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Published Version:
Trade liberalization, democratization, and technology adoption / Cervellati, Matteo; Naghavi, Alireza; Toubal, Farid. - In: JOURNAL OF ECONOMIC GROWTH. - ISSN 1381-4338. - STAMPA. - 23:2(2018), pp. 145-173. [10.1007/s10887-018-9155-5]

Availability:
This version is available at: https://hdl.handle.net/11585/635240 since: 2022-02-23

Published:
DOI: http://doi.org/10.1007/s10887-018-9155-5

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Trade Liberalization, Democratization, and Technology Adoption*

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December 2017

Abstract

A general equilibrium theory with heterogeneous skills predicts a complementarity between trade and democracy in creating demand for superior technologies. Trade liberalization or democratization alone may lead to vested interests that limit technology adoption. We use panel data on technology adoption, at a disaggregated level, for the period 1980-2000. Exploiting within-country variation over time and the heterogeneous timing of trade liberalization and democratization, we document a significant and sizable positive interaction between trade openness and democratization for technology adoption. The result that transitions to open democracies are beneficial for technological dynamics is robust to a large set of checks.

JEL-classification: F16, J24, O14, P51, F59

Keywords: Trade Liberalization, Democratization, Political Economy Theory, Technology Adoption, Disaggregated Panel Data, Within Country Variation.

*We are particularly grateful to the editor for guidance during the revisions, to four anonymous referees for useful comments and to an associate editor for very detailed and useful feedback. We also thank Jacques Melitz, Fabian Gouret, and Jose Tavares for insightful suggestions. The paper also benefited from comments from seminar participants at Heriot-Watt, Luxembourg, Reading, the UNCTAD-WTO seminar on trade and development in Geneva, and the audiences at the 7th Annual Conference on Economic Growth and Development in New Delhi, Midwest International Trade Meeting in St Louis, European Trade Study Group in Leuven and the International Workshop on Economics of Global Interactions in Bari. Financial support from MIUR through the project PRIN2015 - The Legacy of Institutions for Long Term Development 2015T9FYZZ is gratefully acknowledged.

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1 Introduction

Will trade liberalization and democratization bring economic prosperity? Are technological improvements outcomes of greater openness to trade and more political freedom? In the last decades many arguments have been proposed that suggest a positive answer to these questions. The consequences of these regime changes for technological improvement are, nonetheless, not straightforward from a theoretical perspective and have not been systematically explored empirically. This paper presents a theoretical and empirical investigation of the role of trade liberalization, democratization, and their interaction for technology adoption.

Existing theoretical literature has predicted that openness and democracy increase productivity, but mainly through indirect channels (see the related literature in Section 2). Trade leads to more efficient use of available resources, reducing the scope for inefficient rent-seeking made possible by economic protectionism. Democracy reduces the ability of the rent-seeking oligarchic elite to protect their vested interests, allowing the population to reap the benefits of their economic efforts. Opening to trade may therefore restrict the economic power of the elite while democratizing erodes their political power. The starting point of our analysis is the idea that, from a positive perspective, improving institutions in one dimension, but not in the other, may create an unbalanced shift in economic and political power that materializes in vested interests and political resistance to technology adoption. A natural implication of this view is the existence of a complementarity between trade liberalization and democratization for incentives to adopt new technologies.

We study a general equilibrium occupational choice framework in which the population is composed of a rentier elite and a majority of workers are endowed with heterogeneous skill levels. The model derives predictions on the impact of a shift to free trade or democracy on the demand for skill-biased technology adoption by different groups. Production takes place in two sectors: one traditional sector using manual labor and natural resources, the rents of which are extracted by the minority elite, and a modern manufacturing sector using skilled labor. Workers with heterogeneous skills optimally relocate between the two sectors with endogenously determined wages. The framework is used to characterize the preferences of the ruling political group regarding technology adoption in each trade and political regime.

The theory predicts that, starting from a closed autocracy, the elite may not benefit from the adoption of new technologies in the transition to an open economy, as it reduces the rents they can extract. In turn, a process of democratization in autarky may materialize in vested interests of the newly politically enfranchised because technology adoption may reduce the earnings of the less-skilled portion of the population. Consequently, the model predicts that trade liberalization or democratization alone does not necessarily lead to an increase in the demand for technological improvements. A transition to an open democracy nonetheless leads to an unambiguous increase in the demand for better technologies on the part of all workers (skilled and unskilled) that are assumed to be politically pivotal in democracies. The model therefore predicts the existence of a positive complementarity between the trade and the political regime in creating demand for more productive technologies.

The role of the interaction between the trade and political regimes for the adoption of better technologies has not been empirically explored. The theoretical predictions are tested using disaggregate measures of adoption at the level of single technologies using the CHAT database for 83 technologies in 104 countries during the period 1980 to 2000. As a benchmark, we exploit within-country variation in panel regressions with country and time fixed effects, and add technology or technology×time fixed effects to deal with the highly unbalanced nature of the dataset. The baseline specification therefore investigates the effects of both regime changes separately and jointly by exploiting a difference-in-difference design. The explanatory variables of main interest are the timing of trade liberalization and the timing of democratization. This methodology essentially compares a country that liberalized (or democratized) in a certain year to countries that did not experience institutional changes in that year.

The results show that the average (treatment) effect of either trade liberalization or democratization is generally statistically insignificant when exploiting within-country variation over time. Once the empirical specification is extended to the consideration of the predicted non-linear effects, the results reveal a large positive and highly statistically significant interaction between trade liberalization and democratization within countries over time. In particular, countries that undertake both transitions experience significant improvements in productivity and technology adoption. The positive effect of a joint regime transition is persistent over time. The findings therefore reveal that the average effects of trade liberalization or democratization hide relevant heterogeneity and suggest that studying their role in linear regressions frameworks can be misleading.

Several concerns have been raised in the literature about the effects of trade liberalization or democratization on macroeconomic outcomes at the country level (see also the discussion of the related literature in Section 2). We follow the literature and address the issue of omitted variable bias by restricting attention to within-country variation over time rather than cross-country variation. Period-specific effects (e.g., technological waves), technology-specific effects (differential patterns of adoption in different technologies), and period-technology specific effects (e.g., trends of adoption and dismissal in some specific technologies) are controlled for by including fixed effects on each of these dimensions. Another concern is a potential reverse causality running from aggregate economic conditions (e.g., income growth) to regime changes (trade liberalization or democratization). This concern has been addressed by running event studies analyses that exploit the potential randomness of the timing of the regime changes (rather than the randomness of the regime changes *per se*) in difference-in-difference designs and/or by exploiting the panel structure of the data. In our application, reverse causality should be less of a concern because the variable of interest is the changes in technology adoption at a highly disaggregated level (and not the change of a dependent variable at the country level, like income level), which also allows us to account for specific period-technology dynamics. As argued in the literature, this limits by construction the likelihood of problems of reverse causality running from technology adoption in each single technology to the timing of regime changes at the country level.

Another concern, that can be serious when dealing with macroeconomic (country level) outcomes and trade liberalization or democratization, relates to the existence of time-varying omitted factors that drive both technology adoption and regime changes. The potential role of third factors is, however, less straightforward in the specific application under consideration because a main empirical result of the paper is the existence of heterogeneous effects in non-linear specifications. More specifically, it is not obvious which type of reverse causality, or time-varying third factors, could deliver consistently opposite statistical biases when opening to trade in different political regimes or when democratizing under different trade regimes.

To assess the robustness of the results, and to investigate the empirical relevance of some side predictions, we perform an extensive set of checks. The results are robust to controlling for relevant covariates such as income per capita and population, consistently emerge in different samples using annual data and five-year intervals, and are robust with other (for instance continuous) measures of our independent variables. The results are qualitatively and quantitatively very stable when including initial conditions in each technology (thereby allowing for the convergence effect at the technology level). In addition, we measure technology adoption at the extensive margin to account for the introduction of different technologies in each country at different points of time, which also allows us to account for technology×country fixed effects while retaining within-country variation in the timing of adoption. Finally, we show in the Supplementary Material that the findings are not driven by a specific technology sector, and qualitatively hold when using manufacturing value added per worker as an alternative measure of technology adoption, when using leads as counterfactuals, or when restricting attention to countries that change only one regime, thereby iteratively ruling out reverse causality by construction in trade and political transitions.

The paper is organized as follows. Section 2 discusses the related theoretical and empirical literature. Section 3 presents the theoretical framework. Section 4 introduces the data, the estimation strategy, and the empirical results, while Section 5 concludes. The proofs and information on data sources are relegated to the Appendix. The full list of countries with the timing of regime changes, the summary statistics, the robustness checks, and the further results are collected in the Supplementary Material.

2 Background Literature

The theoretical roles of trade liberalization and democratization in the dynamics of technological change (and workers' productivity) have been studied, mainly independently, by trade and political economists. Wood (1995) was among the first to highlight the possible effects of trade openness on the "incentives" for (defensive) technology adoption. Thoenig and Verdier (2003) point out that firms that may have had little incentive to adopt technologies prior to trade liberalization undertake skill-biased innovations or adopt existing technologies to face the more intense competition from international markets. Acemoglu (2003) argues that trade liberalization also increases the possibility of adopting superior technologies. He notices, however, that not all countries appear to have equally profited from this opportunity and highlights the need to investigate the incentives for endogenous technology adoption.

The roles of political institutions, public policies, and implementation of informal arrangements for technology adoption have been largely discussed in both political science and economic history. Olson (1982) and, in particular, Mokyr (1998) provide extensive discussions on how policies implemented by political rulers can be strategically designed to facilitate, or slow down, technological dynamics through non-competitive arrangements, transparency and efficiency of the bureaucracy, or the cost of market entry. Acemoglu, Aghion, and Zilibotti (2006) endogenously relate the existence of barriers and alternative strategies that affect technology adoption to the distance to the technological frontier.

Following Melitz (2003) and Melitz and Ottaviano (2008), a number of recent contributions in international trade predict that aggregate industry productivity grows with trade liberalization through a selection effect, produced by the reallocation of resources towards more productive firms. This self-selection mechanism, which is supported by a growing body of evidence, can explain part of the losses faced by the autocratic elite should they concentrate their interests in relatively less efficient firms (or sectors of production).[1] In terms of a

[1]See also Melitz and Redding (2014) for a comprehensive overview. Aidt and Gassebner (2010) provide

differential role of political regimes, it has been argued that oligarchies raise more significant entry barriers against new entrepreneurs, whereas more diffused political power in democracies tends to dismantle such barriers, making it easier for the population at large to take advantage of new technologies; see Acemoglu (2006).

We contribute to the theoretical literature by providing an investigation of the preferences of the group in power over policies that facilitate or block the adoption of new technologies under different trade regimes. To this end we set up a theoretical framework in which workers with heterogeneous productivity self-select into different sectors. The theory builds on Yeaple (2005), and extends it to two sectors, one skill-intensive (modern) and one unskilled (traditional), to study wage differentials in general equilibrium. Along the lines of Galor and Moav (2000), we consider ability-biased technological progress that generates different changes in wage inequality both within and between the skilled and unskilled workers.

Technology adoption depends on the interaction between trade and political regimes. The paper contributes to recent literature that highlights the crucial role of political institutions in determining the impact of trade openness on aggregate outcomes in terms of *economic institutions*. The theoretical argument parallels, and complements, the one proposed by Falkinger and Grossman (2005) on public investment in education. Other works, like Segura-Cayuela (2006), Do and Levchenko (2009), and Stefanadis (2010) have investigated the role of interactions between trade and political regimes for redistributive policies, contract enforcement, and property rights protection, respectively.

When exploiting cross-country variation in trade or political regimes the typical finding is a positive effect of these institutional changes on income (or income growth).[2] Acemoglu et al. (2008) note that the results may be driven by omitted country-specific characteristics and show that the cross-country correlation between income and democracy completely disappears once country (and time) fixed effects are included. Subsequent works by Cervellati et al. (2014) and Murtin and Wacziarg (2014) qualify previous findings, showing that the effect depends on sample composition and on the time horizon of the analysis. Two further problems are related to the conceptualization and measurement of trade openness and democracy and the lack of exogenous (worldwide) variation in these regime changes. The problems have been recently addressed by a careful coding of the regime changes that have

evidence that oligarchic rulers are more free to extract resources in countries protected by trade barriers by, for example, exploiting trade taxes.

[2]There is a vast literature studying the determinants of income growth at the cross-country level. Przeworksi and Limongi (1993), Barro (1996), Tavares and Wacziarg (2001), Persson (2004), Rodrik and Wacziarg (2005), and Papaioannou and Siouraounis (2008) study the effect of democracy, while Greenaway, Morgan, and Wright (2002), Dollar and Kraay (2003), and Edwards (2008) focus on the effect of trade liberalization.

been used to identify the effects of trade liberalization and democratization by exploiting the heterogeneous timing of the transitions in difference-in-difference frameworks. Most notably, Rodrik and Wacziarg (2005), Papaioannou and Siouraounis (2008), and Persson and Tabellini (2009) find a positive and significant causal effect of democratization on income growth. Slaughter (2001) documents a positive effect of trade liberalization on per capita income convergence across countries. Wacziarg and Welch (2003, 2008) provide a systematic coding of the years of trade liberalization and the first robust evidence of the effects of trade liberalization on income growth (and investments) within countries over time.[3] Giavazzi and Tabellini (2005) extend the scope of the analysis to explore the dynamic feedbacks between economic and political liberalization for investment and income growth. Their findings suggest that studying the effects of each reform separately can be misleading.

The existence of an interaction between trade liberalization and democratization for technology adoption at a disaggregate level has not been investigated in the empirical literature. Limited data availability has until recently prevented the possibility of addressing this empirical question. Comin and Hobijn (2004) collected data for the pre- and post-WWII era across 25 major technologies in 23 countries over a period of 200 years and document that openness to trade increases the speed at which countries adopt technologies.[4] The cross-country panel data on technology adoption at a disaggregate level that has recently been made available (in the CHAT database) by Comin and Hobijn (2009a) for over 100 technologies in more than 150 countries is best suited for our purposes.[5] We investigate the interaction between changes in trade and political regimes, accounting for country-specific unobserved heterogeneity and waves of technological change by using a difference-in-difference framework with country and time fixed effects. As a benchmark we use the data on trade openness from Wacziarg and Welch (2008) and the data on democratization from the Polity IV database and Papaioannou and Siouraounis (2008).

[3]Aghion, Alesina, and Trebbi (2008) show that democracy fosters value added per worker in the more advanced sectors of an economy by reducing the protection of vested interests and granting freedom of entry into markets.

[4]Comin and Hobijn (2009b) and Comin, Dmitriev, and Rossi-Hansberg (2012) also highlight the role of political economy and trade in technology adoption by showing how lobbies and geographical distance slow down technology diffusion.

[5]Comin and Mestieri (2010) explore the intensive margin of technology adoption further by filtering out the effect of aggregate demand on technology adoption.

3 Theoretical Analysis

3.1 Set-Up

Preferences and Production. Consider an economy in which individuals have preferences over a manufacturing good X and a traditional good Z,

$$u = x^{\beta} z^{1-\beta}, \tag{1}$$

where x and z are the individual consumption of goods X and Z. We set the price of good Z to unity as numeraire and denote by p the (relative) price of the manufacturing good.

There are two factors of production: labor, denoted by L, and a fixed factor of production, N, that stands for, for example, land or natural resources. The population is divided into two groups: a unit mass of workers, who are endowed with a skill level θ distributed according to a cumulative distribution function $G(\theta)$ with density $g(\theta)$ where $\theta \in [1, \infty)$, and a smaller (minority) group of size $\sigma < 1$, referred to as the elite, who do not supply labor, but are the residual claimants of the income produced in the economy net of the remuneration of workers.[6] As discussed below, we assume that only the elite have political power to enforce policies in autocracies, whereas policy choices reflect the preferences of the majority of the population (composed of workers) in democracies. In the context of technology adoption, this implies the assumption that related policy decisions in the two regimes are made by the elite and by workers, respectively.

Production of the two goods takes place in two perfectly competitive sectors: (i) a resource-based traditional sector, which uses manual labor, L, and N to produce good Z; and (ii) a productivity-based manufacturing (modern) sector, which uses skilled labor to produce good X. Workers can freely supply their labor to either of the two sectors.

The good Z is produced using a Cobb-Douglas production function with constant returns,

$$Z(L, N) = L^{\eta} N^{1-\eta}. \tag{2}$$

The effective labor supplied by any individual working in the Z sector is independent from his skill level θ and is normalized to one. On the contrary, the amount of effective labor supplied in sector X depends on the skill level θ and is equal to $l(\theta, A) = \theta^{A}$, where $A \in [1, \overline{A}]$ represents the productivity of available technologies and $1 < \overline{A} < \infty$ is an exogenously given world technology frontier. Production in sector X is given by the total number of goods produced by all workers employed in that sector,

$$X(G(\theta), A) = \int_{\theta} l(\theta, A)\, dG(\theta), \tag{3}$$

[6] That the elite do not supply labor is stated only for simplicity. The results require only that these individuals are able to extract resources on top of the returns from supplying labor.

and depends both on the number of workers in the sector and on their productivity.[7]

Factor Income. Denote by y the individual factor income. For a given price of the manufacturing good, p, an individual supplying $l(\theta, A)$ units of effective labor to the X sector earns

$$y_X = \theta^A p. \tag{4}$$

The wage earned by a worker in the Z sector equals his marginal productivity and is independent from his skill level, as no skills are used in the production of the traditional good. The individual factor income of a worker in the traditional sector is therefore given by,[8]

$$y_Z = w(L, N) = \frac{\partial Z(L, N)}{\partial L}. \tag{5}$$

The elite are the residual claimants of the production in the traditional sector, that is, they appropriate (and distribute evenly among their group of size σ) all income produced in that sector net of the wages paid to workers:

$$y_E = [Z(L, N) - w(L, N)L](1/\sigma). \tag{6}$$

Notice that because the production function (2) has constant returns, this is equivalent to assuming that the elite control all rents accruing to the natural resources N. For our purposes we do not need to specify the means by which the (oligarchic) elite extract resources in the traditional sector. Empirically, the economic and political ruling groups in developing economies extract rents by various means, including the control and ownership of natural resources (like oil or land) that are priced on regulated markets, by controlling the state apparatus (which involves public patronage, corruption, fiscal transfers, and directed benefits), or by controlling state monopolies, to name just some of the possibilities.[9]

Two main features of the model drive the theoretical predictions. The first is that more advanced sectors of production are skill- (or human capital) intensive and better able to absorb technological improvements, while traditional sectors rely more on the use of less-skilled labor. The second is that the economic interests of the (oligarchic) elite in terms of extractable rents predominantly rely on the returns produced with a relative higher intensity of low skills and natural resources rather than human capital. This set-up aims at modeling these two features in the simplest way.[10]

[7]This modeling of the production function of the manufacturing sector essentially follows Yeaple (2005).

[8]Recall that the price of the Z good is normalized to one.

[9]See Acemoglu (2006) for an extensive discussion of these issues.

[10]For instance, the assumption that an increase in A affects only the production of good X is only to

Trade and Political Regimes. We consider a dichotomous representation of the trade regime. The economy can be either closed (in autarky) with no possibility for trade, or open, where all goods can be traded at zero cost. In an autarky the entire demand must be covered through internal production, and the domestic relative price, p, may differ from the one prevailing in international markets, p^*. In an open economy the internal demand is unrelated to internal production and the domestic relative price coincides with the world relative price: $p = p^*$.

We consider two extreme political regimes. In an autocracy, the elite control the state and extract all rents (net wages) produced in the traditional sector. Only the elite are politically represented, because they are the only ones allowed, *de jure*, to vote (due to the existence of constraints on the political franchise); they also can *de facto* control public policies by influencing or controlling elections and thereby set policies in their own self-interest. In a democratic regime all individuals can vote, and policies mirror the preferences of the majority of the population which, by assumption, is made up of workers.[11] The key assumption is that a process of democratization reduces the ability of the elite to defend their economic interest by exploiting their political power.

3.2 Equilibrium

Labor market equilibrium. Individuals face the choice between working in the Z sector, supplying one unit of (unskilled) labor, or working in the X sector, supplying their individual skill that amounts to θ.

Workers take earnings, prices of goods, and the technology of production as given when making optimal choices, which essentially amounts to comparing the expected income that can be earned in each sector, (4) and (5), given their individual skill level θ. A worker with productivity $\underline{\theta}$ is indifferent to working in either sector if, and only if,

$$\underline{\theta}^A p = w\left(L, N\right). \tag{7}$$

A worker with strictly higher skills, $\theta > \underline{\theta}$, optimally chooses to work in the X sector because from (7) we have

$$\theta^A p = (\theta/\underline{\theta})^A w(L, N) > w(L, N),$$

simplify illustration. The results require only that productivity in the modern sector is relatively more elastic to technological improvements than in the traditional sector.

[11] As discussed in Section 4, in line with the literature, the empirical coding of the political regime is based on information on the extension of the political franchise (whether it is restricted or universal), on the presence of free and contested elections, and on the extent of substantive political and civil liberties (which are measured by the Freedom House and the Polity Projects).

where $(\theta/\underline{\theta})^A$ is the wage premium enjoyed by a worker with skills θ, given A. Alternatively, any worker with $\theta < \underline{\theta}$ optimally chooses to work in the traditional sector and earns $w(L, N)$.

The equilibrium in an open economy requires only that the labor market is in equilibrium because the prices of goods are unaffected by the allocation of labor across sectors (as free trade implies convergence of relative prices to the international levels) and total consumption of each good does not need to be equal to its total production. Hence, we have

Lemma 1 [Equilibrium in an Open Economy] *For any $\{A, G(\theta), N\}$, in an open economy there exists a unique threshold level of skills, which is denoted by $\underline{\theta}^o(A)$ and characterized by (7) evaluated at $p = p^*$, for which the economy is in equilibrium.*[12]

Product market equilibrium. In a closed economy, the production of each good must equal its total demand. The characterization of the macroeconomic equilibrium therefore requires that both the labor and the product markets clear.

Given the utility function (1), the demand (in terms of aggregate expenditure) of each good is proportional to nominal income. Since in a closed economy the aggregate demand of each good must equal its total production we have that the product market clears if, and only if,

$$(1-\beta)pX(G(\theta), A) = \beta Z(L, N). \tag{8}$$

The economy is in equilibrium if the product and the labor markets both clear, that is, when (7) and (8) jointly hold. Given the production functions (2) and (3), this is the case if, and only if,

$$\beta G(\underline{\theta})\underline{\theta}^A = \eta(1-\beta)\int_{\underline{\theta}}^{\infty} \theta^A dG(\theta). \tag{9}$$

We therefore have

Lemma 2 [Equilibrium in a Closed Economy] *For any $\{A, G(\theta), N\}$, in a closed economy there exists a unique threshold level of skills denoted by $\underline{\theta}^c(A)$ for which (9) holds so that both the product and the labor markets are in equilibrium.*

Proof: See Appendix.

[12] Treating the skill levels as unbounded guarantees an interior solution to Lemma 1 in terms of the threshold level of skills that puts the economy in equilibrium. When skills are bounded, we could have a corner solution in which the manufacturing sector is closed down in an open economy when imports are sufficiently cheap, that is, low p^*.

3.3 The Effects of Technological Improvements

To characterize the conflict of interests regarding technological improvements across different groups, consider the possibility of a costless increase in the productivity of (skilled) labor in the modern sector, A. This can be interpreted, for instance, to be a consequence of the adoption of a new technology that allows a country to advance towards the world technological frontier. It can also come from a policy aimed at attracting better technologies through foreign direct investment, investing in research and development, or the reduction of barriers to entry in modern business through better property rights protection, and so on. The assumption that technological improvement is costless allows us to focus on the conflicts of interest regarding its economic consequences by abstracting from redistributive issues related to the financing of these policies.[13]

Let us characterize first the effect of a rise in productivity, A, in a closed economy:

Lemma 3 [Technological Improvements in a Closed Economy] *In a closed economy, a marginal increase in A increases the equilibrium threshold skill level, denoted by $\underline{\theta}^c(A)$ (thereby decreasing the share of workers in sector X). The total production of both sectors X and Z increases, the relative price of the manufacturing goods, p, decreases, and*
(i) nominal wages in the traditional sector, w, decrease;
(ii) the skill premium of workers in the manufacturing sector, $(\theta/\underline{\theta}^c)^A$, increases only for workers with $\theta > \overline{\theta}(A) > \underline{\theta}^c(A)$, so that in the X sector only workers with a high enough skill level experience an increase in nominal earnings, $w(L(\underline{\theta}^c), N)(\theta/\underline{\theta}^c)^A$.

Proof: See Appendix.

In a closed economy, improvements in productivity in the X sector lead to a shift of workers away from this sector. This seemingly counter-intuitive effect is due to the fact that in a closed economy the internal demand and supply of each good must equalize in general equilibrium. A higher A expands the economy's production possibility frontier, thereby increasing total income, so that the equilibrium demand and the production of all goods increase. Since the larger demand can be satisfied only by domestic production, it requires more workers in the traditional sector (which does not experience an increase in productivity). The larger demand for X is satisfied by an increase in production using fewer, but more productive, workers. Notice that this continues to hold under CES utility with an elasticity of substitution greater than one.

[13]Empirically one can explore only the sign, or equivalently the direction, of changes in technology adoption in response to regime changes and not an optimal level of technology. To simplify the derivation of the prediction on the direction of the change we have limited our analysis to the consideration of a costless (marginal) change in A.

As labor becomes more abundant, the equilibrium nominal wage in the traditional sector, w, is reduced. An increase in the threshold $\underline{\theta}^c$ eliminates the skill premium of the workers moving to the traditional sector and reduces the skill premium of the least-skilled workers still employed in the manufacturing sector. Consequently, technology adoption reduces the nominal wages of these workers, and rent extracted by the elite from the traditional sector increase at the expense of the displacement of manufacturing workers at the lower end of the skill spectrum. Among workers still employed in the manufacturing sector, only those with sufficiently high skills $\theta > \overline{\theta}(A)$ experience an increase in their nominal wages as a result of the increase in their skill premium. More productive technologies therefore replace low-skilled workers in a closed economy and increase competition between the skilled. These predictions are along the lines of Galor and Moav (2000), who show that ability-biased technological change leads to an increase in wage inequality both within the skilled and between the skilled and unskilled workers. The utility of workers experiencing a drop in nominal wages can increase only if the reduction in the relative price of manufacturing is large enough to increase their real wages.

Next, let us characterize the effect of increasing productivity in an open economy:

Lemma 4 [Technology Adoption in an Open Economy] *In an open economy, a marginal increase in A decreases the equilibrium threshold skill level of the indifferent worker, $\underline{\theta}^o(A)$ (thereby increasing the share of workers in sector X). The production of X increases, while that of Z decreases. Prices remain unchanged at $p = p^*$ and*
(i) nominal wages in the traditional sector, w, increase;
(ii) the skill premium of all workers in the manufacturing sector, $(\theta/\underline{\theta}^o)^A$, and hence their nominal earnings, $w(L(\underline{\theta}^o), N)(\theta/\underline{\theta}^o)^A$, both increase.

Proof: See Appendix.

In an open economy, an improvement in the productivity of the modern sector attracts more workers, thereby increasing the production of X. Local production of the traditional good decreases and the larger demand is met by imports. In the traditional sector, where labor becomes more scarce and marginally more productive, the indifference wage required by workers increases. Once the economy has liberalized to trade, a rise in productivity, A, therefore increases the skill premium both directly (for any skill level) and by reducing the minimum skill level $\underline{\theta}^o$ required to work in that sector. With prices unchanged, the adoption of better technologies in an open economy therefore increases real wages of all workers and reduces the rents that the elite can extract.

3.4 The Effect of a Regime Change on Technology Adoption.

The ultimate goal of the analysis is to study the change in incentives for technological improvements (an increase in A) in response to a change in the trade and/or the political regime. To this end, we next characterize who gains and who loses from the adoption of a new technology that results in a higher A under each trade regime. We then relate the adoption decision to the preferences of the group in power under each political regime.

In this set-up, with Cobb-Douglas preferences, the expenditure levels on the two goods are fixed shares of total expenditure. This implies that the utility of each individual is given by,

$$u(x(A), z(A)) = \widetilde{\beta}\frac{y(A)}{p(A)^{\beta}}, \tag{10}$$

where $\widetilde{\beta} \equiv \beta^{\beta}(1-\beta)^{1-\beta}$ and $y(A)$ and $p(A)$ denote the equilibrium individual nominal income and relative price for any given A, respectively. Individual utility increases with nominal income and decreases with the price, $p(A)$. The effects of increasing productivity A on the nominal income of different individuals and prices in closed and open economies are studied in Lemmas 3 and 4.

Consider an economy initially characterized by an autarkic trade regime and ruled by the autocratic elite, that is, a closed autocracy. As discussed in more detail in Section 4, empirically no country experienced a contemporaneous change in both trade and political regime during the observation period 1980 to 2000. The historical transitions from closed autocracies to open democracies have therefore always involved, as an intermediate step, either a transition to an open autocracy or a transition to a closed democracy. Accordingly, we investigate the change in incentives for technology adoption after trade liberalization, after democratization, and after a (long-run) transition that involves both.

Let us first study how the incentives of the ruling autocratic elite towards technological improvements differ in an open economy. From Lemma 3, in a closed economy, a larger A leads to a reduction in the price p, which increases the utility of all individuals in the economy by making manufacturing goods cheaper. The oligarchic elite, who are the residual claimants of production in the traditional sector, gain from the reduction in baseline wages, w, which is associated with a higher skill premium in the manufacturing sector and tougher competition facing the less-skilled workers. Both effects unambiguously increase the real income and, therefore, the utility of the autocratic elite. In an open economy, technology adoption does not deliver advantages in terms of prices (since they are set in international markets). Also from Lemma 4, the autocratic elite face a reduction in their ability to reap the benefits of more productive technologies in an open economy because wages increase following the shift of workers towards the manufacturing sector. They are therefore worse off if productivity A increases.

Opening the economy increases the vested interests of the autocratic elite. Said the other way around, a process of trade liberalization alone is therefore expected to reduce the incentives for technological improvements on the part of the ruling oligarchic elite.

Proposition 1 [Trade Liberalization] *For any $\{A, G(\theta), N\}$, in a closed autocracy the incentives of the ruling elite for fostering technological improvements are reduced after opening to trade.*

Proof: See Appendix.

Consider now the effect of a process of democratization of a closed autocracy. By assumption the political power to implement (technology adoption) policies shifts from the elite to the workers. A rise in the political representation of workers reduces the political ability of the (former) autocratic elite to defend their economic interests. However, in view of Lemma 3, technology adoption can have different effects on the well-being of different workers. Although for different reasons than those for the (former) oligarchic elite, the more-skilled workers of the manufacturing sector unambiguously gain from higher productivity (their wages increase and they enjoy lower prices). A transition to democracy should therefore leave incentives for technological improvements essentially unchanged if these workers become politically pivotal (if they are, for instance, the new median voters). In turn, the workers in the traditional sector and the less-skilled in the manufacturing sector enjoy a net gain only if the reduction in equilibrium prices more than offsets the reduction in their wages. If this is not the case and the less-skilled workers outnumber the highly-skilled workers, then the process of democratization may even lead to a reduction in the demand for adoption of new technologies and, accordingly, for the incentives to facilitate improvements in this dimension.[14]

Depending on the actual gains or losses of workers with lower skills in terms of their real wages and their political power in democracy, we should therefore expect a process of democratization in a closed economy to have either no effect (if both elite and workers favor adoption) or a negative effect on the incentives to promote technological improvements.[15]

[14] This appears the most likely scenario in less-developed countries, where the low income workers tend to be politically pivotal; see Tavares (2008).

[15] If technological progress is not skill-biased, it always leads to higher real wages for all workers and democratization would always leave the incentives to foster technology improvements unchanged.

Proposition 2 [Democratization] *Consider a closed autocracy. For any* $\{A, G(\theta), N\}$, *transferring political power from the elite to the workers, that is, a process of democratization, either leaves incentives for fostering technological improvements unchanged or reduces them.*

Proof: See Appendix.

Finally, from Lemma 4, technological improvements unambiguously benefit all workers in an open economy. Experiencing a transition to an open democracy raises incentives to adopt new technologies. In view of Proposition 2, the increase in such incentives is smaller (or absent) if trade liberalization takes place in a country that has already experienced a transition to a democracy, where the highly-skilled workers benefiting from a larger A are politically pivotal.

Proposition 3 [Trade Liberalization and Democratization] *Consider a transition to an open democracy. For any* $\{A, G(\theta), N\}$, *the incentives of the ruling political group for fostering technological improvements:*
i) strictly increase after democratization of an open autocracy;
ii) increase, or are left unchanged, after trade liberalization in a closed democracy.

Proof: See Appendix.

The joint consideration of Propositions 1, 2, and 3 also implies that the total effect of moving from a closed autocracy to an open democracy is theoretically ambiguous, as it also depends on the potential slowdown in technology adoption during the first transition. Recall that there are two phases to the transition. From Propositions 1 and 2, the first step of the transition (towards openness or democracy) either leaves unchanged or negatively affects the incentives for technology adoption. From Proposition 3, the second phase of the transition will tend to promote technology adoption.

Before turning to the empirical evidence some remarks are in order. To derive testable implications for the interaction between regimes and technological dynamics, the theory studied the effect of technology adoption on the utility of the different individuals. As discussed also in Section 2 above, the literature has studied several public policies and interventions used by political rulers to defend their interests and, in particular, affect technology adoption. To the extent to which technological dynamics are endogenous to individual and political choices, the previous propositions characterize the incentives for different individuals, and for the group in power (the autocratic elite in an oligarchy and the workers in a democracy) to facilitate or slow down the dynamics of technology adoption conditional on the trade regime.

The predictions were derived considering exogenous changes in the political and/or the trade regime, which may nonetheless also be subject to deliberate shifts. However, it is important to notice that the theoretical predictions on the differential incentives for technology adoption hold irrespective of the actual reasons behind the change in the political and trade regimes. The primary goal of the empirical analysis is therefore to explore the novel predictions of a significant complementarity between changes in political and trade regimes for technology adoption. Although the proposed theory does not allow clear-cut conclusions for endogenous regime changes that may follow (or aim at) technology adoption, the question on the role of technological dynamics for endogenous democratization and opening to trade remains interesting and empirically relevant.[16]

4 Empirical Evidence

The theoretical framework delivers several testable predictions. Propositions 1, 2, and 3 characterize changes in the demand and incentives for the adoption of new technologies after trade liberalization or/and democratization. The theory predicts, in particular, a complementarity between trade and political regimes. In the model, and in the data, the joint transition in both regimes therefore represents the long-run situation resulting from two transitions over time.

In this section, we investigate the empirical relevance of the theoretical insights and conduct a series of sensitivity exercises to explore the robustness of the baseline findings. To devise an estimation strategy, let us recall that the theory does not deliver any prediction on the level of technology in closed and open countries or in autocracies and democracies, but on the changed incentives for technology adoption in response to changes in regimes. A test of the predictions therefore requires exploiting variation in regimes and technology *within* countries over time, rather than across countries at each point of time.

4.1 Data

We investigate the effect of trade liberalization and democratization for technology adoption during the period 1980 to 2000, which encompasses most of the third wave of democratization and many episodes of trade liberalization. The baseline information on trade liberalization

[16]Notice that, in view of the model presented above, we should not expect technological dynamics to be a main driver of either regime change. The autocrats are not enticed to extend the franchise, which would at any rate not affect (or even dissuade) technology adoption on the part of the new ruler, and do not have any long-run gains from opening to trade, since this would impair their incentives for technology adoption.

is from Wacziarg and Welch (2008), which update and improve the Sachs and Warner (1995) openness indicators and identify the trade liberalization dates. The liberalization date is the year after which the openness indicators are met.[17] The trade liberalization variable takes the value of one at the starting date indicated by Wacziarg and Welch (2008), and zero otherwise. This coding involves permanent trade regime changes. As baseline information for democratization we use data on political regimes from the Polity IV database. As a benchmark, we use the coding of democratization by Papaioannou and Siourounis (2008), which further accounts for political stability, thereby restricting attention to the subset of permanent democratic transitions.[18]

In line with the theory, and following the empirical literature discussed in Section 2, we consider a dichotomic representation of the trade and the political regimes as baseline.[19] The use of binary coding also allows us to implement the baseline empirical specifications as difference-in-difference(-in-difference) and to limit the typical problems associated with the use of slow-moving variables in panel regressions with country and time fixed effects. For robustness, we also use continuous measures of both democracy and trade openness. The full list of the countries in the sample, including the dates of change of their trade and political regimes and the list of countries in the different bins of trade and political regimes, can be found in the Supplementary Material.

In the absence of direct measures, the early empirical literature has focused on the Solow residual as proxy for factor productivity. A main limitation of this strategy is that this measure captures (by construction) also the effect of all other factors beyond technology adoption such as, for example, the variation of capacity utilization, labor hoarding, and the inefficiencies of the economy related to formal and informal institutions. The best available information on technological dynamics within countries over time is the level of adoption at the level of single technologies that is available from the Cross-Country Historical Adoption of Technology (CHAT) dataset assembled by Comin and Hobijn (2009a). For the period 1980 to 2000, we exploit a baseline sample that contains data on the adoption of 83 technologies

[17]According to the original classification by Sachs and Warner, a country is defined as being open if none of the following criteria is met: (i) average tariffs exceed 40 percent, (ii) non-tariff barriers cover more than 40 percent of trade, (iii) it has a socialist economic system, (iv) the black market premium on the exchange rate exceeds 20 percent, or (v) there is a state monopoly on major exports. The original index has been subject to several criticisms as it also captures aspects of liberal policies as well as trade policies.

[18]The Polity IV variable measures the quality of democratic institution and varies from +10 (strongly democratic) to -10 (strongly autocratic). To check the robustness of the results we also use alternative codings of political regimes, such as Golder (2005).

[19]The conceptualization of trade openness and democracy as dichotomic follows a large empirical literature; see Munck and Verkuilen (2002), Przeworski et al. (2000), and Wacziarg and Welch (2008).

for 104 developed and developing countries. The data provide information on the number of units of capital that embody a given technology or the amount of output produced using it in an economy, and is available for a wide range of technologies, countries, and years.[20]

4.2 Empirical Specification

Testing the predictions requires estimating the effect of changes in either the trade or the political regime, or both. The baseline explanatory variables of interest are $Open_{jt}$, a dummy variable that takes the value of one in the years after opening to trade and zero otherwise, and $Demo_{jt}$, which takes the value of one once the country has democratized and zero otherwise. To study how the possible complementarities between the trade and the political regimes affect adoption, we consider the interaction between the two variables, $Open_{jt} \times Demo_{jt}$.

The empirical strategy exploits information on changes in trade and political regimes within countries over time (rather than the mere status of openness and democracy at each point of time). We use information on technology adoption at the disaggregate level from the CHAT database and estimate the model

$$\begin{aligned} ln\left(TechA_{ijt}\right) &= \beta_0 + \beta_1 Open_{jt_{-1}} + \beta_2 Demo_{jt_{-1}} + \beta_3 \left(Open_{jt_{-1}} \times Demo_{jt_{-1}}\right) \\ &+ \beta_4 X_{jt} + \Phi_{i/j/t} + \varepsilon_{ijt}, \end{aligned} \tag{11}$$

where X_{jt} denotes time-varying country-level covariates and ε_{ijt} is a technology-, country- and time-specific error term. The standard errors allow for clustering at the country level to account for heteroskedasticity and non-independence across the repeated observations within countries.[21]

The empirical model (11) encompasses (and will be specialized to investigate) different panel data specifications. The vector $\Phi_{i/j/t}$ generically indicates the possible inclusion of different types of fixed effects at the level of technology i, country j, and time t (and possibly their interactions). As baseline we treat both openness and democracy (and their interaction) as dichotomous measures, with two-way fixed effects, $\Phi_{i/j/t} = \phi_j + \phi_t$. The inclusion of country fixed effects, ϕ_j, accounts for time-invariant country-specific characteristics that may jointly affect the technology level, the trade and the political regime, and omitted variables such as geography or social norms that may differently affect technology adoption

[20] For robustness checks we also use information on country-level labor productivity from Mayer, Paillacar, and Zignago (2008) that still offers only an indirect measure of technology adoption at the country level.

[21] This level of clustering is chosen as benchmark because the information on trade and political regimes is at the country level. For robustness we have nonetheless also considered clustering the errors at the technology-country level and at the technology level.

in different countries. The inclusion of common time fixed effects, ϕ_t, allows us to account for global waves in technological adoption. This specification is the typical difference-in-difference model, henceforth d-i-d, used in the literature discussed above.

The CHAT database is highly unbalanced in nature and the different technologies are measured in different units. To account for these features, an extended specification also includes technology fixed effects, ϕ_i, so that $\Phi_{i/j/t} = \phi_i + \phi_j + \phi_t$. Following Comin and Hobjin (2009b), we also use technology×time fixed effects denoted by ϕ_{it} (rather than technology and time fixed effects separately) to account more flexibly for the possibility that different technologies follow different adoption paths over time, so that $\Phi_{i/j/t} = \phi_j + \phi_{it}$.[22] Finally, we explore a specification that includes technology×country fixed effects, ϕ_{ij}, to account for country specificities that can favor/disfavor the adoption of specific technologies, so that $\Phi_{i/j/t} = \phi_{ij} + \phi_t$.

4.3 Baseline Results

Technology Adoption Within Countries Over Time (Yearly Frequencies). The theoretical model provides testable predictions on the effect of *changes* in the trade and/or the political regime on the incentives to adopt new technologies rather than on different levels of technology under different regimes. We therefore start by investigating the role of changes in regimes within countries over time, estimating the empirical model (11). The analysis essentially exploits the differential timing of the transition from close autocracies to open autocracies or to closed democracies, respectively, and eventually the timing of the transition to open democracies. In view of the theory, the existence of vested interests, and of a possible slowdown during a partial transition out of closed autocracies (to either openness or democracy), should be temporary. The theory predicts that in the long run the final transition to open democracies should nonetheless be beneficial. In this section we explore the empirical role of regime transitions exploiting the standard d-i-d framework at yearly frequencies. In Section 4.4, we further explore the role of initial conditions and the timing of the effects of the different regime transitions.

The results of the within estimates need to be interpreted with reference to the omitted category that (as in a standard d-i-d framework) is the set of countries that do not change

[22] For many technologies the data reports information on the number of capital goods per capita (e.g., the number of computers per capita). For some technologies the information refers to the output produced (e.g., the amount of steel produced in electric arc furnaces), while for some the data report information on technology level of diffusion (e.g., the number of credit and debit card transactions per capita). We refer to Comin and Hobjin (2009a) for an exhaustive description of the data.

the respective (trade or/and political) regimes at each point in time. To isolate the role of regime changes, for instance the effect of a *transition* to democracy, the d-i-d literature typically evaluated the effect with respect to all countries that do not democratize at each point in time, including both those that remain autocracies and those that are already (and always) democracies. Similarly, the mere effect of opening to trade can be studied using a reference group including both countries that do not open to trade and countries that are already open.

Estimating the effect of a transition from autocracy to democracy requires dropping from the reference (omitted category) all countries that are already democracies at the beginning of the observation period. Similarly, countries that are always open must be excluded from the omitted category if one wants to estimate the effect of a transition from closed to open economies. As baseline we therefore focus the analysis on the sub-samples of countries that start closed, or autocratic, or both. This allows us to explore the effect of each regime change and the predicted complementarity between regimes, and to interpret the effect of passing from each (trade-political) regime bin to the next and the magnitude of the total effect (of moving from a closed autocracy to an open democracy).[23]

The descriptive statistics and the correlation tables of the baseline sample are presented in the Appendix. The within correlation between democracy and openness is about 0.05, between democracy and the interaction is 0.36, and between openness and the interaction is around 0.7.

Table 1 reports the results. Columns (1) and (2) present the d-i-d effects of opening to trade and democratization. The effect of each regime change on technology adoption is, respectively, positive and negative, but generally statistically insignificant at conventional levels. Column (3) confirms the patterns when accounting for both transitions. According to the theory, however, the average effect of each transition should be expected to conceal important heterogeneous effects and, in particular, a complementarity between both regimes. To test this prediction, column (4) includes the interaction effect between the two regimes by estimating empirical model (11) that nests the specifications of columns (1) to (3) as special cases. The results reject the null hypothesis of an insignificant interaction $\beta_3 = 0$ in the empirical model (11), and document the existence of a positive, large, and highly significant effect of the interaction between openness and democracy.

Columns (5) and (6) extend the specification by including further covariates, in particular

[23]This amounts to excluding from the omitted category the countries that are open democracies from the beginning of the sample period. This involves restricting attention to 104 countries from the full sample of 129. We have replicated all the analysis in the full sample (thereby including open democracies in the reference category) and obtained similar qualitative results.

Table 1: TRADE OPENNESS AND DEMOCRACY: TECHNOLOGY ADOPTION

Dep. Variable	Technology Adoption - Disaggregate Level CHAT Data					
	(1)	(2)	(3)	(4)	(5)	(6)
Openness	0.072		0.075	-0.129	-0.142**	-0.134**
	(0.790)		(0.810)	(-0.950)	(-2.374)	(-2.444)
Democracy		-0.016	-0.024	-0.110	-0.014	-0.022
		(-0.188)	(-0.274)	(-1.213)	(-0.337)	(-0.538)
Open×Demo				0.302**	0.210***	0.227***
				(2.022)	(3.272)	(3.786)
Population (log)	No	No	No	No	Yes	Yes
GDP per Capita (log)	No	No	No	No	Yes	Yes
Fixed Effects:						
Country	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	No
Technology	No	No	No	No	Yes	No
Tech×Years	No	No	No	No	No	Yes
Observations	38,735	38,735	38,735	38,735	36,222	36,107
Countries	104	104	104	104	97	97
Adjusted R^2	0.067	0.067	0.067	0.067	0.951	0.954

Dependent variable, $\ln(TechA_{ijt})$, is the adoption of technology i in country j in year t. Panel data at yearly frequencies. OLS estimates with robust standard errors adjusted for clustering by country. Student ts are in parentheses. ***, **, * significantly different from 0 at 1%, 5%, and 10% levels, respectively.

population and GDP per capita, that are relevant drivers of technology adoption within countries over time. These specifications respectively include technology and technology×year fixed effects in order to flexibly (nonlinearly) control for the specificities in the diffusion paths of different technologies (see Comin and Hobjin, 2009b, p. 235).[24] Compared to the baseline, these are not standard d-i-d specifications because the estimates are based on the variability that is left in the data after netting out technology-specific time effects that are assumed to be common across countries.

Across the different specifications the joint transition to open democracy involves a sizable acceleration in technology adoption, in the order of at least 20 percent. Passing from a closed autocracy to an open democracy leads to an increase in technology adoption that, depending on the specifications, ranges from 15 percent for the d-i-d to 7 percent in the most extensive specification, controlling for population, GDP, and time-varying technology-specific diffusion patterns.

[24]For space reasons we directly report the most extensive specifications in columns (5) and (6). The results are similar when controlling for the covariates in the d-i-d framework and when excluding them in the specifications with alternative technology and time fixed effects.

Discussion. The literature on trade openness and democratization has raised the issue that the estimates of the effect of political or trade regimes can be affected by reverse causality if the variable of interest, for instance income growth or the level of foreign direct investments, consistently affects the probability that a country will undergo trade liberalization or a transition to democracy.[25] In our application the variable of interest is not, as is typical in the literature, at the level of countries (e.g., GDP) but is at the level of single technologies whose dynamics appear unlikely to affect trade openness or democratization at the country level. Endogeneity problems may arise also if time-varying omitted third factors affect both regime transitions and technology adoption in a specific way. The lack of convincing instruments for the transition in openness, democracy, and their interaction limits the applicability of instrumentation strategies in this context. Following the literature we try to mitigate these concerns by restricting attention to within-country variation over time (that explicitly deals with time-invariant omitted factors) in d-i-d frameworks that exploit the differential timing of the regime transitions across countries rather then regime changes *per se*. The identification of the effect of the regime changes essentially requires that the timing of the transitions (and the timing of the final transition to open democracies) are not driven by the change in technology adoption at the disaggregated level or by omitted time-varying third factors.

We have implemented a set of robustness and sensitivity checks that can be informative on endogeneity and on some side predictions. Given the arguments proposed in the literature, reverse causality should bias the estimates of the effect of either trade liberalization or democratization upwards, delivering 'false' positive effects if improvements in technology adoption facilitate opening to trade and/or democratization. Recall that the main empirical result is on the existence of an interaction between changes in both regimes and technology adoption, however. In this respect, it is not obvious which type of reverse causality, or which type of time-varying third factors (above and beyond the evolution of population dynamics, income per capita and the time patterns that are implicitly controlled for with the inclusion of technology$\times$year fixed effects), could deliver consistently opposite statistical biases when opening to trade in different political regimes or when democratizing under different trade regimes.[26] In fact the qualitative patterns emerge when restricting attention to the subset of countries that switch only one regime, thereby iteratively ruling out by construction endogeneity in either trade openness and democratization. The analysis has

[25] See Bertrand, Duflo, and Mullainathan (2004) and Giavazzi and Tabellini (2005) for extensive discussions of this issue.

[26] For instance, there are about 60 transitions to trade openness (the full list of trade and political regimes and transitions years that is reported in the Supplementary Material). About 40 percent of these transitions take place in autocracies and 60 percent take place in democracies.

been replicated in the sub-samples obtained by dropping iteratively each technology sector to explore the sensitivity of the results (both in terms of reverse causality and time-varying omitted factors). The baseline findings are robust to the inclusion of three- and five-year leads (as counterfactual). We also replicated the analysis using manufacturing productivity from Mayer, Paillacar, and Zignago (2008) as an alternative, indirect proxy for (aggregate) technology adoption. The measure is at the country level, which makes it more prone to reverse causality, but the balanced sample makes it more suitable to use GMM estimators which could help in dealing with endogeneity of regime transitions. Although none of these exercises is in itself conclusive, the emergence of a consistent pattern is at least suggestive of the robustness of the baseline findings.[27]

4.4 Robustness and Further Results

The baseline results in Table 1 illustrate the patterns of the effect of trade liberalization, democratization, and their interaction that typically emerge from different panel specifications. Before concluding we present results obtained by exploiting five-year panel frequencies; using non-dichotomous measures of technology adoption; controlling for country and technology initial conditions and different lags of regime changes; looking at the extensive margin of technology adoption in a balanced panel at yearly frequencies.

Five-Year Frequencies. A first check involves exploring panel specifications at five-year rather than yearly frequencies. In spite of a shorter time dimension (involving five time series observations) and a substantially reduced sample, the resulting panel is more balanced. A five-year time horizon also allows us to study the effect of regime changes in technology adoption by implicitly accounting for the existence of some delays in the effect of regime changes.[28]

The results are reported in Table 2. At five-year frequencies the effect of openness alone in column (1) is positive and (marginally) significant, while no significant effect of democratization can be detected in column (2). Columns (4) to (6) confirm the baseline findings at yearly frequencies with similar size, in terms of both the interaction and total effect, and in statistical significance.

[27]These checks are reported in the Supplementary Material. The findings at yearly frequencies are also robust to the use of alternative codings of democratization and are not driven by a specific set of countries, in particular those belonging to the former Soviet bloc that went through a transition to market economies in the 1990s.

[28]The within correlations of the panel with five-year intervals are 0.03 between demo and openness, 0.36 between democracy and the interaction, and around 0.65 between openness and the interaction.

Table 2: Technology Adoption - Five-Year Frequencies

Dep. Variable	Technology Adoption - Five-Year Frequencies					
	(1)	(2)	(3)	(4)	(5)	(6)
Openness	0.206*		0.221*	-0.142	-0.164**	-0.152**
	(1.669)		(1.783)	(-0.804)	(-2.094)	(-2.156)
Democracy		-0.111	-0.131	-0.277**	-0.051	-0.050
		(-1.016)	(-1.150)	(-2.293)	(-1.083)	(-1.083)
Open × Demo				0.540***	0.239***	0.253***
				(2.833)	(2.833)	(3.220)
Population (log)	No	No	No	No	Yes	Yes
GDP per Capita (log)	No	No	No	No	Yes	Yes
Fixed Effects:						
Country	Yes	Yes	Yes	Yes	Yes	Yes
Period	Yes	Yes	Yes	Yes	Yes	No
Technology	No	No	No	No	Yes	No
Tech.×Period	No	No	No	No	No	Yes
Observations	9,115	9,115	9,115	9,115	8,434	8,397
Countries	104	104	104	104	97	97
Adjusted R^2	0.059	0.059	0.059	0.059	0.950	0.954

Dependent variable, $\ln(TechA_{ijt})$, is the adoption of technology i in country j in period t. OLS estimates with robust standard errors adjusted for clustering by country. Student ts are in parentheses. ***, **, * significantly different from 0 at 1%, 5%, and 10% levels, respectively.

Non-Dichotomous Measures of Trade and Political Regimes. As a further robustness check it is useful to investigate the effect of openness and democratization in terms of non-dichotomous measures. Implementing this strategy is subject to some caveats that have been raised in the literature. The interpretation of the results cannot be made along the lines of a standard d-i-d set-up, and the variation overtime in non-dichotomous measures should be interpreted with caution as they are potentially more noisy, and endogenous, compared to dichotomous ones. An additional complication for trade openness is that no standard non-dichotomous measures are available for trade reforms overtime.[29] We use five years panel data on the "freedom to trade internationally" index from the Fraser Institute and the Polity IV continuous index to explore their role of technological dynamics.[30] The results, reported

[29]Measures of trade openness often used in the literature, such as the total imports and exports over GDP, cannot be used for our purposes because they inform on the actual trade flows and not on the trade regime changes (or trade reforms). These measures are also typically regarded as likely endogenous to technological dynamics.

[30]With non-dichotomous measures the within correlation between openness and democracy, openness and the interaction, and democracy and the interaction are around 0.07, 0.67, and 0.40, respectively.

in Table 3, confirm the patterns obtained with the d-i-d estimators at five-year frequencies, even if the coefficients are slightly less precisely estimated.

Table 3: NON-DICHOTOMOUS MEASURES OF TRADE AND POLITICAL REGIMES

Dep. Variable	Technology Adoption - Five-Year Frequencies					
	(1)	(2)	(3)	(4)	(5)	(6)
Openness Score	-0.170		-0.164	-0.151	-0.010	0.004
	(-0.505)		(-0.485)	(-0.450)	(-0.057)	(0.022)
Democracy Score		-0.068	-0.064	-0.039	0.038	0.041
		(-0.389)	(-0.365)	(-0.221)	(0.480)	(0.521)
Open Sc. x Demo. Sc.				1.001*	0.621**	0.594**
				(1.828)	(2.031)	(2.121)
Population (log)	No	No	No	No	Yes	Yes
GDP per Capita (log)	No	No	No	No	Yes	Yes
Fixed Effects:						
Country	Yes	Yes	Yes	Yes	Yes	Yes
Period	Yes	Yes	Yes	Yes	Yes	No
Technology	No	No	No	No	Yes	No
Tech×Period	No	No	No	No	No	Yes
Observations	7,225	7,225	7,225	7,225	7,225	7,187
Countries	76	76	76	76	76	76
Adj. R^2	0.0459	0.0459	0.0457	0.0457	0.952	0.957

Dependent variable $\ln(TechA_{ijt})$ is the adoption of technology i in country j in period t. Openness and democracy scores are continuous indices normalized to range from 0 to 1. The alternative continuous openness measure is taken from the Fraser Institute and is the index of "Freedom to Trade Internationally." The democratization index is taken from the Polity IV database. OLS estimates with robust standard errors adjusted for clustering by country. Student ts are in parentheses. Panel data at five-year frequencies. ***, **, * significantly different from 0 at 1%, 5%, and 10% levels, respectively.

Initial Technological Levels and Timing of the Effects. The highly unbalanced nature of the CHAT database is not suited to perform dynamic panel estimates. The availability of data from different technologies within each country nevertheless allows us to control for initial conditions in the form of the initial level of technology.[31] Column (2) of Table 4 extends the baseline results, replicated for comparability in column (1), to the consideration of the initial level of each technology. The results reveal that the heterogeneous effects of regime changes are not imputed to the omission of country- and technology-specific initial conditions.[32]

[31] The inclusion of technology×year fixed effects can help account for technology-specific dynamic patterns over time. Controlling for the initial level of each technology in each country nonetheless appears a natural, although quite demanding, robustness check.

[32] In spite of the different techniques and dependent variable, the findings confirm the insights obtained from GMM results that account for the role of the lag of manufacturing productivity discussed above.

The results of Tables 2 and 3 suggest that the effect of the joint transitions can be detected also on a five-year horizon. The remaining columns of Table 4 further extend the yearly analysis, considering three- and five-year lags of the change in trade openness and democracy (on top of the initial conditions in technology adoption). This allows us to investigate the longer-term effect of these regime changes on the intensive margin of technology adoption more explicitly. The results uncover very similar patterns, but suggest more persistent effects of the positive complementarity between trade liberalization and democratization. The effect of a switch in the trade regime only is strongest in the first few years after the regime change, but becomes insignificant after five years. On the contrary, the positive effect of the joint transition appears to be more long-lasting.

Table 4: Initial Conditions and Lagged Effects - Yearly Frequencies

Dep. Variable	Technology Adoption - Intensive Margin					
	One-Year Lag		Three-Year Lag		Five-Year Lag	
	(1)	(2)	(3)	(4)	(5)	(6)
Openness	-0.134**	-0.088**	-0.106**	-0.067	-0.075	-0.038
	(-2.444)	(-2.159)	(-2.191)	(-1.571)	(-1.507)	(-0.848)
Democracy	-0.022	0.012	-0.028	-0.001	-0.019	-0.004
	(-0.538)	(0.411)	(-0.713)	(-0.045)	(-0.553)	(-0.130)
Open×Demo	0.227***	0.084*	0.249***	0.098**	0.267***	0.106**
	(3.786)	(1.980)	(4.178)	(2.027)	(4.271)	(2.073)
Population (log)	Yes	Yes	Yes	Yes	Yes	Yes
GDP per Capita (log)	Yes	Yes	Yes	Yes	Yes	Yes
Tech. Initial Cond.	No	Yes	No	Yes	No	Yes
Fixed Effects:						
Country	Yes	Yes	Yes	Yes	Yes	Yes
Tech.×Years	Yes	Yes	Yes	Yes	Yes	Yes
Observations	36,107	36,107	36,107	36,107	36,107	36,107
Num. of Countries	97	97	97	97	97	97
Adjusted R^2	0.954	0.986	0.954	0.986	0.954	0.986

Dependent variable $\ln(TechA_{ijt})$ is the adoption of technology i in country j in year t. OLS estimates with robust standard errors adjusted for clustering by country. Student ts are in parentheses. ***, **, * significantly different from 0 at 1%, 5%, and 10% levels, respectively. Columns (1) and (2) consider the effect of regime changes with a one-year lag (baseline). Columns (3) and (4) consider the effect of regime changes lagged by three years, while columns (5) and (6) consider regime changes lagged by five years. Columns (2), (4), and (6) include the initial level of technology in the respective sector and country.

Extensive Margin of Technology Adoption. A specific feature of the CHAT technology adoption data is that it is highly unbalanced, with different technologies entering the database with different delays. As an alternative dependent variable, we consider a dummy taking the value one once a given technology is adopted in a country for the first time and zero otherwise. The resulting empirical specification essentially exploits variation in the timing of the introduction of each technology within each country.[33] Relying on information on technology adoption at the extensive margin also allows us to exploit a balanced panel database, and to include technology×country fixed effects while retaining within-country variation in the timing of adoption.

The results are reported in Table 5.[34] Trade openness alone tends to increase technology adoption at the extensive margin; democratization is not significant.

Table 5: Extensive Margin of Technology Adoption - Yearly Frequencies

Dep. Variable	Technology Adoption - Extensive Margin						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Openness	0.017***		0.018***	0.001	0.003	0.004	0.003
	(4.067)		(4.254)	(0.222)	(0.554)	(0.751)	(0.554)
Democracy		-0.005	-0.006	-0.013**	-0.014**	-0.015***	-0.014**
		(-0.920)	(-1.227)	(-2.540)	(-2.445)	(-2.649)	(-2.445)
Open × Demo				0.025***	0.021***	0.019**	0.021***
				(3.173)	(2.733)	(2.505)	(2.734)
Population (log)	No	No	No	No	Yes	Yes	Yes
GDP per Capita (log)	No	No	No	No	Yes	Yes	Yes
Fixed Effects:							
Country	Yes	Yes	Yes	Yes	Yes	Yes	No
Year	Yes	Yes	Yes	Yes	Yes	No	Yes
Technology	No	No	No	No	Yes	No	No
Technology×Years	No	No	No	No	No	Yes	No
Technology×Country	No	No	No	No	No	No	Yes
Observations	135,698	135,698	135,698	135,698	122,376	122,363	122,376
Countries	104	104	104	104	97	97	97
Adj. R^2	0.031	0.031	0.031	0.031	0.759	0.804	0.874

Dependent variable is a dummy variable for the presence of any given technology j in a country i and year t, $TechA_{ijt}$. OLS estimates with robust standard errors adjusted for clustering by country. Student ts are in parentheses. ***, **, * significantly different from 0 at 1%, 5%, and 10% levels, respectively.

5 Concluding Remarks

This paper provides a theoretical and empirical analysis of the interplay between trade liberalization and democratization for the dynamics of technology adoption. A theoretical model

[33] Comin and Hobjin (2010) study adoption lags using cross-sectional information on the delay in adoption of each technology in each country so that the unit of observation is at the level of technology-country. In our analysis we exploit variation within countries over time where the unit of observation is instead at the level of technology-country-year.

[34] The within correlations between openness and democracy, openness and the interaction, and democracy and the interaction are around 0.05, 0.65, and 0.40, respectively.

is set up to study the incentives of different social groups to favor, or oppose, technological change. The theory predicts the existence of a complementarity between trade liberalization and democratization for the dynamics of productivity. The predictions are tested exploiting within-country variation over time in trade openness, democracy, and their interaction for the evolution of technology adoption at disaggregated level over time for a large set of countries. The findings document the existence of a positive and significant interaction between trade openness and democratization for technological dynamics. The results, which prove robust to a large set of checks, qualify the common wisdom and have relevant policy implications.

The theoretical predictions on the role of changes in trade and political regimes are tested in reduced form by exploiting a rich panel dataset. The theory predicts differential effects of technology adoption on the rents of the elite, on unskilled wages, and on the skill premia in the different regimes. The channel proposed in the theory therefore relates to the demand for technology adoption, or the existence of vested interests, by the part of the politically decisive groups conditional on the trade regime. Lack of data on rent extraction, employment, and wages at the sector level for a large enough panel of countries currently prevents a deeper investigation of the possible channels behind the documented heterogeneous effects. Extending the analysis of the effects of trade liberalization and democratization to the considerations of further effects beyond technology adoption appears to be a fruitful direction for further research.

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6 Appendix

6.1 Analytical Derivations and Proofs

Proof of Lemma 2. The Cobb-Douglas preferences in (1) together with equations (2)-(4) imply that the aggregate demand for each good is given by

$$p \int_{\underline{\theta}}^{\infty} \theta^A dG(\theta) = \beta E, \tag{12}$$

and

$$Z(L(\underline{\theta}), N) = (1-\beta) E. \tag{13}$$

where E denotes total expenditure.

In a closed economy the total demand for each good must be covered by internal production. The product market clears when (12) and (13) jointly hold, that is if, and only if,

$$p = \frac{\beta}{1-\beta} \frac{Z(L(\underline{\theta}), N)}{\int_{\underline{\theta}}^{\infty} \theta^A dG(\theta)}. \tag{14}$$

Recall that the labor market is in equilibrium at $\underline{\theta}$ if (5) and (4) jointly hold, which implies

$$p = \frac{w(L(\underline{\theta}), N)}{\underline{\theta}^A}. \tag{15}$$

The product and the labor markets therefore clear at $\underline{\theta}$ if, and only if, (14) and (15) hold simultaneously, which implies

$$Z(L(\underline{\theta}), N) = \frac{1-\beta}{\beta} \frac{w(L(\underline{\theta}), N)}{\underline{\theta}^A} \int_{\underline{\theta}}^{\infty} \theta^A dG(\theta). \tag{16}$$

Recall that, for any given $\underline{\theta}$, the share of workers in the traditional sector is

$$L(\underline{\theta}) = \int_1^{\underline{\theta}} g(\theta) d\theta = G(\underline{\theta}). \tag{17}$$

Given $w(L(\underline{\theta}), N)L(\underline{\theta}) = \eta Z(L(\underline{\theta}), N)$ from (2), and using (17), the equilibrium condition (16) can be finally expressed as

$$G(\underline{\theta})\underline{\theta}^A = \eta \frac{1-\beta}{\beta} \int_{\underline{\theta}}^{\infty} \theta^A dG(\theta). \tag{18}$$

The equilibrium in a closed economy exists, is interior and is unique because:

- Looking at the limits: (i) When $\underline{\theta} = 1$ the left-hand-side (LHS, henceforth) is zero as $G(1) = 0$. The right-hand-side (RHS, henceforth) instead would be strictly positive as $\int_1^{\infty} \theta^A dG(\theta) > 0$. (ii) when $\underline{\theta} \to \infty$, the LHS is strictly positive, whereas the RHS goes to zero as $\int_{\infty}^{\infty} \theta^A dG(\theta) = 0$. Continuity of the functions insure the existence of at least one equilibrium since the two curves must intersect for a finite level of skill.

- The LHS of (18) is strictly increasing in $\underline{\theta}$, while the RHS is strictly decreasing in $\underline{\theta}$, which guarantees uniqueness.

Notice that this is also the case if the skill level is bounded as the same concept holds. Consider for instance a distribution of skills that is bounded from above at a level $\tilde{\theta}$. When evaluated in the limit case in which $\underline{\theta} = \tilde{\theta}$, the LHS of equation (20) equals $\tilde{\theta}^A > 0$, while the RHS is still zero as $\int_{\tilde{\theta}}^{\tilde{\theta}} \theta^A dG(\theta) = 0$

Proof of Lemma 3. Denoting by $\underline{\theta}$ the equilibrium threshold in a closed economy and rewriting the equilibrium condition (18), define

$$F(\underline{\theta}, A) = G(\underline{\theta})k - \frac{\int_{\underline{\theta}}^{\infty} \theta^A dG(\theta)}{\underline{\theta}^A} = 0, \tag{19}$$

where $k = \frac{1}{\eta}\frac{\beta}{1-\beta}$. To see the effect of an increase in A on $\underline{\theta}$ we use the implicit function theorem to get

$$\frac{\partial \underline{\theta}\,(A)}{\partial A} = -\frac{\partial F(.)/\partial A}{\partial F(.)/\partial \underline{\theta}} = -\frac{-\int_{\underline{\theta}}^{\infty} \theta^A \left(\ln\theta - \ln\underline{\theta}\right) dG(\theta)/\underline{\theta}^A}{G'(\theta)k - \frac{\underline{\theta}^A\left(-\underline{\theta}^A\right) - A\underline{\theta}^{A-1}\int_{\underline{\theta}}^{\infty}\theta^A dG(\theta)}{[\underline{\theta}^A]^2}} > 0, \tag{20}$$

because by Leibniz rule

$$\frac{\partial \int_{\underline{\theta}}^{\infty} \theta^A dG(\theta)}{\partial \underline{\theta}} = -\underline{\theta}^A < 0$$

and because $\partial L\left(\underline{\theta}\right)/\partial\underline{\theta} > 0$.

The observation above also directly implies a reduction in the wage w in the traditional sector following an increase in A. The effect of an increase in A on the skill premium is given by

$$\frac{\partial\left(\theta^A/\underline{\theta}\,(A)^A\right)}{\partial A} = \left(\theta^A/\underline{\theta}\,(A)^A\right)[\ln\theta - \ln\underline{\theta}\,(A)\,\frac{\partial\underline{\theta}\,(A)}{\partial A}]. \tag{21}$$

From (20) $\partial\underline{\theta}\,(A)/\partial A > 0$ and because $\ln\theta$ is strictly monotonic in θ, there exists a unique level of $\theta \equiv \overline{\theta}\,(A)$ above which (21) is positive.

The increase in the labor occupied in the traditional sector, Z, implies an increase in the total production in that sector. In principle the equilibrium production in the X sector may increase (due to A) or decrease (due to higher $\underline{\theta}$) depending on the sign of $d\left(\int_{\underline{\theta}}^{\infty} \theta^A dG(\theta)\right)/dA$. But the equilibrium condition requires that the positive direct effect of a better technology A dominates and always increases total output in the X sector as well. This can be seen by considering again the condition for the equilibrium in a closed economy,

$$G(\underline{\theta})\underline{\theta}^A = \eta\frac{1-\beta}{\beta}\int_{\underline{\theta}}^{\infty}\theta^A dG(\theta). \tag{22}$$

As shown above, a higher A increases $\underline{\theta}$, so the LHS of (22) is increasing in A, so that the RHS must also increase, which requires an increase in total production in the X sector: $d\left(\int_{\underline{\theta}}^{\infty} \theta^A dG(\theta)\right)/dA > 0$. Finally, notice from (15) that the reduction in equilibrium wages w and the increase in the threshold level of skill $\underline{\theta}$ imply a reduction in p.

Proof of Lemma 4. The equilibrium in an open economy is implicitly characterized by (15) evaluated at the international prices $p = p^*$. That $\frac{\partial \underline{\theta}^o(A)}{\partial A} < 0$ and, therefore, that the labor supply L and total production in Z decrease can be directly verified by looking at (15), (17), and the Cobb-Douglas production function for the traditional sector.

As p is fixed in this case, a higher A cannot be followed by an increase in $\underline{\theta}$ because this would make the denominator on the RHS increase further while it would necessarily decrease $w(L(\underline{\theta}), N)$ in the numerator, which would violate the equality. All the remaining results directly follow as in the proof of Lemma 3. One can conclude, since prices are fixed by world markets, that the effect of an increase in A monotonically decreases the utility of the elite and increases that of all workers.

Proof of Proposition 1. We need to characterize the change in attitude towards technological improvements by the part of the political rulers in an autocracy following a process of openness to trade. The total income of the elite, which is the residual claimant of the income produced in the Z sector, is given by $Y^E = (1 - \eta)Z$, and by dividing it by the size of elite, denoted by σ, one gets the per-capita income of each member of the elite. From (10) each member of the elite strictly gains from an increase in the productivity A if, and only if, their real income increases. From Lemma 3, in a closed economy an increase in A increases the indirect utility of the elite because it increases Z and reduces the price p. From Lemma 4, however, Z decreases in response to higher A in an open economy (while $p = p^*$). In a closed economy, the elite benefits from technology adoption, whereas this is not true in an open economy.

Proof of Proposition 2. From Lemma 3 the nominal wage of workers in the traditional sector, $w(L, N)$, decreases with a higher A in a closed economy. Under autarky, the workers in the traditional sector can gain from technological improvements if, and only if, the reduction of price p more than compensates the reduction in their nominal income. In turn, from (4), the nominal earnings of an individual with skill θ working in the modern sector are given by the base wage times the skill premium, $w(L, N)\left(\theta/\underline{\theta}\right)^A$, that from Lemma 3 can be increasing only for the highly-skilled workers, for whom the increase in skill premium $\left(\theta/\underline{\theta}\right)^A$ more than compensates the reduction in the base wage, w. Therefore, compared to a closed autocracy, the process of democratization strictly reduces the incentives for technology adoption if the new political ruler (the new pivotal voter) is a worker who loses from technology adoption (e.g., a less-skilled worker). The sign of the effect of technology adoption is unchanged if the new political ruler gains from technology adoption (e.g., a highly-skilled worker).

Proof of Proposition 3. Compared to an open autocracy, the emergence of an open democracy strictly increases the incentives to increase A since, from Lemma 4, in an open economy all workers (the new political rulers) gain from higher A, while the elite lose. Compared to a closed democracy, openness to trade (weakly) increases the incentives for technology adoption since (again from Lemma 4) all workers gain from higher A, while (from Lemma 3) in a closed democracy (only) the highly-skilled workers are (more) likely to gain from higher A.

6.2 Summary Statistics and Partial Correlations

We report the summary statistics and the within correlations for the baseline samples of Technology Adoption (CHAT data).

Table 6: Summary Statistics

Variable	**Observations**	**Mean**	**Std. Dev.**	**Observations**	**Mean**	**Std. Dev.**
	Baseline			Five-year Frequencies		
Technology Adoption	38735	7.685	5.871	9115	7.413	5.978
Openness	38735	0.371	0.483	9115	0.361	0.480
Democracy	38735	0.463	0.499	9115	0.461	0.499
Open×Demo	38735	0.253	0.435	9115	0.246	0.430
Population (log)	36222	9.591	1.443	8434	9.588	1.440
GDP per Capita (log)	36222	0.956	0.907	8434	0.952	0.899
	Non-Dichotomous			Extensive Margin		
Technology Adoption	7,225	7.688	5.978	135,698	0.156	0.362
Openness	7,225	0.504	0.195	135,698	0.344	0.475
Democracy	7,225	0.526	0.345	135,698	0.440	0.496
Open×Demo	7,225	0.026	0.0616	135,698	0.222	0.416
Population (log)	7,225	9.742	1.438	122,376	9.369	1.395
GDP per Capita (log)	7,225	1.028	0.898	122,376	0.822	0.910

The non-dichotomous indices of openness and democracy have been normalized to range from 0 to 1 and centered around their mean in the econometric exercises. We present the summary statistics of the interaction between the centered variables.

Table 7: Within Correlation Matrices: Different Samples

Samples:	Baseline		Five-year Frequencies		Non-Dichotomous		Extensive Margin	
	Open.	Demo.	Open.	Demo.	Open.	Demo.	Open.	Demo.
Openness	1		1		1		1	
Democracy	0.0541	1	0.0256	1	0.0073	1	0.0544	1
Open × Demo	0.6955	0.3580	0.6601	0.3593	0.6726	0.3330	0.6565	0.4016

The within correlations are calculated using country and time demeaned variables.