

Appendix A: Major Industry Shocks and Responses, 1975-2000

MEXICO AUTO			
Year	**Shock**	**Influencing policy paradigm**	**Industry-level Response**
1976-1980	Balance of payments crisis	Market-led approach	Growing emphasis on exports, decreasing attention paid to local content requirements, new incentives to attract FDI, especially in the supplier segment (see the Decrees of 1972 and 1977).
1973	Oil shock	Market-led approach	Increasing emphasis on exports to make up for the shortfall in domestic sales.
1980s	Labor strife	Market-led approach	Declining support for unions in central Mexico, growing emphasis on export-oriented investment in the northern border, adoption of "California Labor Relations" approach (see Carrillo 1995).
1980-1985	Domestic recession	Market-led approach	Continued support for exports, initial import market liberalization, partial decentralization of policy-making (devolves power from federal to local governments) (see Decrees of 1977 and 1987)
1994-1996	Domestic recession	Market-led approach	Emphasis on export orientation of auto and parts, rapid growth of global mega supplier presence, liberalization of domestic market (see NAFTA)
BRAZIL AUTO			
Year	**Shock**	**Influencing policy paradigm**	**Industry-level Response**
1974-1976	Balance of payments crisis	State-led approach	Emphasis on local content requirements - much higher than in the Mexican industry, and more strictly enforced.
1973	Oil shock	State-led and market-led approach	Introduction of the export-promoting Special Fiscal Benefits for Exports (BEFIEX) program, and creation of the state-run PROALCOOL to foster ethanol use

1978-1980	Labor strife	Market-led approach	Migration of some auto plants away fro the heavily unionized Sao Paulo region to other Brazilian non-unionized locations
1987-1989	Domestic recession	Market-led approach	Emhphasis on export promotion, particularly to the Mercosur region, to overcome falling domestic demand
1990-1992	Domestic recession	State-led and market-led approach	Domestic import market liberalization coupled with the state-supported, demand-focused Carro Popular Program
MEXICO PETROLEUM			
Year	**Shock**	**Influencing policy paradigm**	**Industry-level Response**
1976-1982	Balance of payments problems and IMF loan program	Market-led	Industry shifts from exploration and production for local consumption to maximizing exports for foreign exchange; massive increase in ouptut and productivity improvements.
BRAZIL PETROLEUM			
Year	**Shock**	**Influencing policy paradigm**	**Industry-level Response**
1973-1979	Oil shocks	Market-led	After years of heavy emphasis on state-led investment, President Geisel institutes petroleum risk contracts for private firms. Petrobras accelerates efforts at learning exploration technology so as to stay ahead of imminent competition.
1982-1985	Debt crisis	State-led	Facing falling political legitimacy, the military regime increases Petrobras' production goals. MNCs are repelled by Brazil's political and economic climate. Petrobras is able to capitalize on the situation to make major offshore discoveries, but increasingly scarce resources prevent it from making the investments needed to bring them to

			production.
1995-2001	State privatization reforms	Market-led	State exposes Petrobras to foreign competition and public stock offering; the infusion of foreign capital allows Petrobras to make delayed investments to deliver on previous capacity-building and rapidly increase productivity to stay ahead of foreign competition.

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