Manuscript version: Working paper (or pre-print)
The version presented here is a Working Paper (or 'pre-print') that may be later published elsewhere.

Persistent WRAP URL:
http://wrap.warwick.ac.uk/170157

How to cite:
Please refer to the repository item page, detailed above, for the most recent bibliographic citation information. If a published version is known of, the repository item page linked to above, will contain details on accessing it.

Copyright and reuse:
The Warwick Research Archive Portal (WRAP) makes this work by researchers of the University of Warwick available open access under the following conditions.

Copyright © and all moral rights to the version of the paper presented here belong to the individual author(s) and/or other copyright owners. To the extent reasonable and practicable the material made available in WRAP has been checked for eligibility before being made available.

Copies of full items can be used for personal research or study, educational, or not-for-profit purposes without prior permission or charge. Provided that the authors, title and full bibliographic details are credited, a hyperlink and/or URL is given for the original metadata page and the content is not changed in any way.

Publisher's statement:
Please refer to the repository item page, publisher's statement section, for further information.

For more information, please contact the WRAP Team at: wrap@warwick.ac.uk.

Climate Change, Gender Equality, and Firm-Level Innovation: Cross-Country Evidence

Eman Abdulla, King Yoong Lim, Diego Morris & Faten Saliba

October 2022 No: 1429

Warwick Economics Research Papers

ISSN 2059-4283 (online)
ISSN 0083-7350 (print)

Climate Change, Gender Equality, and Firm-Level Innovation: Cross-Country Evidence

Eman Abdulla*, King Yoong Lim**, Diego Morris***, Faten Saliba****

This Version: October 10, 2022

Abstract

This paper examines the nexus between gender equality, climate change, and innovation at the firm level. Based on three hypotheses derived from a novel theoretical framework linking climate change and gender equality to within-firm innovation activities, we use a cross-section dataset of $87,996$ firms across 36 industries in 103 countries, surveyed across different waves during the 2010-2020 periods to implement an instrumental variable strategy and show that environmental policies unambiguously induce firm-level process and product innovation, through its influence on the endogenous bargaining power of women in society and firms. We document that female productivity has both a direct effect on innovation (0.1-1.3% increase in the likelihood of innovation) and an indirect effect (serving as the intermediation for the environment-innovation nexus). Contrarily, greenhouse gas emissions by themselves have an ambiguous effect on innovation. The type of greenhouse gas emissions and the measure of innovation both contribute to this ambiguity. Overall, our results show that it is not the physics of climate change that induces innovation but rather the countervailing human responses to policies that mitigate climate change that stimulate innovation.

JEL Classification Numbers: D24, J16, L25, O32, Q58,

Keywords: Climate change, firm-level analysis, gender equality, innovation.

---

*Department of Economics, University of Warwick, Email: Eman.Abdulla@warwick.ac.uk; **International Business School Suzhou, Xi'an Jiaotong-Liverpool University, Email: KingYoong.Lim@xjtlu.edu.cn; ***Nottingham Business School, Nottingham Trent University, Email: diego.morris@ntu.ac.uk; ****International Monetary Fund, Email: fsaliba@imf.org.
The views expressed are our own.
Technical Appendices can be made upon request.

1 Introduction

The nexus between gender equality, innovation, and climate change is not well understood, although there is a widespread acknowledgement that bilaterally these variables have a strong effect on each other and ultimately on economic growth. As examples, Bilgili et al. (2022), show that there is a gender dimension in the environmental Kuznets curve, Eastin (2018) points out that climate change reduces gender equality in developing states while studies such as Wu et al. (2021), Dai et al. (2019) and Konadu et al. (2022) argue that innovation reduces gender inequality. Examining the nexus between gender equality, climate change, and innovation at the firm level is the focus of our paper and thus our contribution to the literature.

Specifically, based on three hypotheses derived from a novel theoretical framework linking climate change and gender equality to within-firm innovation activities, we provide empirical insights towards an improved understanding of the impact of climate change and gender equality on firm-level innovation. To our knowledge, our cross-sectional evidence ($87,996$ firms across 36 industries in 103 countries, surveyed across different waves during the 2010-2020 periods) is the largest to examine this nexus at the firm level. We also contribute to the understanding of whether: (i) a complementarity exists between environmental policy and gender equality; and (ii) it is the direct biological effect of carbon emission on labour productivity or the competitiveness-enhancing institutional effect of environmental policy that matters more in promoting firm-level innovation.

To preview, we find that environmental policies unambiguously induce firm-level process and product innovation, through its influence on the endogenous bargaining power of women in society and firms. We document that female productivity has both a direct effect on innovation (0.1-1.3% increase in the likelihood of innovation) and an indirect effect (serving as the intermediation for the environment-innovation nexus). Contrarily, greenhouse gas emissions by themselves have an ambiguous effect on innovation. This suggest that it is not the physics of climate change that induces innovation but rather the countervailing human responses to policies that mitigate climate change that stimulate innovation. All of these results are robust across different measures of innovation, climate change policy, and gender equality and various methodological experiments.

The rest of the paper is structured as follow. Section 2 reviews existing theoretical paradigm and empirical evidence linking the trifecta of environment, gender equality, and innovation. Based on this, we then build a theoretical framework linking the three in Section 3, resulting in the derivation of three hypotheses. Section 4 discusses our data, measurement, and the empirical strategy. Section 5 evaluates our empirical findings. Section 6 concludes the paper.

2 Literature Review

While the interplay between environment, gender, and innovation remains an underexamined area, studies focusing on the nexus between environment and innovation and to a lesser extent, gender and innovation are well documented. The former can broadly be classified into two types, where theoretical contributions tend to be of macroeconomic nature positing the adverse effects of environmental pollution on innovation and growth; while a voluminous number of empirical contributions in the tradition of the "*Porter Hypothesis*" (PH) (Porter, 1991; Porter & Van der Linde, 1995) have shown that well-designed environmental policies and regulations could promote firm-level innovation. In essence, the former suggests that environmental degradation, irrespective of air pollution or carbon emission, transmits through biological mechanisms by affecting health and well-being of individuals, hence, their innovation capacity. In contrast, the latter proposes incentive mechanisms that arise from institutional and regulatory forces, which then result in innovation within firms.

The macroeconomic literature concerning the nexus of growth and environment can be traced to John & Pecchenino (1994), who theorizes that economic growth is first associated with declines in environmental quality, and then subsequent improvements as the economy becomes richer. While the model doesn't explicitly deal with innovation, it does introduce environmental quality as a public good that affects the well-being of agents, and the needs for environmental investments. Since then, intergenerational models linking environment quality or pollution externalities to growth have mushroomed (e.g., Jouvet et al., 2000; Jones & Manuelli, 2001; Economides & Philippopoulos, 2008), focusing searching for socially optimal (or incentive-maximizing) abatement policies/technologies.

Indeed, the potential interplay with research and development (R&D) and innovation is captured in studies such as Rubio et al. (2009), Lambertini et al. (2017), which show that while capital accumulation and production are polluting, when pollution is large enough then it becomes profitable for agents to invest in R&D to reduce emissions. The transmission from environmental quality to productive capacity is subsequently made clear in theoretical contributions that explicitly introduce health into the model. Non-exhaustively, such studies include Balestra & Dottori (2012), Wang et al. (2015), Bretschger & Vinogradova (2017), Fu et al. (2020), all of which model the negative spillover effects to health status of individuals and consequently, average labour productivity in the economy. To the extent that innovation depends on labour productivity, it is straightforward to infer that the main transmission mechanism of the environment-innovation nexus takes place via the health and productivity channels. More recent studies introduce green preferences, and it is shown that in the presence of environmentally conscious consumers, there may exist either complementarity or trade-off between green investments and emission taxes

(Gil-Moltó & Varvarigos; 2013, Langinier & Chaudhuri, 2020), educational policies (Constant & Davin, 2019; Wei & Aadland, 2019), or more generally, knowledge diffusion channels (Wan et al., 2018).

In terms of empirical contributions motivated by the PH, a comprehensive literature review is beyond the scope of this paper. We provide a brief overview of the key progression in the paradigm with respect to the academic consensus on PH based on selective reviews of firm-level studies that have innovation as the 'end game' and leave readers to monograph style studies such as Kemp & Pontoglio (2011), Kozluk & Zipperer (2015), Ambec et al. (2020), and their citations thereafter for a more exhaustive coverage. The initial contribution by Porter (1991) stresses the importance of well-designed environmental regulations, but subsequent mixed empirical evidence have shed light on what constitutes 'well-designed', resulting in the distinction between a 'weak', 'narrow', and 'strong' form of PH. In essence, unlike either the 'weak' form, or the 'narrow' form, where incentive-compatible design of regulatory policies is stressed over prescriptive policies, a strong form of PH is evidenced by environmental regulatory measures (not accounting for incentive mechanism design) that promote innovation and more than offset additional regulatory costs, resulting in an increase in firm competitiveness and knowledge spillover effects (Jaffe & Palmer, 1997; Kozluk & Zipperer, 2015).

Empirical evidence on this is largely mixed, with significant heterogeneity found across countries of different development stages and types of environmental policies. Specifically, Chiu et al. (2012) and Albrizio et al. (2017) are studies that document significantly higher average environmental efficiency in advanced economies than developing economies, and this perhaps suggests why the latter found strong PH to be more significant and correlate positively with industry- and firm-level productivity growth in advanced economies, but not developing economies. In a meta-analysis of 103 studies, Cohen & Tubb (2018) find that it is more likely to find a positive relationship between environmental regulation and productivity at the more aggregated country or regional level than at the sectoral and firm level.

This appears to be the case. Earlier studies focusing on PH in specific industries in the US tend to find negative effects on firm performance (e.g., Greenstone et al., 2012, on American manufacturing firms during the 1972-93 period; Rassier & Earnhart, 2015, on chemical manufacturers during the 1995-2001 period). Early cross-country studies such as Lanoie et al. (2011), which focuses on manufacturing facilities in 7 OECD countries in year 2003, and Rubashkina et al. (2015), which focuses on 9 manufacturing sectors in 17 non-large European countries during the 1997-2009 period, do not find evidence of strong PH too.

More recent contributions have since documented stronger cross-country evidence. For instance, using environmental taxes as instruments for regulatory stringency, Franco & Marin (2017) document strong PH effect on innovation and productivity based on a panel of 8 European countries for 13 manufacturing sectors over the 2001-07 period. Likewise, Martínez-Zarzoso et al. (2019), which directly uses OECD's environmental policy stringency index for 14 OECD countries over the 1990–2011 period, document strong PH effect on patenting and R&D over the long run. Hille & Möbius (2019), who use shadow and industrial energy prices to control for endogeneity, find less convincing evidence based on panel data of 14 manufacturing sectors across 28 OECD countries, though still document positive and significant overall effects of environmental regulation on productivity growth.

For the developing economies, which to our knowledge suffers from a lack of cross-country evidence, Samant et al. (2020) find that incentive-based pull policies (narrow PH) tend to promote innovation in mature industries in their four-country sample (Turkey, India, Brazil, China), whereas prescriptive push policies (strong PH) promote innovation in novel technologies. In terms of country-specific evidence, consistent with her command-and-control policy regime, strong PH tends to be documented empirically for China (e.g. Zhang et al., 2011; Bu et al., 2020).

Similar innovation-promoting effects from environmental regulations are documented for Taiwanese manufacturing sectors (Yang et al., 2012), firms in Jordan (Eiadat et al., 2008), and Indian leather and textile industries (Chakraborty & Chatterjee, 2017). Recent evidence from developed economies tends to be robust too. In Italy, Borghesi et al. (2015) investigate the effect of European emissions trading scheme and find positive effect onto firms' innovation, though there seems to be substitutability effect in that, sector-specific stringency index become negatively associated with innovation. Similar evidence is found for Britain, where Calel (2020) finds the European carbon market to encourage greater low-carbon patenting and R&D spending among regulated British firms.

In terms of product and process innovation, in Spain, De Miguel & Pazó (2017) analyse the effects of environmental protection regulation on innovation decisions of Spanish manufacturing firms throughout the 2009–14 period and find environmental regulation to positively impacts process innovation in large firms. Likewise, in Germany, Rennings & Rammer (2011) find that environmental regulation generates greater new products and cost savings. With such robust strong PH effects in recent years, the key questions then concern the potential transmission mechanisms. Indeed, focusing on waste management industries across EU countries, Cecere & Corrocher (2016) find the PH effect to be non-linear, perhaps suggesting the possible existence of intermediate transmission channels. In Rexhäuser & Rammer (2014), it is speculated that this largely takes place via within-firm resource efficiency.

Likewise, in Qiu et al. (2018), it is shown that the PH effects holds only for the high-capability firms, whereas in Consoli et al. (2016) this effect is directly attributed to the difference in skill requirements between green and non-green jobs. Insofar as improved gender composition in a firm enhances its organizational efficiency and skills distribution, these, together with the labour productivity mechanisms reviewed from the theoretical literature, suggest a potential intermediating role of workplace gender equality.

The number of studies examining the nexus between gender equality and innovation is a lot smaller, though except for studies in countries with deep rooted gender equality, such as the Indian female business leaders-based studies of Reutzel et al. (2018), most studies find positive effects of gender diversity to innovation, as in the review of De Vita et al. (2014) and Arun & Joseph (2020). Based on cross-country evidence from a similar dataset as ours, Dohse et al. (2019) find female owners to likely introduce innovation, but the effect for female managers is weak. Indeed, given that board gender diversity is documented to result in less environmental violations (Liu, 2018), it is unsurprising that most studies documenting the positive effects of board gender diversity on innovation concern environmental innovation. For instance, Nadeem et al. (2020) argue that women tend to be more eco-friendly, therefore in a greater position to facilitate PH effects. Konadu et al. (2022) document similar findings for S&P500 firms.

More specifically, based on China public listed companies, He & Jiang (2019) find the threshold required for this innovation-enhancing effects to take place to be at least two seats on the board. Indeed, the positive effects of more balanced gender representation goes beyond corporate board diversity, as similar innovation-enhancing effects are documented in science (Ko et al., 2021), as well as transcends through time, as documented for the American film industry writers' market in the 1907-27 period (Smith-Doerr, 2010). We theorize that this translates through capabilities-enhancement mechanism proposed by Ray (2015), where firms with more gender equality tends to have greater organizational effectiveness and overall capabilities, therefore more effective in realizing the PH effects that translate to more innovation and productivity growth.

3 Theoretical Framework

Based on the literature surveyed, we develop a novel small theoretical model of the firms linking climate change and gender equality to within-firm innovation activities. Similar to firm-level studies such as Brambilla (2009), Lim & Morris (2022), the main purpose is to provide a theoretical basis towards the derivation of empirically testable hypotheses. As such, although we introduce households in a collective family decision-making structure to formally model the impact of climate change on gender equality, the key focus is on the firms, and it is therefore not our intention to solve for a general equilibrium solution.[1]

---

[1] See Vermeulen (2002), Himmelweit et al. (2013) for general surveys of collective household models. For more family oriented applications of the collective household models, see Lundberg & Bettio (2008), Browning et al. (2014) for reviews and discussions.

3.1 Firms

There are a continuum number of firms indexed by $j \in (0, 1)$. For analytical convenience, we assume that each firm produces a unique variety of its own and that the entry and exit flows of firms exactly cancel out in each period. Each firm is a price setter for its own variety but too small to neither affect the aggregate price level nor the greenhouse gas emission level. In contrast, firms are price takers in the input markets. To capture the reality where individual firms have vastly different production costs, there are both deterministic and stochastic components in the fixed and unit marginal costs of each firm. As would have become clear, the unobserved components contribute to the deviations in actual observed differences across firms' costs. Specifically, the expected total costs incurred by a firm j, TC_{jt}, in each period t is given by

$$TC_{jt}(Y_{jt}) = FC_{jt} + MC_{jt}Y_{jt}, \tag{1}$$

where Y_{jt} is its production volume in period t, FC_{jt} and MC_{jt} are fixed and unit marginal costs respectively. The fixed cost, $FC_{jt} = \tilde{F}_{jt} + F_{jt}$, consist of a stochastic component, $\tilde{F}_{jt}$, and a deterministic component, F_{jt}, where the latter can arise from the innovation decision undertaken by firm (to be elaborated later). Likewise, the unit marginal cost, $MC_{jt} = \widetilde{mc}_{jt} + mc_{jt}$, consist of a stochastic component, $\widetilde{mc}_{jt}$, and a deterministic component, mc_{jt}, determined by the cost minimization problem of a firm j. In the beginning of each period t, as firms learn their production and cost structures, each firm j randomly draws a pair of $(\tilde{F}_{jt}, \widetilde{mc}_{jt})$ from general distributions, $\Upsilon(\tilde{F}_{jt})$ and $\Omega(\widetilde{mc}_{jt})$, common to all firms: the realization of $\tilde{F}_{jt}$ and $\widetilde{mc}_{jt}$ in the end of the period is therefore influenced by stochastic functions.

The production technology is represented by a constant returns-to-scale, Cobb-Douglas form,

$$Y_{jt} \leq (A^f_{jt}N^f_{jt})^{\alpha}(A^m_{jt}N^m_{jt})^{\alpha}(\Phi^E_{jt})^{1-2\alpha}, \tag{2}$$

where quantities of *effective* labours for both male, $A^m_{jt}N^m_{jt}$, female, $A^f_{jt}N^f_{jt}$, and an energy-intensive input, Φ^E_{jt}, are used in production. Following Agénor (2017), the output elasticity with respect to labour, $\alpha \in (0, 1)$ is specified as the same for both gender, with A^i_{jt}, $i = f, m$ the productivity levels. Facing (2), firm j solves:

$$\min_{N^f_{jt}, N^m_{jt}, \Phi^E_{jt}} MC_{j,t} = \widetilde{mc}_{jt} + w^f_t A^f_{jt}N^f_{jt} + w^m_t A^m_{jt}N^m_{jt} + P^E_t \Phi^E_{jt},$$

where P^E_t is the energy price. As shown in Appendix A, this yields:

$$w^f_t / w^m_t = A^m_{jt}N^m_{jt} / A^f_{jt}N^f_{jt}; \tag{3}$$

$$\frac{P_t^E}{w_t^m} = \frac{(1-2\alpha)}{\alpha}\frac{A_{jt}^m N_{jt}^m}{\Phi_{jt}^E}; \text{ or alternatively, } \frac{P_t^E}{w_t^f} = \frac{(1-2\alpha)}{\alpha}\frac{A_{jt}^f N_{jt}^f}{\Phi_{jt}^E}. \tag{4}$$

Following Agénor et al. (2021), a well-established labour market observation indicates that if there is workplace gender discrimination female is only paid a fraction $z \in (0,1)$ of male wage, $w_t^f = zw_t^m$, which from (3) results in $z = A_{jt}^m N_{jt}^m / A_{jt}^f N_{jt}^f$. Given these, the optimized unit marginal cost of firm j, mc_{jt}, is

$$mc_{jt} = \Theta_\alpha (w_t^f)^\alpha (w_t^m)^\alpha (P_t^E)^{1-2\alpha}, \text{ where } \Theta_\alpha = \frac{\alpha^{2a}}{(1-2\alpha)^{1-2\alpha}}. \tag{5}$$

Equation (5) shows that the optimal unit marginal cost for the deterministic component is the same across all firms since all of them are input price-takers. Given that $w_t^f = zw_t^m$, if there is existing gender discrimination in the labour market, it also reveals that any direct attempt in improving pay disparity in the labour market (higher z) would represent an increase in firm j's unit marginal cost $[\partial mc_{jt}/\partial z > 0$ from (5)$]$, therefore unlikely for individual firms to voluntarily do so.

For the firm's problem, the order of the fixed cost choice and price-setting decision is mathematically irrelevant as they can be determined independently of each other, taking the expected value of the other as given. For the latter, faced with this optimal unit marginal cost, firm j sets its product price to maximize expected (real) profits subject to its variety's demand function (relative to the total aggregate demand). As this is very standard in the literature (but peripheral to the main purposes of our study), to save space we do not explicitly introduce a CES demand specification with differentiated products, and merely state that firm j sets its price based on a constant mark-up optimal pricing, $P_{jt} = \mu mc_{jt}$, where $\mu > 1$.

Finally, taking the expected revenue and optimal unit marginal cost as given, each firm j would decide whether to invest in innovation in period t. Specifically, on top of the randomly drawn fixed cost, $\tilde{F}_{jt}$, a firm would incur an additional fixed cost, $\phi_j(\cdot)$, if it decides to invest in innovation, whose success is uncertain. The innovation investment cost differs across firms, and consistent with studies such as He & Jiang (2019), Nadeem et al. (2020), is specified as a declining function of the within-firm relative productivity of female workers to the male workers,

$$\phi_j(\cdot) = \phi_0 \left(\frac{A_{jt}^f}{A_{jt}^m}\right)^{-\phi_1}, \tag{6}$$

where $\phi_0 > 0$, and $\phi_1 \geq 0$ measures the elasticity.[2]

The success of innovation is modelled by a two-state stationary Markov process. At a probability $q \in$

---

[2] Despite the many studies on gender-innovation nexus reviewed, a chauvinistic critic may think that the specification is rather arbitrary. An alternative specification is then to write $\phi_j(\cdot) = \phi_0 \left[\min(1, \frac{A_{jt}^f}{A_{jt}^m})\right]^{-\phi_1}$, with the range of A_{jt}^f being smaller than A_{jt}^m. In such an instance, it is the productivity disparity/gap within firms that matters. Intuitively, this means the smaller the productivity gap is between the two groups of workers, the more harmonized the organizational operation will be, hence the cheaper it is to bring in innovation or technology.

$(0, 1)$ the innovation investment is successful, which results in a cost-saving benefit of $(1-\gamma) \in (0, 1)$ fraction of the fixed cost. On the opposite end, at a probability $1 - q$ the investment fails and there is no cost-saving benefit. Given this, the expected (real) profits for a firm j that invests in innovation is

$$\mathbb{E}_t(\pi_{jt}^{Innov}) = q\left\{(\mu - 1)(mc_{jt} + \widetilde{mc}_{jt}) - [\gamma\tilde{F}_{jt} + \phi(\cdot)]\right\} + (1 - q)\left\{(\mu - 1)(mc_{jt} + \widetilde{mc}_{jt}) - [\tilde{F}_{jt} + \phi(\cdot)]\right\} \quad (7)$$

whereas if it opts not to invest,

$$\mathbb{E}_t(\pi_{jt}^{No}) = (\mu - 1)(mc_{jt} + \widetilde{mc}_{jt}) - \tilde{F}_{jt}. \quad (8)$$

Firm j invests in innovation if and only if $\mathbb{E}_t(\pi_{jt}^{Innov}) \geq \mathbb{E}_t(\pi_{jt}^{No})$. As shown in Appendix A, there exists a "hurdle rate" of success, q^C, above which a firm j would innovate:

$$q_j^C \geq \frac{\phi_j(\cdot)}{(1 - \gamma)\tilde{F}_{jt}}, \quad (9)$$

which shows that the higher the cost, the higher the required hurdle rate of success.

3.2 Households:

From (6)-(9), we see that within-firm innovation success critically depends on the within-firm relative productivity of female workers to the male workers. To model this as an endogenous variable, we introduce a simple collective household specification where the economy is also populated by a continuum of infinitely lived families indexed by $h \in (0, 1)$.[3] Given the infinitely lived specification, a family h consists only of a husband and a wife, supplying effective labour to a firm j not owned by themselves.

A family h's life-long collective utility function is given by

$$U_{ht} = \mathbb{E}_t \sum_{s=0}^{\infty} \beta^s \left[\varpi U_{ht}^f + (1 - \varpi)U_{ht}^m\right], \quad (10)$$

where $\beta \in (0, 1)$ is subjective discount factor, $\varpi \in (0, 1)$ measures the woman's bargaining power in the family, and the gender-specific utility functions are expressed respectively as:

$$U_{ht}^f = \ln C_{ht} + \zeta_H^f(\ln H_{ht+1}^f + \ln H_{ht+1}^m), \quad (11)$$

---

[3] Most dynamic models in the gender and growth literature usually assume an overlapping generational (OLG) structure, as the core research focus is usually on endogenous fertility choice, child-rearing costs, and intergenerational health externalities (e.g., Echevarria & Merlo, 1999; Cavalcanti & Tavares, 2011). For our research questions, notwithstanding the fact that the usual time dimension for OLG models are inappropriate, the effect of the climate change pass-through can also be adequately modelled without introducing child-rearing choice and intergenerational health transmission mechanism.

$$U_{ht}^{m} = \ln C_{ht} + \zeta_{H}^{m}(\ln H_{ht+1}^{f} + \ln H_{ht+1}^{m}), \tag{12}$$

where C_{ht} is consumption, H_{ht+1}^{i}, $i = f, m$ are next-period health status of female and male members, and $\zeta_{H}^{f} > \zeta_{H}^{m}$ is assumed to be consistent with developing-country evidence (e.g., Alderman & King, 1998; Agénor, 2017) where the husband generally cares less about investing in the health status (or human capital) of the female members of households (assuming that both cares equally about the male member's health status). In our benchmark specification, woman's bargaining power, ϖ is assumed to be constant and exogenous. However, as explored in later extension, when this is endogenously determined via a simple Nash bargaining specification, it is straightforward to assume ϖ_t to be a positive function of the relative health ratio, H_{ht}^{f}/H_{ht}^{m}, as in $\partial\varpi_t/\partial(H_{ht}^{f}/H_{ht}^{m}) \geq 0$.[4]

Consistent with the abundance of studies reviewed, environmental quality is a key factor in affecting health statuses. Specifically, based on a conventional equation of motion, health status evolves according to

$$\mathbb{E}_t H_{t+1}^{i} = I_{ht}^{i} + (1 - \delta_{t}^{i})H_{t}^{i}, \;\; i = f, m, \tag{13}$$

where I_{ht}^{i} refers to the gender-specific investment on health chosen by the family, and δ_t^i is a gender-specific 'depreciation' rate of health status, given by:

$$\delta_{t}^{i} = \delta_0 \left(\frac{\Gamma_t}{\Gamma_{t-1}}\right)^{\nu_{\Gamma}^{i}}, \;\; i = f, m, \tag{14}$$

where $\nu_{\Gamma}^{i} \geq 0$. The variable, Γ_t refers to the accumulated stock of greenhouse gases, whose growth rate negatively impacts the health statuses. As it is essentially a public externality, it is exogenous to individual families. It can either be treated as pure exogenous or *pseudo*-endogenous, in that its accumulation is also governed by an equation of motion:

$$\Gamma_t = (1 - \delta^{\Gamma})\Gamma_{t-1} + \upsilon_{\Gamma}[\int_0^1 (\Phi_{jt-1}^{E})^{\eta} dj]^{1/\eta}, \; \forall t,$$

$$\text{implying } \frac{\Gamma_t}{\Gamma_{t-1}} = (1 - \delta^{\Gamma}) + \upsilon_{\Gamma}\frac{[\int_0^1 (\Phi_{jt-1}^{E})^{\eta} dj]^{1/\eta}}{\Gamma_{t-1}}, \; \forall t, \tag{15}$$

where $\delta^{\Gamma} > 0$ is the nature's recovery/purity rate, $\eta \in (0, 1)$ and $1/(1 - \eta) > 1$ is the elasticity governing carbon transformation from the usage of energy-intensive input of firm j in the previous period, $\upsilon_{\Gamma} \geq 0$ is an implicit parameter measuring environmental policy effectiveness.

---

[4] The within-household bargaining power of woman can be endogenously determined using vastly different specifications. For instance, Chen & Woolley (2001) applied a Cournot-Nash model, Chiappori et al. (2002) formally modelled Marriage market interaction, while Doepke & Tertilt (2019) used a noncooperative bargaining framework. Despite the difference in approach, when relative health or human capital is of concern, this is a relationship that is consistently arrived at.

Without losing generality, we assume health status to have a one-to-one relationship with productivity, $h^i_{ht} = A^i_{ht}$, and that raw labour hours supplied are constant for all families ($N^f_{ht} = N^f_0$; $N^m_{ht} = N^m_0$). In each period t a family h maximizes (10) subject to (11)-(15) and budget constraint,

$$C_{ht} + I^f_{h,t} + I^m_{h,t} \leq w^f_t h^f_{ht} N^f_{ht} + w^m_t h^m_{ht} N^m_{ht} + J^F_{t-1}, \tag{16}$$

where J^F_{t-1} is the household share of profits from owning firms, by choosing sequences $\{C_{ht}\}^{\infty}_{t=0}$, $\{h^f_{ht+1}\}^{\infty}_{t=0}$, $\{h^m_{ht+1}\}^{\infty}_{t=0}$, taking wage rates ($w^f_t$, w^m_t) and endowed raw labour hours as given. As shown in Appendix A,

$$C_{ht} = \left\langle \frac{[\varpi\zeta^f_H + (1-\varpi)\zeta^m_H]}{H^f_{ht+1}} + \frac{\beta}{C_{ht+1}} \left\{ w^f_{t+1} N^f_{ht+1} + \left[1 - \delta_0 \left(\frac{\Gamma_{t+1}}{\Gamma_t} \right)^{\nu^f_\Gamma} \right] \right\} \right\rangle^{-1}, \text{ and} \tag{17}$$

$$\frac{H^f_{ht}}{H^m_{ht}} = \left\{ \begin{array}{c} \Theta_\varpi\left(\frac{C_{ht}}{H^m_{ht}} - \frac{C_{ht}}{H^f_{ht}}\right) + \beta w^m_t N^m_{ht} \\ + \beta\delta_0 \left[\left(\frac{\Gamma_t}{\Gamma_{t-1}}\right)^{\nu^f_\Gamma} - \left(\frac{\Gamma_t}{\Gamma_{t-1}}\right)^{\nu^m_\Gamma} \right] \end{array} \right\}^{-1} \left(\beta w^m_t N^m_{ht}\right), \tag{18}$$

where $\Theta_\varpi = \varpi\zeta^f_H + (1-\varpi)\zeta^m_H$. Equation (17) is the corresponding Euler equation of consumption for this model, and more importantly equation (18) provides an expression determining the relative health statuses.

3.3 Equilibrium, Hypotheses, and Extension

Before the derivation of empirically testable hypotheses, for completeness we close the model by stating the final goods market equilibrium as

$$Y_t = \int_0^1 Y_{jt} dj = \int_0^1 C_{ht} dh + \int_0^1 I^f_{h,t} dh + \int_0^1 I^m_{h,t} dh, \tag{19}$$

and the markets for both types of labour and the energy-intensive inputs are in equilibrium. As the key objective is not macroeconomic analysis, we stop short at imposing a complete symmetric equilibrium. Instead, if we assumed symmetric behaviours across all households, then given the one-to-one relationship between health and productivity, we have:

$$\frac{A^f_t}{A^m_t} = \left\{ \begin{array}{c} \Theta_\varpi\left(\frac{C_t}{H^m_t} - \frac{C_t}{H^f_t}\right) + \beta w^m_t N^m_t \\ + \beta\delta_0 \left[\left(\frac{\Gamma_t}{\Gamma_{t-1}}\right)^{\nu^f_\Gamma} - \left(\frac{\Gamma_t}{\Gamma_{t-1}}\right)^{\nu^m_\Gamma} \right] \end{array} \right\}^{-1} \left(\beta w^m_t N^m_t\right), \tag{20}$$

which, in the context of a firm j's "hurdle rate" of success for innovation, q_j^C $[$see 6)-(9)$]$, implies

$$\frac{\partial q_j^C}{\partial (A_t^f/A_t^m)} = -\frac{\phi_0 \phi_1}{(1-\gamma)\tilde{F}_{jt}} \left(\frac{A_t^f}{A_t^m}\right)^{-(\phi_1+1)} < 0. \tag{21}$$

HYPOTHESIS 1:

For a given unique fixed cost, $\tilde{F}_{jt}$, the higher the relative productivity of female workers to the male workers, the lower a firm j's "hurdle rate" of success for innovation, therefore greater likelihood of the firm engaging in innovation.

Next, we examine the impact of climate change on firm-specific innovation. First, we measure climate change as defined by contemporaneous growth rate of greenhouse gases, Γ_t/Γ_{t-1}. To assess the comparative statics, equation (9) is rewritten as:

$$q_j^C = \frac{\phi_0}{(1-\gamma)\tilde{F}_{jt}} \left(\left\{ \begin{array}{c} \Theta_{\varpi}(\frac{C_t}{H_t^m} - \frac{C_t}{H_t^f}) + \beta w_t^m N_t^m \\ +\beta\delta_0 \left[\left(\frac{\Gamma_t}{\Gamma_{t-1}}\right)^{\nu_\Gamma^f} - \left(\frac{\Gamma_t}{\Gamma_{t-1}}\right)^{\nu_\Gamma^m} \right] \end{array} \right\}^{-1} (\beta w_t^m N_t^m) \right)^{-\phi_1}, \tag{22}$$

As seen in Appendix A, due to the dynamic complications associated with the Euler equation (17), we also must derive $\partial C_t/\partial(\Gamma_t/\Gamma_{t-1})$, which in itself depends on the relationship between expected future-period greenhouse gas emission growth rate and contemporaneous emission growth rate. Differentiating (22) with respect to Γ_t/Γ_{t-1}, if the range of $H_t^m - H_t^f$ is greater than zero, we find that the sign of $\partial q_j^C/\partial(\Gamma_t/\Gamma_{t-1})$ is analytically ambiguous and depends on the sign of the following expression:

$$\frac{\Theta_{\varpi}}{(H_t^m - H_t^f)} \frac{\partial C_t}{\partial(\Gamma_t/\Gamma_{t-1})} + \beta\delta_0 \left[\frac{\nu_\Gamma^f \left(\frac{\Gamma_t}{\Gamma_{t-1}}\right)^{\nu_\Gamma^f} - \nu_\Gamma^m \left(\frac{\Gamma_t}{\Gamma_{t-1}}\right)^{\nu_\Gamma^m}}{(\Gamma_t/\Gamma_{t-1})} \right]. \tag{23}$$

HYPOTHESIS 2:

The effect of the contemporaneous growth rate of greenhouse gases on a firm j's hurdle rate of success in innovation is ambiguous.

If future carbon emission growth is expected to remain status quo, and that woman's health is more adversely affected by climate change than man's ($\nu_\Gamma^f > \nu_\Gamma^m$), then the contemporaneous growth rate of greenhouse gases positively affects the hurdle rate of success, i.e. $\partial q_j^C/\partial(\Gamma_t/\Gamma_{t-1}) > 0$. Hence, firm j is less likely to innovate. Nevertheless, due to the dynamic complications, if future carbon emission is expected to be significantly reduced (while today's growth rate is positive), then $\partial(\Gamma_{t+1}/\Gamma_t)/\partial(\Gamma_t/\Gamma_{t-1}) < 0$. Carbon emission growth today then negatively impacts current consumption, $\partial C_t/\partial(\Gamma_t/\Gamma_{t-1})$. To the effect that this outweighs the positivity of the second expression, then it may be possible that $\partial q_j^C/\partial(\Gamma_t/\Gamma_{t-1}) < 0$, i.e., climate change promotes innovation.

To filter out such dynamic complications, as well as to provide a distinction between the biological and institutional effects, we evaluate the comparative static against the parameter υ_Γ in (15) instead. The lower υ_Γ is, the more robust or effective an economy's environmental policy is. From (15),

$$\frac{\partial(\Gamma_t/\Gamma_{t-1})}{\partial \upsilon_\Gamma} = \frac{[\int_0^1 (\Phi^E_{jt-1})^\eta dj]^{1/\eta}}{\Gamma_{t-1}} > 0, \ \forall t, \tag{24}$$

Knowing this, as shown in Appendix A, differentiating (22) with respect to υ_Γ yields $\partial q_j^C/\partial \upsilon_\Gamma > 0$. This provides the theoretical basis for a benchmark Hypothesis 3, where *the more effective an economy's environmental policy is* ($lower\ \upsilon_\Gamma$)*, the lower the 'hurdle rate' of success for innovation investment faced by a firm* j*. Hence, firm* j *is more likely to invest in innovation.*

To ensure analytical robustness, and to better understand the interplay between environmental and gender institutions, we also examine the model in an extension where intrahousehold bargaining power is endogenously determined ($\varpi = \varpi_t$). Specifically, in the beginning of each period, suppose ϖ_t is determined from prior period allocation/bargaining of surplus funds into health investment of the male and female members. If the household were to maximize the value of the following surplus:

$$\max V_t^h = (I^f_{ht-1} - I^f_0)^{\varpi_t}(I^m_{ht-1} - I^m_0)^{1-\varpi_t}, \tag{25}$$

where I_0^f and I_0^m are some reservation investment levels, while I^f_{ht-1} and I^m_{ht-1} are the observed realized investments from previous period. As shown in Appendix A, let $I_0^f = I_0^m = 0$ (this has no material implication), solving this problem yields

$$\frac{\partial \varpi_t}{\partial(I^f_{ht-1}/I^m_{ht-1})} > 0, \text{ which implies that } \frac{\partial \varpi_t}{\partial(A^f_t/A^m_t)} = \frac{\partial \varpi_t}{\partial(H^f_t/H^m_t)} > 0. \tag{26}$$

In other words, with endogenous bargaining power within households, woman's bargaining power, ϖ_t, is an increasing function of the relative productivity of women to men. As shown in Appendix A, the introduction of endogenous bargaining power doesn't change the analytical results associated with Hypotheses 1 and 2. Nevertheless, it does affect Hypothesis 3, which is restated as:

HYPOTHESIS 3:

The more effective an economy's environmental policy is ($lower\ \upsilon_\Gamma$)*, the lower the 'hurdle rate' of success for innovation investment faced by a firm* j*. Hence, firm* j *is more likely to invest in innovation. However, with endogenous intra-household bargaining power, this effect is analytically ambiguous and critically dependent on the relative effect of* *climate change on woman's and man's health.*

4 Data and Empirical Strategy

4.1 Data

We use cross-country firm level survey data from the World Bank Enterprise Survey (WBES), which contains data on accounting information such as sales, inputs, labour, stock of capital, investment, costs, broad cost-of-doing business indicators.[5] Our sample consists of cross-sectional observations of $87,996$ firms across 36 industries (based on ISIC code 3.1 definition) in 103 countries during the periods of 2010-2020. Due to the different country-specific waves of the WBES implemented by the World Bank across different years, the country-specific data are asymmetric and uneven.

To measure climate change, we use data from the World Bank's World Development Indicators (WDI). Consistent with the propositions articulated above, we focus on measures of greenhouse gas emissions, especially carbon dioxide, nitrous oxide and methane. Together, these gasses account for the largest portion of greenhouse gas emissions around the world according to the United States Energy Information Administration.[6] As shown in Figure 1, global emissions of these gasses have risen since 1990. Evident from this figure, carbon dioxide emissions have grown by almost 3 percentage points while nitrous oxide and methane emissions have grown by almost 2 percentage points. For completeness, we also use a total greenhouse gas emissions measure from the WDI. This measure includes carbon dioxide, methane, nitrous oxide, and F-gases and is measured in tonnes of carbon-dioxide equivalents, where "equivalent" means "having the same warming effect as carbon dioxide over a period of 100 years".

We use data on environmental taxes and pollution taxes to account for government level climate change policies. These data are from the International Monetary Fund (IMF) Climate Change Indicator Dashboard. We also use the climate change stringency index in Sharma et al. (2021), which measures a country's willingness to address and collaborate on climate change through the implementation of various international and national agreements and policies. This index is available for 183 countries but when combined with available WBES data, we are restricted to examining only 103 countries. Figure 2 shows the correlation between this index and the share of innovative firms.

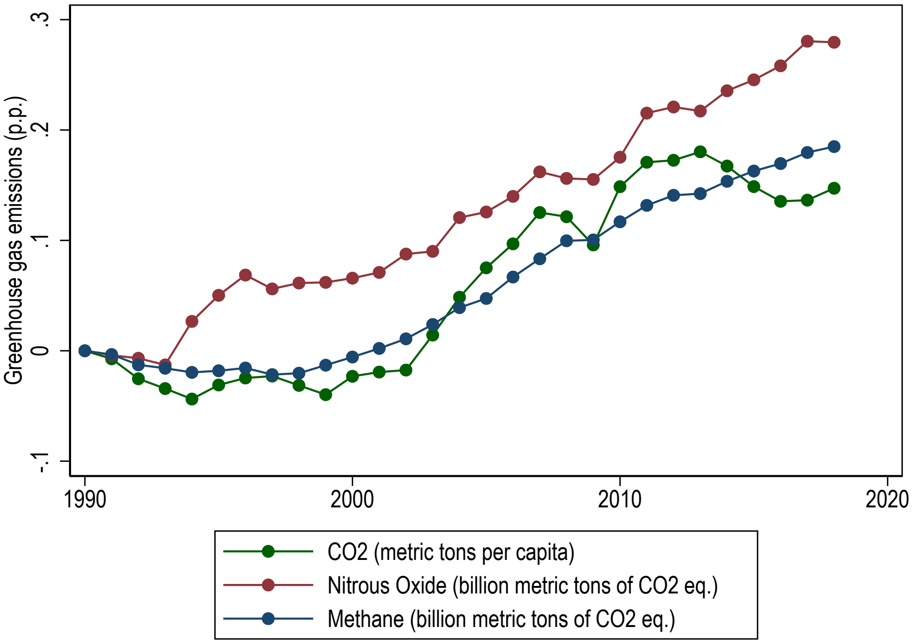
An overview of variables and summary statistics are presented in Table B.1, Appendix B.

---

[5] This dataset has been widely used in the literature. See Lim & Morris (2022) for some examples and a detailed description of the dataset. The dataset is publicly available at `www.enterprisesurveys.org/`.

[6] see `https://www.eia.gov/energyexplained/energy-and-the-environment/greenhouse-gases-and-the-climate.php.`

Figure 1: Change in Worldwide Greenhouse Gas Emissions (%)



Note: This figure shows the percentage change in greenhouse gas emissions from 1990 to 2018 using data from the WDI. This change is indexed at 1990 to show growth over the period.

4.2 Empirical Strategy

For Hypothesis 1, the empirical form is specified as:

$$Innov_{jklt} = \alpha_0 + \alpha_1 Femprod_{jklt} + \sum_{s=1}^{S} \psi_j X_{jklt} + \sum_{k=1}^{K-1} \mu_k + \sum_{l=1}^{L-1} \mu_l + \sum_{t=1}^{T-1} \mu_t + \varepsilon^1_{jklt}, \qquad (27)$$

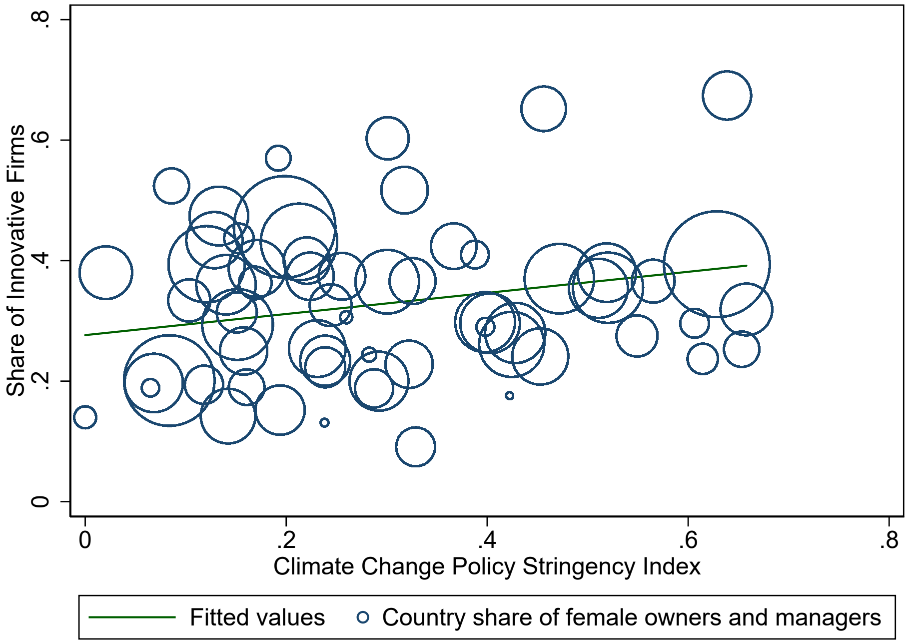
where $Innov_{jklt}$ is the reported innovation of firm j in industry k of country l at time t, $Femprod_{jklt}$ is logarithm of the corresponding firm-specific female productivity measure or empirical proxy, X_{jklt} is a vector of S firm-characteristic variables, μ_k (μ_t) [μ_j] capture industry- (country-) [year-] specific fixed effects, and ε^1_{jklt} is the random error term.

Likewise, to evaluate Hypothesis 2, we estimate the following empirical form:

$$Innov_{jklt} = \beta_0 + \beta_1 \upsilon_{lt} + \sum_{s=1}^{S} \omega_{j,k} X^k_{jt} + \sum_{k=1}^{K-1} \mu_k + \sum_{l=1}^{L-1} \mu_l + \sum_{t=1}^{T-1} \mu_t + \varepsilon^2_{jklt}, \qquad (28)$$

where υ_{lt} is the (logarithm of) greenhouse gas emission for country l at time t, and the relevant vector of firm-specific characteristic variables (X^k_{jt}), industry- (country-) [year-] specific fixed effects remain the same as in (27), and ε^2_{jklt} is the random error term. In other words, the empirical evaluation of Hypothesis

Figure 2: Correlation between innovation and climate change



Note: Each circle represents a country, with the size scaled according to the country's share of female managers and owners. The estimated slope coefficient is 0.175 (p-value= 0.000).

2 merely concerns the effects of a country-level variable on individual firm's innovation decision, after controlling for the effects of other determinants, including the fixed effects.

Finally, concerning the evaluation of Hypothesis 3, the transmission mechanism from climate change to firm's innovation decision would pass through the relative female productivity or gender empowerment channel any statistically significance identified would then underline a significant interplay between the two institutions of environmental and gender policies in driving innovation decision. We adopt a two-stage approach. Specifically, we first regress the impact of climate change on the female productivity proxy measure at the firm level:

$$Femprod_{jklt} = \gamma_0 + \gamma_1 \Xi_{lt} + \sum_{s=1}^{S} \psi_{j,k} X_{jt}^{k} + \sum_{k=1}^{K-1} \mu_k + \sum_{l=1}^{L-1} \mu_l + \sum_{t=1}^{T-1} \mu_t + \varepsilon_{jklt}^{3a}, \tag{29}$$

where Ξ_{lt} is a country-level measure of environment policy, ε_{jklt}^{3a} is the standard error for this specific equation, and the same control strategy (as in the two previous cases) is applied again. Having obtained the fitted value, $\widehat{Femprod}_{jklt}$, we then regress it on innovation, as in:

$$\begin{aligned} Innov_{jklt} &= \varphi_0 + \varphi_1 \widehat{Femprod}_{jklt} \\ &\quad + \sum_{s=1}^{S} \psi_j X_{jklt} + \sum_{k=1}^{K-1} \mu_k + \sum_{l=1}^{L-1} \mu_l + \sum_{t=1}^{T-1} \mu_t + \varepsilon^{3b}_{jklt}, \end{aligned} \tag{30}$$

where ε^{3b}_{jklt} is the standard error for this specific regression. The estimated coefficient for $\hat{\varphi}_1$ is the corresponding counterpart for α_1 in (27)—albeit now containing information from environmental policy stringency. Comparing this to the empirical finding associated with Hypothesis 2, we can gain an understanding in terms of whether the environment's effects on innovation is transmitted via the biological mechanism (greenhouse gases directly affecting labour productivity) or the institutional mechanism (environmental policy, through gender institution) too.

5 Results

5.1 Gender, Productivity and Innovation

Table 1 shows some preliminary results related to hypothesis 1. The table shows six columns of results from individual probit regressions. The numbers displayed are marginal effects at the sample means. As shown in the first row, there is a noticeably positive association between female management/ownership and innovation. These results show that firms with at least one female manager/owner are just over 3% more likely to innovate. This evidence suggests that gender has a potentially important role to play in mediating the relationship between innovation and climate change.

We explicitly examine hypothesis 1 in columns 3 – 6. This hypothesis states that firm level female productivity (α_1 in Eq. 27) is positively associated with innovation. These results provide some support for this hypothesis as the coefficients on the two productivity measures in the table are highly significant and positive in all estimations displayed. We see that the range of magnitude is 0.1% to 1.3%, suggesting that a one percent increase in female productivity is associated with an increase in the likelihood that a firm innovates by as much as 1.3%.

We present our estimation results related to hypothesis 2 next. This hypothesis states that the effect of greenhouse gases on innovation is ambiguous. These results are presented in columns 1-4 in Table 2. We see that the correlation between innovation and change in emissions of the three most common greenhouse gases (carbon dioxide, nitrous oxide and methane) and an aggregate total greenhouse gas emissions variable. The evidence in this table provides some support for hypothesis 2. From the table, carbon dioxide seems to always have a positive association with firm level innovation while the relationship with nitrous oxide and methane are more mixed.

To assess the robustness of this evidence that greenhouse gases have a varied effect on innovation, we present further evidence in columns 5-8 of Table 2. The regressions underlying the results in these columns differ only in the use of product innovation as the dependent variable. There is strong evidence that process and product innovation are highly correlated [see Lim & Morris (2022) as an example] and so we present this evidence to show the extent to which our results vary, depending on the measure of innovation used.

The results in these columns show some striking differences in the effect of greenhouse gases on product versus process innovation. Carbon dioxide has a strong negative association with product innovation, nitrous oxide has a positive relationship while methane has a mixed association. This suggests that one reason for the ambiguity in the relationship between innovation and greenhouse gas emissions may be driven by methodological issues related to the computation of changes in greenhouse gases, specifically as it relates to identifying a base year. Indeed, the varied effects may also suggest that empirical evidence associated with a direct biological effect from greenhouse gases to workers' productivity (and consequently innovation) is mixed and may not be as strong as previously claimed. However, the evidence found is largely consistent with Su & Moaniba (2017) who showed that innovation is positively related to carbon dioxide emissions from gas and liquid fuels but negatively associated with carbon dioxide emissions from solid fuels.

Next, we focus on hypothesis 3, our main hypothesis. This hypothesis, in tandem with hypothesis 2 says that although greenhouse gases have an ambiguous effect on innovation, climate change polices have an unambiguously positive effect on innovation, when the transmission mechanism is institutional, through a directed effect of improved bargaining power of female in society and firms. We adopt an instrumental variable approach to assess hypothesis 3. We first estimate reduced form regressions of climate change policies on female productivity and use predicted female productivity as an instrument in the regression with innovation.

Our baseline results in this regard are presented in Table 3 which contains the first stage regression and 4 which contains the second stage regressions. Our variable of interest in these regressions is the climate change policy variable. We consider four different measures of climate change policies, pollution taxes, energy taxes, environmental policies and the climate change policy index developed by Sharma et al. (2021).

As shown in Table 3, there is a highly significant positive association between female productivity and climate change policies. Using predicted female productivity from these regressions, we estimate two-stage least squares IV probit regressions of female productivity on process innovation in Table 4. These results show an indirect effect of climate change policies on innovation, through female productivity enhancement.

5.2 Robustness Checks

To examine the robustness of our results, particularly as it relates to hypothesis 3, we consider four different variations of the baseline model. First, to assess the robustness of our results to variations in the measurement of labour productivity, we use a second measure of labour productivity based on number of hours worked by females ($Femprod_2$) and re-run the regressions detailed in Table 3 and 4. These equivalent results are presented in Table 5 and 6. These results all show a positive association between climate change policy and female labour productivity and innovation.

Second, a sceptic of the results presented above may argue that innovation and productivity are simultaneously determined, as commonly argued in the innovation literature (see Mohnen & Hall (2013)). Although we employ a 2SLS for the results shown above, this approach is not immune to this criticism since we address the endogeneity in productivity but not innovation in that specification. As such, we present some results in Table 7 that are based on a three stage least square (3SLS) approach which accounts for the simultaneity between innovation and productivity. The results from this approach are broadly in line with the results shown above.

Third, to examine if our results are robust to variations in the measurement of innovation, we replace process innovation with product innovation in another 3SLS implementation, as shown in Table 8. The results show that using product innovation as the main dependent variable does not materially change the intuition of our previous results. Specifically, the positive association between climate change and female productivity and innovation is again confirmed in these results.

Finally, so far we've focused on female worker productivity because our theoretical framework suggests that the impact of climate change on firms will go through the relative gender productivity of firms to their innovation outcomes. Our earlier approach therefore is silent on the impact on male productivity. To address this we compute a relative gender (female to male) productivity measure for each firm. This in a broad sense is a crude measure of gender equality in a firm. The closer this measure is to unity, the less the relative difference in productivity of males and females in a firm and thus the higher is gender equality of productivity. We present the second stage results from regressions using this relative gender productivity measure in Table 9. Again, we see the positive effect of this climate change induced relative productivity measure on innovation, confirming our earlier results and lending firm support to our stated hypothesis 3.

Overall, this evidence clearly shows that our baseline results are robust to several methodological modifications, hence providing empirical support for the three hypothesis shown above.

6 Conclusion

Based on three hypotheses derived off a novel theoretical framework linking climate change and gender equality to within-firm innovation activities, we provide empirical insights towards improved understanding of the impact of climate change and gender equality on firm-level innovation. To our knowledge, our cross-sectional evidence (53,340 firms across 36 industries in 103 countries, surveyed across different waves during the 2010-2020 periods) is the largest documenting statistically significant positive association between gender equality measures and innovation at the firm level. In addition, we also contribute to the understanding of whether: (i) there exists complementarity between environmental policy and gender equality; and (ii) it is the direct biological effect of carbon emission on labour productivity or the competitiveness-enhancing institutional effect of environmental policy/regulation that matters more in promoting firm-level innovation.

We find that environmental policies, through its influence on endogenous bargaining power of women, unambiguously induce firm-level process and product innovation. In contrast, measures based on greenhouse gas emission, produce mixed results that vary across different methodologies used in computing the chemical compounds. These findings reaffirm the increasing need for developing country governments to incorporate carbon-friendly and gender equality-enhancing policies into their medium-to-long term industrial development plans. Our study provides some scientific basis on the complementarity between environmental regulations, gender workplace empowerment, and corporate innovation.

Nonetheless, our analysis is conditioned on some data limitations that are worth mentioning. First, our dataset is an uneven cross section and so firm level heterogeneity could not be explicitly controlled. Second, firm-level measures for gender equality and carbon emission remain inadequate, especially the latter, and our analysis is constrained by data availability of the WBES. Future opportunities that allow for more firm-specific carbon emission, climate change adaptation, and gender empowerment perceptions to be surveyed and measured are welcomed as these will significantly improve the understanding of the interplay between environment, gender, and innovation further. Finally, it is likely that there will be some differences in the estimated magnitude when a continuous measure of innovation is used instead. For this approach to be meaningful, there is need for better data on the proportion of firm output attributable to an innovative activity too. These are all avenues for future research.

Table 1: Proposition 1 - Process Innovation and Female Ownership, Management and Productivity

Dependent Variable: Process	(1)	(2)	(3)	(4)	(5)	(6)
Female owned/managed	0.032***	0.033***				
	(0.003)	(0.003)				
$Femprod_1$			0.011***		0.013***	
			(0.001)		(0.001)	
$Femprod_2$				0.001*		0.001**
				(0.000)		(0.000)
Experience	0.001***	0.001***	0.001***	0.001***	0.001***	0.001***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Foreign Technology	0.139***	0.128***	0.136***	0.139***	0.124***	0.128***
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
Exports	0.001***	0.000***	0.001***	0.001***	0.001***	0.001***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Size	0.040***	0.038***	0.042***	0.040***	0.040***	0.038***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
N	87855	87855	87855	87855	87855	87855
Pseudo R^2	0.185	0.184	0.185	0.185	0.209	0.208
Year FE	✓	✓	✓	✓	✓	✓
Industry FE	✗	✓	✗	✗	✓	✓
Country FE	✓	✓	✓	✓	✓	✓

Standard errors in parentheses are robust. These results are from different probit regressions. The numbers displayed are marginal marginal effects at the sample mean.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 2: Proposition 2 - Greenhouse Gasses and Innovation

Dependent Variable:	Process Innovation				Product Innovation			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
TGHGE	0.010***				-0.011***			
	(0.002)				(0.002)			
Carbon Dioxide		0.003***	0.004***	0.008***		-0.007***	-0.006***	-0.023***
		(0.001)	(0.001)	(0.002)		(0.001)	(0.001)	(0.003)
Nitrous Oxide		0.019***	0.020***	-0.036***		0.017***	0.017***	0.016
		(0.002)	(0.002)	(0.012)		(0.002)	(0.002)	(0.012)
Methane		-0.022***	-0.058***	0.093***		-0.036***	-0.078***	0.039***
		(0.003)	(0.003)	(0.011)		(0.003)	(0.003)	(0.011)
Experience	-0.001***	-0.000**	-0.000*	-0.000***	0.001***	0.001***	0.001***	0.001***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Foreign Technology	0.117***	0.122***	0.120***	0.124***	0.127***	0.138***	0.136***	0.142***
	(0.006)	(0.005)	(0.005)	(0.005)	(0.006)	(0.005)	(0.005)	(0.005)
Exports	0.001***	0.001***	0.001***	0.001***	-0.000	0.000**	0.000*	0.000**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Size	0.046***	0.040***	0.040***	0.040***	0.036***	0.033***	0.033***	0.033***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
N	62638	87993	87993	87993	62638	87993	87993	87993
Pseudo R^2	0.101	0.103	0.100	0.117	0.056	0.059	0.054	0.073
Year FE	✓	✓	✓	✓	✓	✓	✓	✓
Industry FE	✓	✓	✓	✓	✓	✓	✓	✓

Standard errors in parentheses are robust. The numbers are marginal effects at the sample mean. Each column has a different computation of changes in greenhouse gases. Columns (2) and (6) are changes between 1990 and 2018, columns (3) and (7) are between 1990 and 2010 and columns (4) and (8) are between 2010 and 2018.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 3: Proposition 3 - Female Productivity and Climate Change Policy - First Stage Estimates

Dep. Var: $Femprod_1$	(1)	(2)	(3)	(4)
Climate Change Policy	5.697***	0.652***	0.241***	1.591***
	(0.508)	(0.026)	(0.004)	(0.162)
Subsidiary	0.005***	0.006***	0.007***	0.005***
	(0.001)	(0.001)	(0.001)	(0.001)
Experience	0.015***	0.017***	0.012***	0.020***
	(0.002)	(0.002)	(0.002)	(0.002)
Foreign Tech	0.160***	-0.007	0.072	0.011
	(0.058)	(0.056)	(0.054)	(0.067)
Age	-0.259***	-0.226***	-0.163***	-0.265***
	(0.022)	(0.021)	(0.021)	(0.025)
Exports	-0.002*	-0.003***	-0.002**	-0.004***
	(0.001)	(0.001)	(0.001)	(0.001)
Size	-0.097***	-0.081***	-0.113***	-0.172***
	(0.015)	(0.015)	(0.015)	(0.017)
N	25322	26742	25565	19286
R^2	0.224	0.187	0.280	0.189
Year FE	✓	✓	✓	✓
Industry FE	✓	✓	✓	✓
Region FE	✓	✓	✓	✓

Standard errors in parentheses are robust. Each column of numbers represents a different regression based on the climate change policy measure. Column (1) uses pollution taxes, column (2) is energy taxes, column (3) is environmental taxes and column (4) is the CCPS index.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 4: Proposition 3 - Predicted Female Productivity and Process Innovation - Second Stage Estimates

Dep. Var: Process	(1)	(2)	(3)	(4)
$\widehat{Femprod}_1$	0.044***	0.039***	0.046***	0.060***
	(0.005)	(0.005)	(0.004)	(0.006)
Subsidiary	0.000	-0.000	0.001*	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Experience	-0.005***	-0.005***	-0.006***	-0.006***
	(0.001)	(0.001)	(0.001)	(0.001)
Foreign Tech	0.314***	0.311***	0.311***	0.295***
	(0.029)	(0.028)	(0.028)	(0.032)
Age	-0.061***	-0.063***	-0.068***	-0.092***
	(0.010)	(0.010)	(0.010)	(0.012)
Exports	0.004***	0.004***	0.003***	0.003***
	(0.001)	(0.001)	(0.001)	(0.001)
N	24424	26742	25565	19280
Estimation Method	2SLS	2SLS	2SLS	2SLS
$Chi^2 Exog.$	55.467	41.049	80.149	92.892
Year FE	✓	✓	✓	✓
Industry FE	✓	✓	✓	✓
Country FE	✓	✓	✓	✓

Standard errors are in parentheses. These results are coefficients from IV Probit regressions using predicted first stage regressions corresponding to the columns of numbers in Table 3.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 5: Proposition 3 - Female Productivity and Climate Change Policy - First Stage Estimates

Dep. Var: $Femprod_2$	(1)	(2)	(3)	(4)
Climate Change Policy	8.393***	0.699***	0.193***	6.794***
	(0.834)	(0.055)	(0.008)	(0.352)
Subsidiary	0.005***	0.006***	0.006**	0.003*
	(0.002)	(0.002)	(0.003)	(0.002)
Experience	0.011***	0.012***	0.007**	0.003
	(0.003)	(0.003)	(0.003)	(0.004)
Foreign Tech	0.465***	0.288***	0.384***	0.282**
	(0.111)	(0.107)	(0.110)	(0.128)
Age	-0.403***	-0.312***	-0.258***	-0.197***
	(0.043)	(0.042)	(0.043)	(0.051)
Exports	-0.000	-0.001	0.000	-0.002
	(0.002)	(0.002)	(0.002)	(0.003)
Size	0.707***	0.712***	0.680***	0.621***
	(0.028)	(0.028)	(0.029)	(0.033)
N	25322	26742	25565	19286
R^2	0.123	0.098	0.104	0.116
Year FE	✓	✓	✓	✓
Industry FE	✓	✓	✓	✓
Region FE	✓	✓	✓	✓

Standard errors in parentheses are robust. Each column of numbers represents a different regression based on the climate change policy measure. Column (1) uses pollution taxes, column (2) is energy taxes, column (3) is environmental taxes and column (4) is the CCPS index.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 6: Proposition 3 - Predicted Female Productivity and Process Innovation - Second Stage Estimates

Dep. Var: Process	(1)	(2)	(3)	(4)
$\widehat{Femprod_2}$	0.027***	0.018***	0.027***	0.032***
	(0.004)	(0.004)	(0.004)	(0.004)
Subsidiary	0.000	0.000	0.001**	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Experience	-0.005***	-0.005***	-0.006***	-0.005***
	(0.001)	(0.001)	(0.001)	(0.001)
Foreign Tech	0.277***	0.280***	0.269***	0.248***
	(0.030)	(0.028)	(0.029)	(0.032)
Age	-0.070***	-0.070***	-0.077***	-0.108***
	(0.011)	(0.010)	(0.010)	(0.012)
Exports	0.003***	0.003***	0.003***	0.003***
	(0.001)	(0.001)	(0.001)	(0.001)
N	24424	26742	25565	19280
$Chi^2 Exog.$	111.668	64.882	106.921	90.152
Year FE	✓	✓	✓	✓
Industry FE	✓	✓	✓	✓
Country FE	✓	✓	✓	✓

Standard errors are in parentheses. These results are coefficients from IV Probit regressions using predicted first stage regressions corresponding to the columns of numbers in Table 5.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 7: Proposition 3 - Female Productivity, Process Innovation and Climate Change Policy - 3SLS Results

	(1)	(2)	(3)	(4)
Panel A: Dep. Var - $Femprod_1$				
Climate Change Policy	9.322***	0.104***	0.269***	5.914***
	(0.458)	(0.032)	(0.005)	(0.239)
Panel B: Dep. Var - Process				
$\widehat{Femprod}_1$	0.011***	0.015***	0.014***	0.003***
	(0.002)	(0.002)	(0.001)	(0.001)
Subsidiary	0.000*	0.000	0.001***	0.000***
	(0.000)	(0.000)	(0.000)	(0.000)
Experience	-0.002***	-0.002***	-0.002***	0.001**
	(0.000)	(0.000)	(0.000)	(0.000)
Foreign Tech	0.147***	0.142***	0.149***	0.147***
	(0.010)	(0.009)	(0.009)	(0.008)
Age	-0.018***	-0.021***	-0.023***	-0.016***
	(0.003)	(0.003)	(0.003)	(0.003)
Exports	0.001***	0.001***	0.001***	0.001***
	(0.000)	(0.000)	(0.000)	(0.000)
N	25322	26742	26843	35621
R^2	0.430	0.377	0.440	0.410
Year FE	✓	✓	✓	✓
Industry FE	✓	✓	✓	✓
Country FE	✓	✓	✓	✓

Standard errors are in parentheses. For Panel A, each column of numbers represents a different regression based on the climate change policy measure. Column (1) uses pollution taxes, column (2) is energy taxes, column (3) is environmental taxes and column (4) is the CCPS index.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 8: Proposition 3 - Female Productivity, Product Innovation and Climate Change Policy - 3SLS Results

	(1)	(2)	(3)	(4)
Panel A: Dep. Var - $Femprod_1$				
Climate Change Policy	8.987***	0.053*	0.265***	6.076***
	(0.454)	(0.031)	(0.005)	(0.238)
Panel B: Dep. Var - Product				
$\widehat{Femprod}_1$	0.041***	0.044***	0.039***	0.021***
	(0.002)	(0.002)	(0.002)	(0.001)
Subsidiary	0.000	-0.000	0.000***	0.000***
	(0.000)	(0.000)	(0.000)	(0.000)
Experience	0.001***	0.000	0.000	0.002***
	(0.000)	(0.000)	(0.000)	(0.000)
Foreign Tech	0.166***	0.165***	0.176***	0.138***
	(0.010)	(0.010)	(0.009)	(0.008)
Age	0.000	-0.001	-0.002	-0.007**
	(0.003)	(0.003)	(0.003)	(0.003)
Exports	0.000**	0.000	0.000	0.001***
	(0.000)	(0.000)	(0.000)	(0.000)
N	25322	26742	26843	35621
R^2	0.428	0.375	0.439	0.409
Year FE	✓	✓	✓	✓
Industry FE	✓	✓	✓	✓
Country FE	✓	✓	✓	✓

Standard errors are in parentheses. For Panel A, each column of numbers represents a different regression based on the climate change policy measure. Column (1) uses pollution taxes, column (2) is energy taxes, column (3) is environmental taxes and column (4) is the CCPS index.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 9: Proposition 3 - Predicted Relative Productivity and Process Innovation - Second Stage Estimates

Dep. Var: Process	(1)	(2)	(3)	(4)
$\widehat{Relprod}$	0.004^{***}	0.005^{***}	0.005^{***}	0.004^{***}
	(0.001)	(0.001)	(0.001)	(0.001)
Subsidiary	0.001	-0.000	-0.000	0.001
	(0.001)	(0.001)	(0.001)	(0.001)
Experience	-0.001	-0.001	-0.001	0.002
	(0.002)	(0.002)	(0.002)	(0.002)
Foreign Tech	0.141^{**}	0.155^{***}	0.153^{***}	0.157^{**}
	(0.060)	(0.056)	(0.057)	(0.068)
Age	-0.089^{***}	-0.093^{***}	-0.094^{***}	-0.109^{***}
	(0.022)	(0.021)	(0.021)	(0.024)
Exports	0.003^{***}	0.003^{***}	0.003^{***}	0.001
	(0.001)	(0.001)	(0.001)	(0.001)
N	6121	6805	6796	4964
Estimation Method	2SLS	2SLS	2SLS	2SLS
$Chi^2 Exog.$	54.187	73.067	76.325	48.094
Year FE	✓	✓	✓	✓
Industry FE	✓	✓	✓	✓
Region FE	✓	✓	✓	✓

Standard errors are in parentheses. Each column of numbers represents a different regression based on the predicted productivity from the climate change policy measure. Column (1) uses pollution taxes, column (2) is energy taxes, column (3) is environmental taxes and column (4) is the CCPS index. Panel B results use predicted results from Panel A.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

References

Agénor, P.-R. (2017). A computable overlapping generations model for gender and growth policy analysis. *Macroeconomic Dynamics*, *21*(1), 11–54.

Agénor, P.-R., Ozdemir, K. K., & Pinto Moreira, E. (2021). Gender gaps in the labour market and economic growth. *Economica*, *88*(350), 235–270.

Albrizio, S., Kozluk, T., & Zipperer, V. (2017). Environmental policies and productivity growth: Evidence across industries and firms. *Journal of Environmental Economics and Management*, *81*, 209–226.

Alderman, H., & King, E. M. (1998). Gender differences in parental investment in education. *Structural Change and Economic Dynamics*, *9*(4), 453–468.

Ambec, S., Cohen, M. A., Elgie, S., & Lanoie, P. (2020). The porter hypothesis at 20: Can environmental regulation enhance innovation and competitiveness? *Review of Environmental Economics and Policy*.

Arun, T., & Joseph, R. P. (2020). Gender and firm innovation-a systematic literature review and future research agenda. *International Journal of Entrepreneurial Behavior & Research*.

Balestra, C., & Dottori, D. (2012). Aging society, health and the environment. *Journal of Population Economics*, *25*(3), 1045–1076.

Bilgili, F., Khan, M., & Awan, A. (2022). Is there a gender dimension of the environmental kuznets curve? evidence from asian countries. *Environment, Development and Sustainability*, 1–32.

Borghesi, S., Cainelli, G., & Mazzanti, M. (2015). Linking emission trading to environmental innovation: Evidence from the Italian manufacturing industry. *Research Policy*, *44*(3), 669–683.

Brambilla, I. (2009). Multinationals, technology, and the introduction of varieties of goods. *Journal of International Economics*, *79*(1), 89–101.

Bretschger, L., & Vinogradova, A. (2017). Human development at risk: economic growth with pollution-induced health shocks. *Environmental and Resource Economics*, *66*(3), 481–495.

Browning, M., Chiappori, P.-A., & Weiss, Y. (2014). *Economics of the family*. Cambridge University Press.

Bu, M., Qiao, Z., & Liu, B. (2020). Voluntary environmental regulation and firm innovation in china. *Economic Modelling*, *89*, 10–18.

Calel, R. (2020). Adopt or innovate: Understanding technological responses to cap-and-trade. *American Economic Journal: Economic Policy*, *12*(3), 170–201.

Cavalcanti, T. V. d. V., & Tavares, J. (2011). Women prefer larger governments: Growth, structural transformation, and government size. *Economic Inquiry*, *49*(1), 155–171.

Cecere, G., & Corrocher, N. (2016). Stringency of regulation and innovation in waste management: An empirical analysis on EU countries. *Industry and Innovation*, *23*(7), 625–646.

Chakraborty, P., & Chatterjee, C. (2017). Does environmental regulation indirectly induce upstream innovation? New evidence from India. *Research Policy*, *46*(5), 939–955.

Chen, Z., & Woolley, F. (2001). A cournot–nash model of family decision making. *The Economic Journal*, *111*(474), 722–748.

Chiappori, P.-A., Fortin, B., & Lacroix, G. (2002). Marriage market, divorce legislation, and household labor supply. *Journal of Political Economy*, *110*(1), 37–72.

Chiu, C.-R., Liou, J.-L., Wu, P.-I., & Fang, C.-L. (2012). Decomposition of the environmental inefficiency of the meta-frontier with undesirable output. *Energy Economics*, *34*(5), 1392–1399.

Cohen, M. A., & Tubb, A. (2018). The impact of environmental regulation on firm and country competitiveness: A meta-analysis of the porter hypothesis. *Journal of the Association of Environmental and Resource Economists*, *5*(2), 371–399.

Consoli, D., Marin, G., Marzucchi, A., & Vona, F. (2016). Do green jobs differ from non-green jobs in terms of skills and human capital? *Research Policy*, *45*(5), 1046–1060.

Constant, K., & Davin, M. (2019). Environmental policy and growth when environmental awareness is endogenous. *Macroeconomic Dynamics*, *23*(3), 1102–1136.

Dai, Y., Byun, G., & Ding, F. (2019). The direct and indirect impact of gender diversity in new venture teams on innovation performance. *Entrepreneurship Theory and Practice*, *43*(3), 505–528.

De Miguel, C., & Pazó, C. (2017). Environmental protection, innovation and price-setting behavior in Spanish manufacturing firms. *Energy Economics*, *68*, 116–124.

De Vita, L., Mari, M., & Poggesi, S. (2014). Women entrepreneurs in and from developing countries: Evidences from the literature. *European Management Journal*, *32*(3), 451–460.

Doepke, M., & Tertilt, M. (2019). Does female empowerment promote economic development? *Journal of Economic Growth*, *24*(4), 309–343.

Dohse, D., Goel, R. K., & Nelson, M. A. (2019). Female owners versus female managers: Who is better at introducing innovations? *The Journal of Technology Transfer*, *44*(2), 520–539.

Eastin, J. (2018). Climate change and gender equality in developing states. *World Development*, *107*, 289–305.

Echevarria, C., & Merlo, A. (1999). Gender differences in education in a dynamic household bargaining model. *International Economic Review*, *40*(2), 265–286.

Economides, G., & Philippopoulos, A. (2008). Growth enhancing policy is the means to sustain the environment. *Review of Economic Dynamics*, *11*(1), 207–219.

Eiadat, Y., Kelly, A., Roche, F., & Eyadat, H. (2008). Green and competitive? An empirical test of the mediating role of environmental innovation strategy. *Journal of World Business*, *43*(2), 131–145.

Franco, C., & Marin, G. (2017). The effect of within-sector, upstream and downstream environmental taxes on innovation and productivity. *Environmental and Resource Economics*, *66*(2), 261–291.

Fu, M., Gu, L., Zhen, Z., Sun, M., & Tian, L. (2020). Optimal carbon tax income distribution and health welfare spillover effect based on health factors. *Applied Energy*, *276*, 115475.

Gil-Moltó, M. J., & Varvarigos, D. (2013). Emission taxes and the adoption of cleaner technologies: The case of environmentally conscious consumers. *Resource and Energy Economics*, *35*(4), 486–504.

Greenstone, M., List, J. A., & Syverson, C. (2012, September). *The Effects of Environmental Regulation on the Competitiveness of U.S. Manufacturing* (NBER Working Papers). National Bureau of Economic Research, Inc.

He, X., & Jiang, S. (2019). Does gender diversity matter for green innovation? *Business Strategy and the Environment*, *28*(7), 1341–1356.

Hille, E., & Möbius, P. (2019). Environmental policy, innovation, and productivity growth: Controlling the effects of regulation and endogeneity. *Environmental and Resource Economics*, *73*(4), 1315–1355.

Himmelweit, S., Santos, C., Sevilla, A., & Sofer, C. (2013). Sharing of resources within the family and the economics of household decision making. *Journal of Marriage and Family*, *75*(3), 625–639.

Jaffe, A. B., & Palmer, K. (1997). Environmental regulation and innovation: A panel data study. *Review of Economics and Statistics*, *79*(4), 610–619.

John, A., & Pecchenino, R. (1994). An overlapping generations model of growth and the environment. *The Economic Journal*, *104*(427), 1393–1410.

Jones, L. E., & Manuelli, R. E. (2001). Endogenous policy choice: The case of pollution and growth. *Review of Economic Dynamics*, *4*(2), 369–405.

Jouvet, P.-A., Michel, P., & Vidal, J.-P. (2000). Intergenerational altruism and the environment. *Scandinavian Journal of Economics*, *102*(1), 135–150.

Kemp, R., & Pontoglio, S. (2011). The innovation effects of environmental policy instruments — A typical case of the blind men and the elephant? *Ecological Economics*, *72*, 28–36.

Ko, Y., Ko, H., Chung, Y., & Woo, C. (2021). Do gender equality and work–life balance matter for innovation performance? *Technology Analysis & Strategic Management*, *33*(2), 148–161.

Konadu, R., Ahinful, G. S., Boakye, D. J., & Elbardan, H. (2022). Board gender diversity, environmental innovation and corporate carbon emissions. *Technological Forecasting and Social Change*, *174*, 121279.

Kozluk, T., & Zipperer, V. (2015). Environmental policies and productivity growth: A critical review of empirical findings. *OECD Journal: Economic Studies*, *2014*(1), 155–185.

Lambertini, L., Poyago-Theotoky, J., & Tampieri, A. (2017). Cournot competition and "green" innovation: An inverted-u relationship. *Energy Economics*, *68*, 116–123.

Langinier, C., & Chaudhuri, A. R. (2020). Green technology and patents in the presence of green consumers. *Journal of the Association of Environmental and Resource Economists*, *7*(1), 73–101.

Lanoie, P., Laurent-Lucchetti, J., Johnstone, N., & Ambec, S. (2011). Environmental policy, innovation and performance: New insights on the Porter Hypothesis. *Journal of Economics & Management Strategy*, *20*(3), 803–842.

Lim, K. Y., & Morris, D. (2022). Firm-level impact of the global financial crisis: Evidence on innovation from latin america. *International Journal of Finance and Economics*, In Press.

Liu, C. (2018). Are women greener? Corporate gender diversity and environmental violations. *Journal of Corporate Finance*, *52*, 118–142.

Lundberg, S., & Bettio, F. (2008). Gender and household decision-making. *Frontiers in the Economics of Gender*, 116–134.

Martínez-Zarzoso, I., Bengochea-Morancho, A., & Morales-Lage, R. (2019). Does environmental policy stringency foster innovation and productivity in OECD countries? *Energy Policy*, *134*, 110982.

Mohnen, P., & Hall, B. H. (2013). Innovation and productivity: An update. *Eurasian Business Review*, *3*(1), 47–65.

Nadeem, M., Bahadar, S., Gull, A. A., & Iqbal, U. (2020). Are women eco-friendly? Board gender diversity and environmental innovation. *Business Strategy and the Environment*, *29*(8), 3146–3161.

Porter, M. (1991). America's green strategy. *Scientific American*, *264*(4), 168.

Porter, M., & Van der Linde, C. (1995). Toward a new conception of the environment-competitiveness relationship. *Journal of Economic Perspectives*, *9*(4), 97–118.

Qiu, L. D., Zhou, M., & Wei, X. (2018). Regulation, innovation, and firm selection: The porter hypothesis under monopolistic competition. *Journal of Environmental Economics and Management*, *92*, 638–658.

Rassier, D. G., & Earnhart, D. (2015). Effects of environmental regulation on actual and expected profitability. *Ecological Economics*, *112*(C), 129-140.

Ray, I. (2015). Transformative investments for gender equal sustainable development. In *Gender equality and sustainable development* (pp. 151–173). Routledge.

Rennings, K., & Rammer, C. (2011). The impact of regulation-driven environmental innovation on innovation success and firm performance. *Industry and Innovation*, *18*(03), 255–283.

Reutzel, C. R., Collins, J. D., & Belsito, C. A. (2018). Leader gender and firm investment in innovation. *Gender in Management: An International Journal*.

Rexhäuser, S., & Rammer, C. (2014). Environmental innovations and firm profitability: Unmasking the porter hypothesis. *Environmental and Resource Economics*, *57*(1), 145–167.

Rubashkina, Y., Galeotti, M., & Verdolini, E. (2015). Environmental regulation and competitiveness: Empirical evidence on the porter hypothesis from european manufacturing sectors. *Energy Policy*, *83*, 288–300.

Rubio, S. J., Garcia, J. L., & Hueso, J. L. (2009). Neoclassical growth, environment and technological change: The environmental kuznets curve. *The Energy Journal*, *30*(Special Issue# 2).

Samant, S., Thakur-Wernz, P., & Hatfield, D. E. (2020). Does the focus of renewable energy policy impact the nature of innovation? Evidence from emerging economies. *Energy Policy*, *137*, 111119.

Sharma, S., Ang, J. B., & Fredriksson, P. G. (2021). Religiosity and climate change policies. *Energy Economics*, *101*, 105414.

Smith-Doerr, L. (2010). Flexible organizations, innovation and gender equality: Writing for the us film industry, 1907–27. *Industry and Innovation*, *17*(1), 5–22.

Su, H.-N., & Moaniba, I. M. (2017). Does innovation respond to climate change? Empirical evidence from patents and greenhouse gas emissions. *Technological Forecasting and Social Change*, *122*, 49–62.

Vermeulen, F. (2002). Collective household models: Principles and main results. *Journal of Economic Surveys*, *16*(4), 533–564.

Wan, B., Tian, L., Zhu, N., Gu, L., & Zhang, G. (2018). A new endogenous growth model for green low-carbon behavior and its comprehensive effects. *Applied Energy*, *230*, 1332–1346.

Wang, M., Zhao, J., & Bhattacharya, J. (2015). Optimal health and environmental policies in a pollution-growth nexus. *Journal of Environmental Economics and Management*, *71*, 160–179.

Wei, S., & Aadland, D. (2019). Physical capital, human capital, and the health effects of pollution in an OLG model. *Macroeconomic Dynamics*, 1–42.

Wu, Q., Dbouk, W., Hasan, I., Kobeissi, N., & Zheng, L. (2021). Does gender affect innovation? Evidence from female chief technology officers. *Research Policy*, *50*(9), 104327.

Yang, C.-H., Tseng, Y.-H., & Chen, C.-P. (2012). Environmental regulations, induced R&D, and productivity: Evidence from Taiwan's manufacturing industries. *Resource and Energy Economics*, *34*(4), 514–532.

Zhang, C., Liu, H., Bressers, H. T. A., & Buchanan, K. S. (2011). Productivity growth and environmental regulations-accounting for undesirable outputs: Analysis of China's thirty provincial regions using the Malmquist–Luenberger index. *Ecological Economics*, *70*(12), 2369–2379.